COMPLETE COURSE IN PRACTICAL RADIO

NATIONAL RADIO INSTITUTE

Complete Course in PRACTICAL RADIO

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Radio-Trician

(Trade Mark Reg. U. S. Patent Office)

Special Text

RADIO JOURNALISM

Originators of Radio Home Study Courses
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RADIO JOURNALISM

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Radio-Trician's
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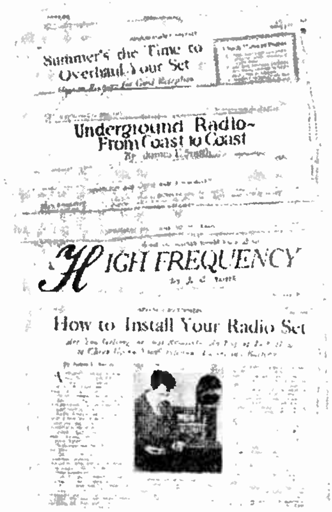
Complete Course in Practical Radio
NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

RADIO JOURNALISM

The ambition to write is possessed by almost every person who has learned to use a pencil or operate a typewriter. Those connected with the Radio industry are no exception to the universal desire to break into print. In fact, because of the many mediums which use Radio manuscripts, there is greater inducement to write the story of Radio experiences, achievements and accomplishments than in fields commanding less public interest and attention.



A few articles contributed to Radio Magazines by the N. R. I. Staff

As a usual thing, however, those well versed in the technique of any science are disqualified from writing about it in a style which the average person can understand. The reason for this is very simple. Those in intimate and daily contact with a line of business such as Radio become accustomed to using technical words and phrases, which to them, have great significance because they are constantly used in their work. But, the man in the street, reading these phrases only frequently, cannot understand them clearly, if at all.

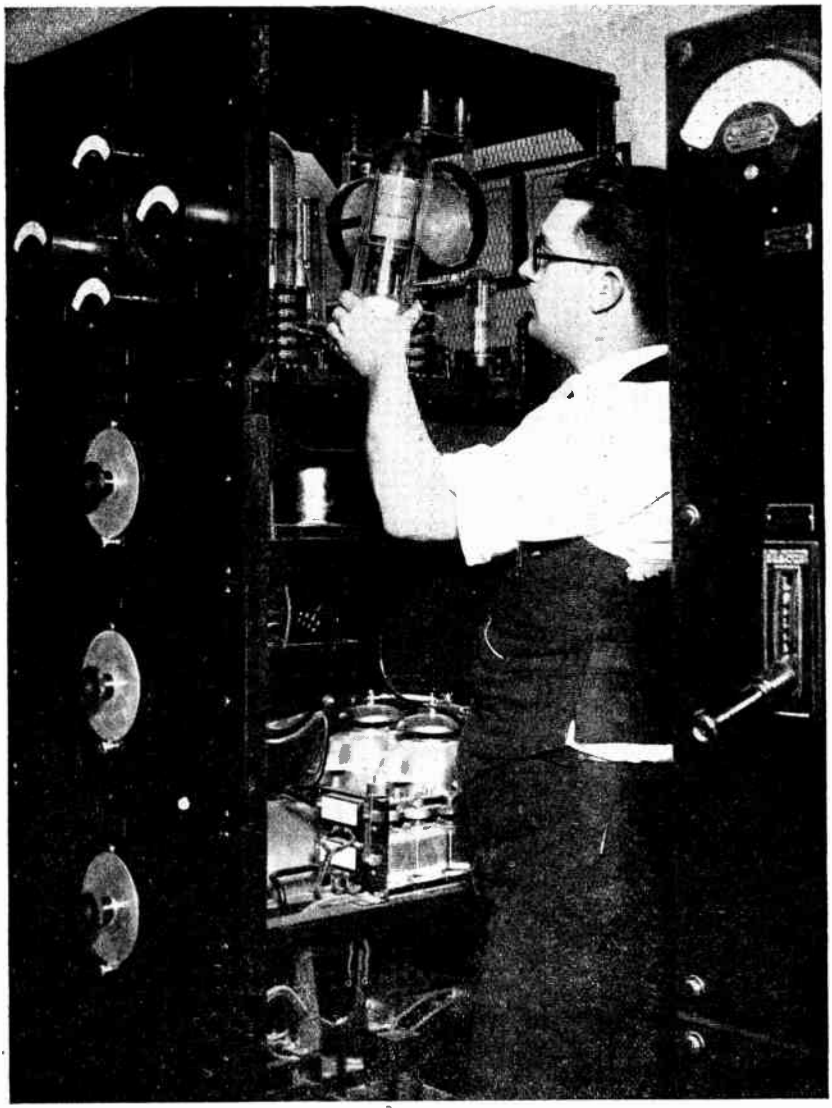
The purpose of this text on Radio Journalism is to tell you of the various types of Radio articles in demand, the most effective way of preparing such articles, and how they can be sold. If you learn but one point, that is, the necessity of writing in a manner which the average reader can understand, we will have given you the one quality most woefully needed in Radio literature today. With this one qualification and a thorough knowledge of Radio, you would be assured of success, because a good quality of Radio articles is always in demand.

KNOWLEDGE OF RADIO AND GOOD STYLE RARELY FOUND

There is no lack of men who can write clearly, but who do not understand Radio theory, nor men who know enough about Radio to prepare articles, but who cannot write them in a manner which is understandable to the average reader. Glance at any Radio newspaper supplement or almost any Radio instruction book and it will be obvious to you that the technical knowledge which the writers possess is the very thing which obscures their ability to write in a style which every one can readily understand.

Again, we repeat, the first and most important fundamental of success in Radio writing is the use of non-technical language. Those who have this ability have a large variety and number of publications which are prospects for their articles. First, there are general magazines which use feature articles on Radio. They are the kind of magazines which everybody reads. The one having the largest circulation is the Saturday Evening Post and the list extends right down the line to small magazines of a few thousand circulation. Ordinarily such magazines rarely print a Radio article, because the editors cannot readily understand the Radio stories which are submitted to them, so technical is the language used. Under the circumstances, the editors are justified in the belief that readers will not get much out of the articles submitted.

Aside from the language used in the articles, the point of view adopted by the usual Radio writer does not take into consideration the nature of the readers of the magazine for which he is writing. It is essential to realize that many readers of general magazines have only a casual interest in Radio. Hence, you must write your story in a manner which will arouse their curiosity and attention. The element of human interest



Many exclusive Radio Magazines have grown quite large, and cover a wide field of activity. The Radio News at present is the largest of all. This picture shows a view of WRNY, the great Radio News Broadcasting Station. N. R. I. Graduate, E. W. Novy, is the chief operator.

must be kept uppermost because more people are interested in what others do than in how machines and processes work. Life and action are more attractive than theory.

The second field for Radio articles is the periodicals devoted to that subject. These publications are numerous and do not present all of the difficulties which must be surmounted in securing the acceptance of an article by a general magazine. They assume their readers are familiar with Radio technical terms. It is important, when considering the preparation of an article for such a publication, that the author make certain it does not cover ground which has already received adequate space in the publication. It usually pays to consult the editor as to the acceptability of the material before preparing an article, in order to avoid duplication of another author's efforts.

THE WRITER'S MARKET

The following is a list of certain magazines and newspapers with a brief digest of the kind of material which they use most frequently:

Trade magazines.—Interested in articles on dealer methods, accounts of successful campaigns, expense control, unusual advertising or selling ideas and marketing Radio and Electrical apparatus.

Electrical Merchandising, 10th Ave. and 36th St., New York City.

American Radio Journal, 25 West 45th St., New York City.

Electrical Record, 461 Eighth Ave., New York City.

Hardware Age, 239 West 39th St., New York City.

Hardware Dealers' Magazine, 370 Seventh Ave., New York City.

The Jobbers' Salesman, 520 North Michigan Avenue, Chicago, Ill.

Music Trade Review, 420 Lexington Ave., New York City.

Phonograph and Talking Machine Weekly, 146 Water St., New York City.

Radio Craft, 96-98 Park Place, New York City.

Sporting Goods Dealer, 217 N. Tenth St., St. Louis, Missouri.

Sporting Goods Journal, 75 East Wacker Drive, Chicago, Ill.

Talking Machine Journal, 5491 Grand Central Terminal, New York City.

Talking Machine World, 420 Lexington Ave., New York City.

Radio Retailing, 10th Avenue and 36th St., New York City.

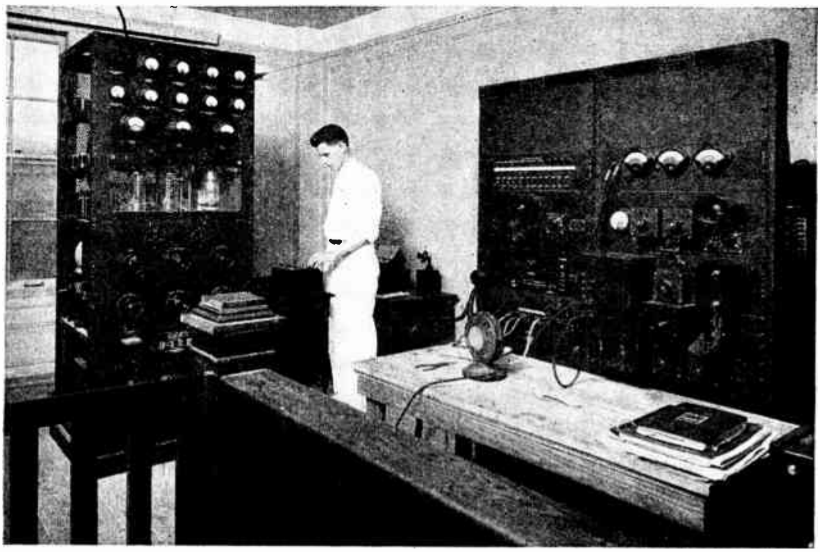
Popular Mechanics, 200 E. Ontario St., Chicago, Ill.

Popular Science, 381 Fourth Ave., New York City.

Science & Invention, 184-10 Jamaica Ave., Jamaica, N. Y.

The Electric Journal, Keenan Bldg., Pittsburgh, Pa.

Journal of Electrical Works, Machinists Bldg., Washington, D. C.



Many newspapers have entered Radio upon an extensive scale, publishing complete Radio sections—sometimes operating large broadcasting stations. This station belongs to The Atlanta Journal.

Radio magazines circulating among broadcast listeners and Radio set builders, etc.:

These can use general interest articles on different phases of radio, i. e., broadcasting, receiving, problems of the radio public in general, etc.; articles describing latest scientific progress in Radio; constructional articles on receivers, amateur transmitters, accessories, etc.; fiction stories having Radio as the main theme. In reference to the latter item, radio technique as a theme is desirable rather than stories dealing with the general side of broadcasting, reception, etc. Photographs of the latest scientific progress in Radio are acceptable; also poetry with Radio as a main theme. Manuscripts are reported on within three weeks, and payment is made on publication.

Radio Engineering, 52 Vanderbilt Ave., New York City.

Radio News, 184-10 Jamaica Ave., Jamaica, N. Y.

Radio, 499 Pacific Bldg., San Francisco, Calif.

Radio (Canada), 60 Adelaide St., Toronto, Ont., Canada.

Radio Broadcast, Garden City, Long Island, N. Y.

Radio World, 145 W. 45th St., New York City.

Radio Manufacturers Monthly, 520 N. Michigan Avenue, Chicago, Ill.

Magazines using articles on short wave amateur transmission and reception:

Q. S. T., Hartford, Conn.

Amateur Radio, 120 Liberty St., New York City.

(These two publications use contributions supplied by enthusiasts almost exclusively and rarely find it necessary to pay for submitted articles.)

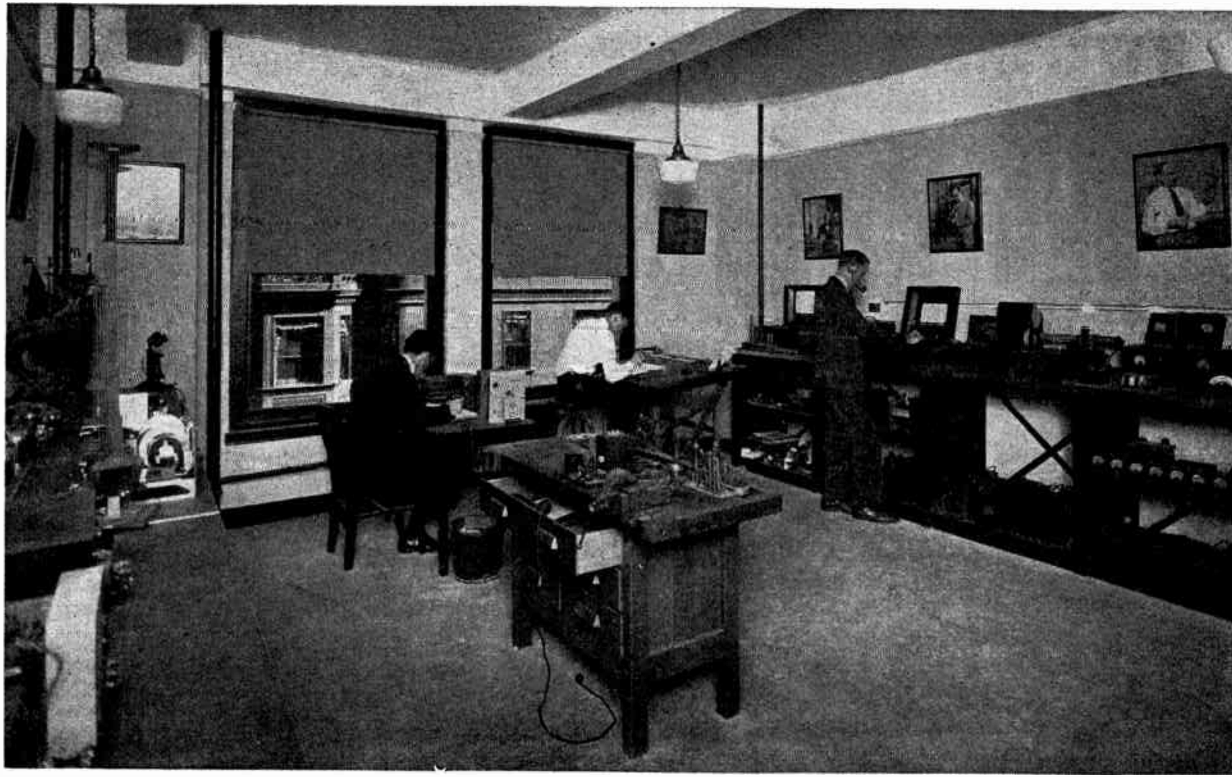
Newspapers publishing Radio articles:

These are especially interested in constructional data, involving the general scientific side of Radio. All of the fascinating happenings in the great field of communication without wires are presented for the lay reader in every-day terminology. Photographs should accompany articles. Manuscripts are reported on promptly.

New York Sun, New York City.
New York Herald, New York City.
New York Times, New York City.
New York Tribune, New York City.
The Evening World, New York City.

The third field of considerable extent is the writing of newspaper articles, particularly for newspapers publishing Radio supplements. The usual newspaper article is too technical and many Radio editors are hungry for the simple style of writing which presents a new thought or fact on Radio, in a manner, which the layman can understand upon first reading.

Fourth, those who have demonstrated their ability to write magazine and newspaper articles can also write advertising



Radio Laboratory of a Radio magazine.

literature and instruction books. Considerable technical knowledge and practical experience is necessary for this work, in order to insure its accuracy. Few writers possess the qualifications for this exacting work and hence this field is particularly profitable.

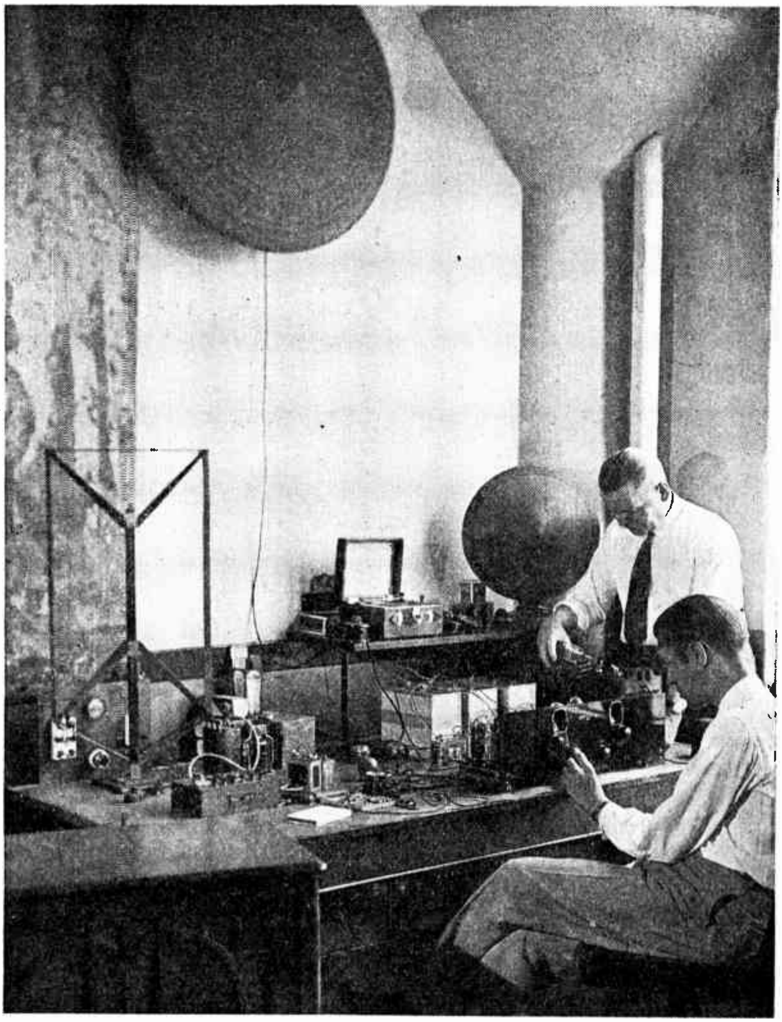
TYPES OF ARTICLES USED

Most of the Radio articles which have been published in magazines and newspapers deal with the design and construction of receiving sets. This is still the largest field of Radio writing and hence it is necessary for us to consider it in some detail.

In writing an article on this subject, it is important to consider the publication for which it is intended. If you were a lecturer, you would adapt your speech to the audience which you were addressing. You would speak differently to a group of small boys than you would to college students or to business men. You would adapt your language to the knowledge and experience of those whom you were addressing.

The same principle must be adopted by writers. When writing for magazines having circulation among experienced Radio constructors, it is possible to assume a fair amount of technical knowledge on the part of those reading the articles. On the other hand, if writing for newspapers, it is advisable to assume the reader to be non-technical and to help him upon every point upon which he may have difficulty in understanding. The easiest way to be sure your style is not "over the heads" of your readers is to imagine yourself talking to them in person. Form a definite conception of the average reader of the story. Many writers use language of a type which indicates that they assume their readers know as much about Radio as they do themselves and hence, if their readers do not have as complete a knowledge as the author, they cannot easily understand the article.

In writing an article on a specific receiver, keep in mind the factor of completeness. When submitting such an article to an editor, be certain that it is accompanied by clear and simple drawings, showing the hook-up used, a layout illustrating the correct placing of parts in the cabinet, the mounting of instruments on the panel, and photographs of the complete receiver.



A corner of the experimental laboratory of Popular Mechanics. Before the Technical Editor's article on a receiving set is written, the set is designed, built and put into successful operation. Then the Technical Editor tells in detail how it was done.

Every writer has his individual style and hence it is not possible to lay down any fixed rule for writing a description of the design and construction of a Radio receiver. It is necessary, however, to point out that the story is not complete unless it describes the general principle upon which the receiver is founded, the theory of its various circuits, the parts required to make it, the correct assembling and wiring, the manipulation of the receiver after it is completed, and the more likely causes of trouble and their correction. In the interest of completeness, when writing a description of a Radio set, ask yourself if you have fulfilled all of these requirements before you submit it for publication.

A second general subject for newspaper and magazine articles having circulation among Radio fans are those dealing with the operation of Radio receivers. This subject is not as frequently attempted as that discussed in the previous paragraphs, because it is difficult to write in a specific way about the skillful way of doing a thing.

You have probably had the experience of observing an able Radio operator sit before a receiver which has not given satisfactory results and, because of his superior skill in tuning, break one record after another for that set and location. If you ask him how he does it, he probably cannot tell you. It is up to a writer to analyze and find out and then describe in terms which every one can understand just how this is done. Because this is so much more difficult to do than the other kind of writing, it is in even greater demand than articles dealing with construction.

The theory of Radio has been the subject of many magazine and newspaper articles. Unravelling the mystery of Radio by simple, clear descriptions of the numerous processes which take place in the transmitter and receiver has been frequently attempted. Again it is a matter of using concrete terms and examples using familiar facts. The theory of Radio is a most fascinating subject if developed in a fascinating way. Newspaper Radio supplements and Radio magazines hunger for a good theoretical explanation of Radio receivers and transmitters. There is no lack of effort to write such descriptions, but there is a lack of people capable of writing such articles suitable for those who know little or nothing about Radio and how it works.

Many articles have been written about the future of Radio by writers who do not have a thorough knowledge of its past. Their predictions have accordingly appeared more or less ridiculous in the eyes of those who know by long study and contact, its full possibilities. Futuristic articles must be written in the light of past experience in order to give the conclusions a sound and convincing basis. Otherwise the reader will not be convinced of the reasonableness of the writer's predictions.

In center—L. G. Biles, former managing editor of "Radio in the Home," shown in the experimental laboratory of that magazine. After graduation from N. R. I., he took a position as technical editor of the Philadelphia Public Ledger. His rise to his present position with the Hammarlund Roberts Ins. has been steady and rapid.

RADIO FICTION A VIRGIN FIELD

For those endowed with the ability to write fiction, the Radio field is practically a virgin one. Not that Radio has not appeared occasionally in fiction, but it has rarely, if ever, been written up in the understanding and sympathetic manner in which one experienced in Radio would write. Radio offers all the variety in the world so far as plots are concerned, but there are few who can both write good fiction and understand Radio sufficiently to avoid the ridiculous. For this reason good Radio fiction is rare.

A new class of writer is gradually making his way in the Radio field. He devotes himself to the criticism of Radio programs for newspapers. At the present time, it is a small field, but there are many who predict that the Radio critic will soon be as essential as the dramatic critic to the modern newspaper.

The successful Radio critic must have a good knowledge of music and its correct rendition, be a good judge of voice and instrument quality and thoroughly familiar with the theory and practice of Radio telephone transmission. He must know, when a program is not well transmitted, just what the cause is; whether it is a matter of poor placement of artists about the microphone or improper operation of the transmitting apparatus. His style must be unique and interesting. Because of the rareness of all of these qualifications, good Radio critics are deserving of large salaries.

ADVERTISING AND PUBLICITY WORK

Another productive field is the preparation of advertising copy either in connection with an advertising agency handling Radio accounts or working with the manufacturers themselves.

Radio writers connected with manufacturing concerns are called upon to advise and approve advertising copy prepared by the advertising agency. The function of the advertising agency is to make contracts with magazines and newspapers for the purchase of space and to prepare the copy to be used. Because of the fact that Radio is such a technical subject, the technical accuracy of the statements made in advertising must be carefully checked by the manufacturer and this duty is performed by the Radio writer or advertising manager of the concern.

In addition, he has the duty of writing booklets, circulars and direct mail advertising which is circulated to the trade and to users of receiving sets. He also writes the instruction booklets which describe the care and manipulation of the receiving set.

Usually another important function is filled by the Radio writer in the preparation of newspaper and magazine articles dealing with Radio to bring out the advantages of the type of set which the manufacturer is marketing. Sometimes added value to such publicity subjects is gained by the use of illustrations showing the receiving set made by that manufacturer.

Naturally such articles, which appear without expense to the manufacturer in newspapers and magazines, do not fulfill the function of advertising but must be of informative and educational value.

Writers are also employed by broadcasting stations with the duty of giving information to the newspapers regarding the activities of the station. The programs which appear in the newspapers are based upon information supplied to the Radio editors by the publicity man of the broadcasting station. He is also called upon to supply brief items regarding the artists and principal features which appear on the station's program. In order to make them acceptable, such items must be written in

Executive and publicity offices of the Atwater Kent Manufacturing Co.

newspaper style, emphasizing the new or "newsy" and possessing a breeziness of style which is characteristic of the newspaper article. Oftentimes men of newspaper experience are selected for this work, not only because of their familiarity with the correct style to be employed in the writing of publicity, but because their acquaintance with men on newspaper staffs is of value in securing the publication of items regarding the station.

HOW TO START AS A RADIO WRITER

So much for the style of writing and the type of article which is in demand. We will assume that the student is satisfied that he is qualified to write articles which will be acceptable. The next point is how to embark upon a career of Radio writing.

It is best to begin by writing a short article not over a thousand words in length. Have this neatly typed double-spaced on only one side of the paper and submit it to the editor of the publication for which it is best adapted. Most successful writers have begun by offering their products to newspapers because they have the greatest difficulty in finding new material. In general, newspapers are not in a position to pay as well for articles as magazines, but the experience gained by writing for newspapers is always a good foundation for future success with magazines.

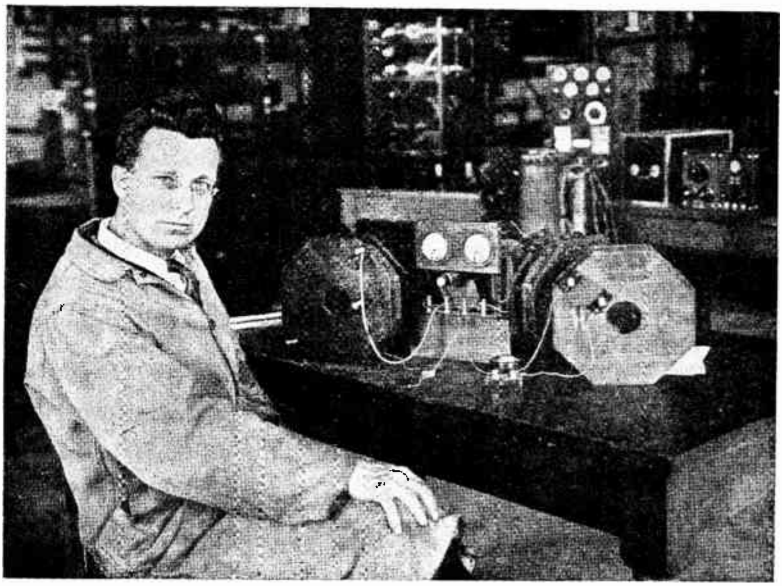
It is essential in securing the acceptance of a story that it be carefully and clearly written, but, of even greater importance, is the point that it be something new, that it express an idea not heretofore published; whether it be the description of a new type of receiving set or a prediction regarding the future of Radio, one of the essentials is novelty, for no newspaper or magazine will knowingly publish an article containing material which has been previously presented to its readers.

Although newspapers and magazines offer a wide scope for the qualified Radio writer, there are many other ways to make money out of writing about Radio. Manufacturers of Radio sets require the services of skilled writers in several ways. There is a big field in writing instruction books, catalogues and sales literature for manufacturers.

NATURALNESS

The key-note of good writing, as of good manners, is be natural. Sincerity is the first requisite for effective writing. When a man says what he knows or believes, he is likely to be interesting, because each human being possesses an individuality, a point of view, that makes him different from his fellows. To say or to write what you do not think, for the mere sake of talking or writing, is a verbal exercise that must be performed with extraordinary skill if it is to be attractive. To be natural is to be yourself, not a poser; to give the reader the best of yourself. Quotations—which are second-hand thoughts—will serve occasionally when the thing you want to say has been said so well by another that it would be waste of energy to try to say it better; but, as a rule, the utterance of the writer himself is more interesting than the quotation, because the writer brings something of himself to bear on the subject. Therefore, say things as best you can in your own way, neither in borrowed words nor in the phraseology that mimics another. Write as if you were speaking to a person whom you desire to persuade or convince. You will then write better than you speak, because, in the first place, you can be more deliberate, and, secondly, you can revise what you have written.

Speaking and writing are similar mental acts, with a difference: the difference between eating food raw and eating it cooked. Some kinds of food gain nothing by being cooked; likewise some kinds of utterance are not bettered by being written



PROFESSOR J. H. MORECROFT
of Columbia University who has made many valuable contributions to the literature of Radio communication.

down first; but most expressions of thought, especially those that deal with complex ideas, must undergo preparation before they can be digested comfortably.

Composition, however, is less natural than speaking. The pen or the pencil intervenes between the thought and the expression, introducing an element of artificiality, as well as one of deliberation. The spoken word cannot be recalled; the written word can be erased. Yet it is unwise to criticize your writing as it proceeds, for such self-criticism tends to embarrassment or self-consciousness. Revise the work carefully after it is done, not before. You have heard of the centipede who was too much aware of his many legs, and became hopelessly entangled. Inopportune self-criticism will cripple writing, just as self-consciousness prevents most men from becoming satisfactory after-dinner speakers.

Each of us has individuality, and that quality ought to be expressed in our writing. It is expressed in our speech, and it will be reflected in our writing if we do not assume an artificial manner.

To be natural in writing, you must have something to say: something concerning which you feel impelled to write. To have something to say is the first requisite for effective speaking or writing. Most speeches and many writings are ineffective, if not worse, because, like an unhappy golfer, the speaker or writer does not see the object of his aim; he does not "keep his eye on the ball." Wait until you have something definite to tell. Only a fool talks for the sake of talking; that is why so many speeches fall flat. It is unnatural for a man to write for the sake of exercising his index finger and thumb. Make sure that you have something to say; then say it; and when you have said it, stop! "The best spoke in the wheel is the fittest, not the longest."

The student while in school, and for some time afterward, is occupied mainly with the effort to acquire knowledge. To write is to convey information to others, which is the reverse of the normal youthful attitude; it involves a pose difficult to assume gracefully or effectively without practice; but such practice should be encouraged, because the effort to record thought involves the mobilization and marshalling of ideas, a disciplinary effort highly beneficial to the student's mind. Therefore, it would be well if some exercise in writing could be taken during the early process of acquiring knowledge.

To write naturally, you must exercise the faculty of writing until it becomes flexible and strong. The best way to learn how to swim is to plunge into the water. Most of those who write well have written much, but you may be sure that they have not published all of it. Do your preliminary cantering in the paddock, not on the race-course. The good writers obtained their reputation by being wise enough to keep their preliminary trials to themselves; meanwhile they noted the results obtained from the methods used by others. Ben Jonson said, "For a man to write well there are three necessaries: to read the best authors, observe the best speakers, and much exercise of his own style." Naturalness comes from exercise, not from carelessness.

The notion prevails that writing is a knack, that the skillful use of the pen is a gift of nature. This is an error. Ability of any sort may be partly inborn, but observations show that most of the easy writers have become so by constant practice. They have written a great deal and have taken particular pains to improve their style. The larger part of the great writing in our literature is the result of persistent effort. An easy fluency has been the undoing of many.

Still another field of Radio writing—the Radio consultant. The young lady in the picture is surrounded by the mail received in one day at a prominent broadcast station. All these letters must be taken by men who understand Radio, and answered correctly. Need for men of this type exists with Radio magazines, newspapers and at Radio manufacturing plants, as well as broadcast stations.

In order that a technical description or discussion may hold the interest of the reader, at least long enough to cause him to read it to the end, the writing must be done carefully and systematically; otherwise it will fail in its purpose of conveying information. Clearness is absolutely essential. "It is not enough to use language that may be understood; it is necessary to use language that must be understood."

The purpose of writing, at least of that which is meant to be read by others, is not only to express ideas but to communicate them. Not explaining subjects clearly may prove as bad as untruthfulness.

Good writing depends not so much upon a large vocabulary as upon the choice of words. The wrong word side tracks the thought; the needless word is an obstruction. A writer that flings needless words about him is like a swimmer who splashes;

neither makes speed. The blue pencil of the editor is the symbol of the knife because we recognize that it removes the useless members of the literary structure. Revision commonly denotes pruning. The greatest fault of the incapable writer is the employment of too many words. Even practised writers err in this respect.

CONSTRUCTION

The writing that is effective is woven with a fine texture into an agreeable pattern; it is free from knots, loose threads, and stray fluff. The instrument that weaves this literary fabric, whether it produce a homely sock or a lordly tapestry, a simple story or a learned treatise, is a disciplined intelligence, as sure as a steel needle, as precise as a swift loom. The simile breaks down at this point, for the product of the men is in keeping with the human spirit and therefore surpasses in beauty anything made by a mere machine.

If words are to be woven into eloquent meaning, they must be well knit. Upon the relation of words to each other and of groups of words to other groups, known as phrases, clauses and sentences, depends the success of writing as a means of transmitting thought from writer to reader. To be understood beyond question, you must know not only what your words denote but how to build your sentences; you must not only choose your words correctly but construct your sentences properly.

COMPOSITION

Do not write until you have something to say. Think first; then write. In order to be understood, you must know what you wish to say. Clear writing is the consequence of clear thinking. Therefore, consider your subject well before you begin to write; ruminate on it; marshal the main facts in your mind; saturate yourself with the ideas you wish to express; then express yourself deliberately. If you are bubbling over with your subject the words will come, but you might as well expect to sail without a breeze as hope to give life to words without the living thought.

Among the uneducated it is a common expectation to acquire the knack of writing without taking the trouble to study the art of writing. A man in a suburban train remarked to his neighbor: "I'd like to be able to write well without stopping to think about it." He was one of many who would like to do a

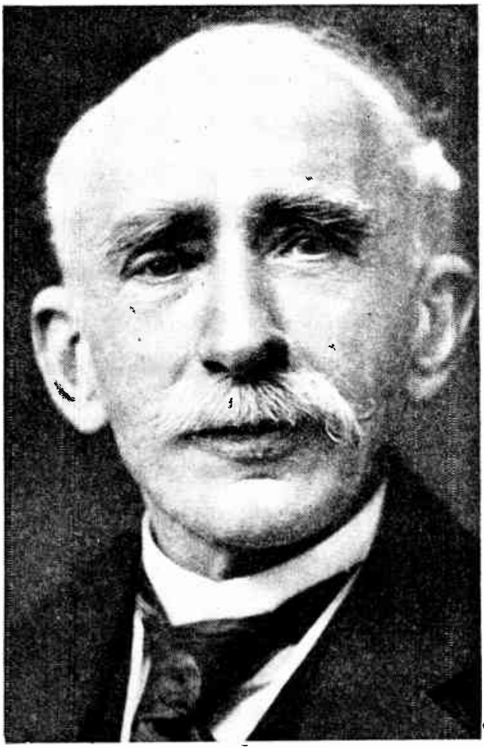
Where Radio News experimental work is done. This laboratory is conducted by the Technical Editor.

thing well without the trouble of thinking; but it cannot be done in respect of anything to which thought is essential. The possession of a good voice does not justify a person in expecting to sing successfully to a large audience; before singing in public one has to master the technique of singing; one has to learn first how to breathe properly, how to enunciate, and many other things. The successful singer is an artist, not a megaphone. Most of us would regard a man or woman without any training in the art of singing as an impostor if he or she were to give a public concert, yet we do not recognize the equal foolishness and imposture of persons who write books before they have studied the technique of writing. That is why so many books are unreadable, and why many books by clever men are difficult to read. They start to write books before they have learned how to write; their style is colloquial, and exhibits the errors of ordinary conversation; it is marked by the inversions and obscurities frequent in the letters dictated by business men; it does not fulfill its purpose, for the purpose of writing is to communicate ideas clearly, comfortably, and convincingly.

Endeavor to visualize the things to be described; consider their relations to one another; let your mind dwell upon the particular phase of their relationship that is to be the subject of your writing. Then prepare an outline of the argument or of the successive stages of the description. Begin the writing with a general statement of the subject to be discussed. Try to strike a clear note; do your tuning where it will not annoy the reader. After making the general statement, proceed to details. Make them vivid; keep them distinct. Then draw your inferences and play upon them until they lead naturally to a definite conclusion, which should embody the purpose and purport of what you have written.

Before beginning to put your ideas in writing, charge your memory with the words, technical terms, and phrases that will furnish the means for effective expression. To acquire an adequate vocabulary, read what others, preferably good authors have written on the subject or on a kindred subject. An artist is not expected to utter the message in his soul until he has mastered the technique of his instrument, neither can a writer be expected to express thought fluently and pleasantly without acquiring the technique of language.

Short sentences are easier to write and easier to understand than long ones. The longer the sentence the more difficult its construction. The long sentence is difficult to manage, but it enables the writer to assemble a group of related ideas into a coherent whole and to make a complete unbroken impression. Variation in the length of sentences is essential to an agreeable style. Avoid an excess of short jerky sentences; avoid also long sentences that are packed with a mass of unsorted and unrelated ideas.



DR. JOHN A. FLEMING—British Radio Expert
Dr. Fleming has written a very large number of papers and books on radio telegraphy and telephony. As a lecturer at the Royal Society of Arts, he has obtained a world-wide reputation for his lectures on electrical oscillations and electrical waves.

A paragraph should be devoted to one main idea, and it should either begin by introducing the idea that it is intended to develop or its beginning should suggest the direction in which the thought is to move.

Technical writing is devoted largely to description and exposition. "Good arrangement is at least one-half exposition. Order is often equivalent to explanation." In describing a Radio set it is advisable to consider the parts in logical order, that is, in the order in which they are placed.

Comparison is indispensable in technical description. By references to similar things the reader is helped to understand the thing described.

The poor quality of much of the technical writing of today is due to the intervention of the stenographer. Dictation tends to develop diffuseness and repetition. Many find it easier to use the mouth in talking than the hand in writing. That is why the average dictated letter, unless it be edited and re-written, is full of unnecessary words. An author who uses pen or pencil can see what has gone before and can compose with a consecutiveness that is conspicuously rare in a dictated composition. Technical men accustomed to dictating their correspondence find it difficult to write an article in long-hand; so they dictate the article also; and the consequence is that the article resembles the dictated letter in failing to be closely knit, clear, or logical.

A good plan is to write with a soft pencil on paper that is not too smooth. The dipping of a pen into the ink introduces an artificial interruption—annoying if it comes in the middle of a sentence. Besides, the point of the pen being hard, the fingers soon tire. The penciled manuscript is given to a typist, and the clean typewritten copy is then revised carefully before it goes to the composing room. The first draft, the typewritten copy, the printer's proof, each in turn, represents a stage of increasing dignity in the development of an article. The earlier a correction is made the better. In former days many of the minor corrections, of spelling and punctuation, even of grammar, were made in the composing room or in the printing office. The real editors were the type-setters or the proof-readers. That practice is becoming obsolete.

Some writers find it convenient to jot down notes on separate cards or small sheets of paper, and then arrange them in orderly sequence. Others, especially the more practised writers, dispense with such aids. As a rule, the beginner will be wise if he prepares an outline of what he intends to write, so as to give sequence and proportion to his treatment of the subject.

Clever men think more rapidly than they can write; other men write more rapidly than they can think; a good writer will form the habit of regulating the speed of his thinking so that it keeps step with the order of his writing. The ability to synchronize the operations of the brain and of the hand is acquired by experience, which, in time, becomes a habit.

BUSINESS PAPER WRITING

The average person seldom realizes that, in his own experience, happenings and circumstances will supply the most acceptable ideas to the average trade and business paper. Almost any man or woman, in business or out and regardless of position, is capable of preparing manuscripts that will bring returns ranging from $5 to $500. In many cases, this remuneration is the result of very little study and purely the relating of that which is a particular hobby or experience.

The biggest difficulty encountered by many when the thought of feature writing enters the mind is the feeling of incapability. Yet, if the average trade paper will be read, the thought cannot help but come to the observer's mind that ideas in print are worded practically as any one would say them. And the ideas themselves are not exceptional. They relate every day occurrence in individual communities that, when told, brings before the public eye some particular fact that has been passed unnoticed by the majority.

A fair command of the English language and an observation of facts cannot help but result in the making of spare-time money. From a continued working with various publications and a general knowledge of editorial requirements—that can only logically develop—the business writing field will build confidence and ability to prepare articles for general publications.

The first question which logically arises is, "What shall I write about?"

With the constant development of the scientific field—pending inventions, radio improvements, etc.—the average man has something to tell the reading public.

By the use of a camera and words, he can make his happy hours materially profitable ones.

The idea of how material being discussed is to be obtained, the next step—and really incidental to the one just mentioned—is the preparation of facts into manuscript form. The first thing to do is to prepare an outline of the entire idea to be discussed. Have an introduction that states what is to follow and tells of the intention toward giving out ideas that can be applied, in a general way. Write as you would talk, staying away from a flurry of adjectives and nouns that would require the use of a dictionary should the average reader attempt to understand them.

After the manuscript has been prepared, be sure that you allow some one in whom you have confidence to read it for criticism. Never lose sight of the fact that comment is a builder of ability. The other fellow's opinion may be just as good as your own. A combination of ideas will only logically build a firmer argument and solution. Having your manuscript read for accuracy and proper development, type it or see that it is typed on plain white paper, double spaced with at least a ¾-inch margin on either side. Number all pages consecutively and carry the title at the top of each. By all means see that a neat typing job is performed. First impressions are lasting and they may have a great deal to do with the placing of your story.

The manuscript being ready, address a letter direct to the editor of the publication to which it is being submitted, making a definite attempt to add the personal element in the paragraphs which follow the salutation. By all means be brief and to the point. The editor is a very busy man, oftentimes at his desk but a week or ten days during a month, the balance of his time being spent with the trade. He wants to know who you are, what you are writing about and why. That's all.

Don't say "Dear Sir" or "Gentlemen," when the editor's name is known, but "Dear Mr. Smith" or "Dear Mr. Brown," unless, of course, editors request that correspondence be addressed to the publication only.

ORDERED WORK

The Importance of Pleasing the Editor Who Requests an Article on a Particular Subject.

One of the highest appreciations of a writer's work is a request from an editor, an order for some type of story or article. Every writer is proud of such an order, and with good reason, but to fill it means work of a peculiarly arduous nature.

He works under a psychological strain not present in the preparation of his "unsolicited" material. He feels that he is being put on his mettle, that he is being tried and must make good; and herein lies an anxiety that often defeats its own purpose.

We know that nervous and muscular tension is a handicap in physical work or games; the pool player, marksman or tennis player does his best work when "going loose." The moment he lets any emotion or overcare get possession of him the muscles involved become more or less tense and fail to work with the necessary smoothness and accuracy. He loses his eye and his stroke.

We have a similar situation in the writer's over-care. It is common knowledge among editors that the author who has sold his first book often fails on his second, the main reason for this is self-consciousness and over-care. Mental tension is just as destructive as physical tension; we must be tension-free, unshackled by fear of failure, to do our best work.

To set fear aside when we tackle a piece of ordered work is not easy. In addition to the natural pride we have in success, there is the feeling that failure may mean a closed door to us in the future, a loss of that editor's confidence. On top of these thoughts, comes the speculation on what we shall do with the manuscript if it comes back. Of course, it is being written with all the special adaptation to that particular magazine that you can give it, being "built on specifications"; what chance will it have on a second journey, under those conditions? All these considerations have an inhibitory effect; right when the writer would like to do his very best, this psychological ball and chain holds him back.

That consideration of a second possible market for the article may be his direct undoing. In leaving out a paragraph or two which he knows the second magazine would not like, or in giving the article some twist that he knows would appeal to the second market, he may lift the manuscript from the "one chance" class, but spoil its best chances with the periodical that has ordered it.

Make good on the job as ordered. Aim primarily to please the editor who sent the request; it's the most profitable course in the end. Do not incorporate anything that actually limits the manuscript's availability to the ordering editor, unless it is necessary. A really good article will find a buyer.

EDITING THE SMALL MAGAZINE

To keep up the interest of your readers in your publication—or, what is even better, to get them to look forward to it is not an easy task. It means constant planning and thought. When you have completed the work on one issue, it isn't the time to sit back and rest till you start work on the next. Those moments when you are not pressed with actual work to do are ideal for thinking up new schemes to make your publication interesting.

You may find that the columns you have been running regularly have become stale—that there is no longer sufficient interesting copy for them. Then don't, by no matter of means, continue them because of their venerable age. Junk them and get new columns or departments in the magazine. If you are devoid of ideas, start a contest among your readers, and offer a prize for the best suggestions for improvements in the magazine.

Occasionally, it is a good idea to send out questionnaires to your readers, or to a selected group of them, asking what they think of the magazine, what their favorite feature is, what they do not like, new features they would like to see included, etc.

By keeping active on the job, looking over other publications for new ideas and taking suggestions from others, you will keep your magazine a live one. It will be read—in fact, your readers will look forward to it.

The field of Radio writing is an extensive one and a writer, having sufficient knowledge of Radio, has many opportunities to utilize his qualifications. Those preferring to work for themselves have open to them the field of free lance writing, contributing to the numerous newspapers and magazines using Radio articles. Those preferring permanent connections may secure positions with manufacturers, broadcasting stations, advertising agencies, newspapers and Radio magazines. Experienced writers, struggling in overcrowded fields, will find it well worthwhile to make a thorough study of Radio in order to utilize their abilities in a field in which there are many mediocre writers, but comparatively few who possess a sufficiently clear style to make technical subjects of interest to the layman.

RADIO BY MAIL

National Radio Institute

STUDENTS ALL OVER THE WORLD

NATIONAL RADIO INSTITUTE

Complete Course in PRACTICAL RADIO

NRI

Radio-Trician

(Trade Mark Registered U. S. Patent Office.)

LESSON TEXT No. 2

(3rd Edition)

PRINCIPLES OF ELECTRIC CIRCUITS USED IN RADIO RECEIVERS

riginators of Radio Home Study Courses

•••Established 1914•••

Washington, D. C.

"It was in making education not only common to all, but in some sense compulsory on all, that the destiny of the free republics of America was practically settled."—*James Russell Lowell.*

THE THREE S's OF SUCCESS

A Personal Message from J. E. Smith

"Systematic-Scientific-Study" is a motto you'll do well to remember. System is the principle of success. You can never hope to reach the greatest success of which you're capable if you are sloven in your habits of work. Therefore, in your study of this course, make up your mind to this one thing: you must be systematic. The three S's of SUCCESS are Systematic-Scientific-Study.

System is the first principle of science; science is the first principle of study, and study is the first principle of success.

There are two classes of students in the world, the systematic and the haphazard. Here are two students, Mr. S., who is systematic, Mr. H., who is haphazard and "hit-or-miss." Mr. S. begins by making a careful estimate of the time he has to spend and of the time required to do the work. He calculates that it will take him so many weeks to do the work by putting in so many hours a day. Mr. H. begins by plunging in headlong without stopping to estimate the time it will take or the energy required, trusting to luck that he will come out all right in the end. Mr. S. keeps a detailed and accurate record of his progress; Mr. H. keeps no record of any sort. Mr. S. has a certain time set aside for study and goes to his work when the time comes. Mr. H. works when "the spirit moves him." Mr. S. masters his work as he goes; Mr. H. skips the hard parts and hopes by good fortune to master them some day. But "some day" never comes. Mr. S. succeeds; Mr. H. fails. Will you be Mr. H. or Mr. S.?

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Printed in U. S. A.

Radio-Trician's
(Trade Mark Registered U. S. Patent Office.)

Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

PRINCIPLES OF ELECTRIC CIRCUITS USED IN RADIO RECEIVERS

In the first lesson of this practical Radio course, we obtained a *bird's-eye view* of what Radio is, what it is supposed to accomplish, and in what manner these things are accomplished. In this, the second lesson of the course, we shall continue to follow out this "bird's-eye view," but in doing so we will gradually drift into the details of *Radio, electricity* and *magnetism.*

We know that electric currents flow along wires, or in fact in all materials. But in some materials the current finds great difficulty in flowing. For instance, the current flowing in the door-bell circuit can easily flow along the wire, and the metallic parts of the push-button. But it will be expected that the wiring, and the bell and the push-button must be mounted on some thing; the door-bell is screwed onto the wall, the batteries are set upon a wooden shelf, etc. It is evident that the electricity must be confined to our particular door-bell circuit. It is also evident that in order to so confine it, we must mount the various instruments on materials that will not easily conduct the electricity away from the circuit.

CONDUCTORS AND INSULATORS

Experience has taught investigators in their study of electrical phenomena that materials may be divided into classes; one class of materials conducts electricity very easily; another class of materials conducts electricity only with difficulty. There is no sharp dividing line between the two classes of materials. For instance, silver conducts electricity slightly better than copper, copper better than aluminum, aluminum better than iron, iron much better than German-silver.

For convenience, it has been found that three groups of materials will cover all practical purposes:

(a) Materials which conduct electricity very easily, called *conductors.*

(b) Materials which conduct electricity with slight difficulty, called *resistors.*

(c) Materials which conduct electricity only with great difficulty, called *insulators.*

Under these three groups fall the following materials:

(a) Conductors: Silver, copper, platinum, mercury, nickel, iron; in fact, nearly all metals.

(b) Resistors: German-silver, carbon, various metallic alloys, as manganin, constantan, etc.

(c) Insulators: Porcelain, bakelite, dry wood, glass, silk, cotton, rubber; in fact, most non-metallic materials.

RESISTANCE IN CIRCUITS

Let us first follow out the line of reasoning that a plumber employs after a house is built and all the water-spigots are installed. The plumber has to connect the water supply pipe between the house and the water main running under the street, which comes from the city pumping-station. The first thing the plumber does, is to count the number of water outlets in the house, and consider how much water is likely to be demanded from the main at any time. If this amount of water is great he then chooses a rather large pipe to connect the water main and the house. If the amount of water is small he need use only a small pipe. In other words, he chooses the size of pipe that will best accommodate the demand for the water. So it is with electricity. The larger the wire chosen to carry the electric current, the easier it will carry it. If we use a very fine wire, it will be able to carry only a small amount of electrical current.

In installing the water supply pipe, the plumber also has to consider the distance between the house and the water main in the street. For the greater this distance, the greater will be the amount of friction encountered by the water in flowing through the pipe, and this friction will make the flow of water slightly more difficult. It is, therefore, necessary, in order to counteract this dropping of the *water-pressure,* to use a larger pipe than he would if the distance were short.

The same thing holds true in electrical circuits, and we can formulate the laws of current flow in a wire in the following manner:

(a) The larger the wire the less the *resistance* it offers to the flow of current.

(b) The shorter the wire the less the *resistance* it offers to the flow of current.

(c) The less the *specific resistance* the less the resistance the wire offers to the flow of electric current.

The student will note that we have used two new terms in the preceding paragraph, viz., *resistance* and *specific resistance.* The word resistance is a general term, signifying the total amount of opposition the wire offers to the flow of current. The term "specific resistance" relates to the opposition a wire offers to the flow of current, regardless of the wire size and length, etc. For instance, if we have two wires of equal length and diameter, one wire having twice the *resistance* of

Testing the Circuits of a Radio Receiver.

the other, we say the *specific resistance* of the one is twice that of the other. In other words, the specific resistance of a conductor depends only upon the material of which it is made; the total resistance of the conductor depends not only on the material, but also on the length and diameter.

When we were talking about the plumber's problem of connecting water pipes to a house, we had occasion to use the word *pressure.* It is well known that when we have a high water-pressure in the water mains, there is a much greater chance of getting all the water we need into the house. Also when the pressure is high, the friction (or resistance) of the pipe to the flow of water is overcome, and a smaller pipe may be used to bring the same amount of water to the house.

Once again, similar things are true of the flow of electric current in wires. A *pressure* of some kind is required to make the electricity flow through the wire just as pressure is required to make the water flow through the water pipe. Water-pressure is measured in pounds, but electric pressure is measused in *volts*. The pressure is also called the "*potential*" in certain cases, which we shall learn about later on.

The amount of water flowing in a pipe is measured in *gallons* and the rate at which it flows in *gallons-per-minute.* In electrical circuits the *amount* of electricity flowing is measured in *coulombs;* the rate at which the electricity flows is measured in *coulombs-per-second.* The phrase "gallons-per-minute" has not been given any special name, but the phrase "coulombs-per-second" has been called "*amperes.*" The "resistance" in an electrical circuit is measured in *ohms.*

Do not be alarmed at these strange names, if you have not heard them before; they are the names of great scientists who made important discoveries in electricity, and who have been honored by having their names used as the various units of electricity. Now let us compare the flow of water in a pipe with the flow of electricity in a wire, in tabular form:

Flow of Water in a Pipe		**Flow of Electricity in a Wire**
Pressure	Pounds	Volts
Opposition	Friction	Resistance
Amount	Gallons	Coulombs
Rate	Gallons-per-minute	Coulombs-per-second (amperes)

We now have a means of calculating what is going on in a simple electrical circuit energized by a battery and carrying an electric current. First let us see how we can calculate what is going on in the water pipe, for that is more familiar to us. Suppose, that in a certain pipe there is water flowing at the rate of 10 gallons per minute. It is clear that in 10 minutes 10x10 or 100 gallons of water will have flowed through the pipe.

In the electric circuit, suppose that electricity is flowing at the rate of 10 coulombs-per-second. Then in 10 seconds 10x10 or 100 coulombs of electricity will have flowed through the wire. Or, if we use the term "ampere" instead of "coulombs-per-second," the same holds true.

OHM'S LAW

There is a simple relation which holds true in simple electric circuits, however, which does not hold true for water systems, so we must drop our water pipe analogy for the present. This simple relation deals with the rate of current flow, the pressure and the resistance. Suppose that our door-bell circuit is connected to a battery which has a pressure of 15 volts. Suppose also that the circuit has a resistance of 5 ohms. Current will then flow through the circuit at the rate of 15 divided by 5 or 3 coulombs-per-second, that is at the rate of 3 ampere. In other words, if we divide the pressure by the resistance we obtain the current. There are *three ways* in which this simple relation can be expressed, so that when we know any *two* of the three quantities, *current, pressure* or *resistance*, we can always find the other quantity. These relations are:

$$\text{Current (in Coulombs-Per-Second or Amperes)} = \frac{\text{Pressure (in volts)}}{\text{Resistance (in ohms)}} \quad (1)$$

$$\text{Pressure (in volts)} = \text{Amperes} \times \text{Resistance} \quad (2)$$

$$\text{Resistance (in ohms)} = \frac{\text{Pressure (in volts)}}{\text{Current (in amperes)}} \quad (3)$$

These relations are quite simple. We can see how simple they are if we abbreviate the ideas. For instance, instead of writing it all out, let us use the letter I for the current in amperes, the letter V (E is sometimes used) for the pressure in volts, and the letter R for the resistance in ohms. Then these relations look as follows:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}} \quad \text{or} \quad I = \frac{V}{R} \quad (4)$$

$$\text{Volts} = \text{Amperes} \times \text{Ohms} \quad \text{or} \quad V = I \times R \quad (5)$$

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}} \quad \text{or} \quad R = \frac{V}{I} \quad (6)$$

Now let us see how things like this apply to the Radio receiver. As you know, there are a number of electron tubes in the set which are very much like ordinary incandescent lamps in certain respects, having a filament something like an incandescent lamp, which is heated by the electric current. This filament is heated by an electric current supplied by a storage battery, as shown in Fig. 1.

There is also an instrument included in the circuit, which is called a *rheostat*. This is a wire made of high resistance material wound upon an insulating strip, perhaps of fibre, and there is a metallic arm which can be revolved by a handle, so that this arm can make contact with the various turns of wire as it slides over them. The purpose of this rheostat is to introduce considerable *resistance* into the electric circuit. The arm is made movable so that we can adjust this resistance to the proper value. The electron tube has been so designed that it will work best when a certain amount of current is flowing through it. If we use more than this amount the "life" of the tube will be shortened, and if we use less than this amount the tube will not operate well. So we adjust the amount of resistance in the circuit so that the proper amount of current is permitted to flow through the filament circuit of the tube.

The electron tube used in many battery operated receivers is known as the UX-201-A. This tube has been so designed that it operates best when a pressure of 5 volts is put upon it, and a current of 0.25 (which is the decimal expression for ¼) of an ampere is flowing through the filament. Now, applying the things that we have learned before, the resistance of the filament in the tube is obtained as follows:

$$R = \frac{V}{I} \quad \text{or} \quad R = \frac{5}{0.25} = 20 \text{ ohms} \tag{7}$$

The resistance of the filament is therefore 20 ohms.

The next problem is to find out how much resistance we must have in the rheostat, in order that 0.25 of an ampere of current shall flow through the circuit, when the pressure of the battery is 6 volts. Once again, in order to find the total amount of resistance required in the circuit, we have:

$$R = \frac{6}{0.25} = 24 \text{ ohms} \tag{8}$$

This is the total resistance required in order that the 6 volt battery will send 0.25 of an ampere through the complete circuit. But the filament of the electron tube already furnishes 20 of the 24 ohms, so all the resistance we need in the rheostat is 4 ohms. We are therefore enabled to choose the proper rheostat immediately. The nearest size rheostat made commercially has a total of 6 ohms of resistance, and by moving the contact arm the resistance can be reduced to less than 1 ohm. By choosing this particular rheostat we can obtain the 4 ohms we need by moving the contact two-thirds the way around so that only two-thirds (or four-sixths) of the resistance is used.

The reason for this can be seen by referring to Fig. 1-A. which is like Fig. 1, excepting that the rheostat (R) has been stretched out straight. We have divided this rheostat into

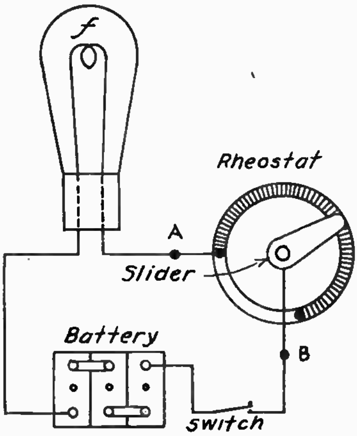

Fig. 1

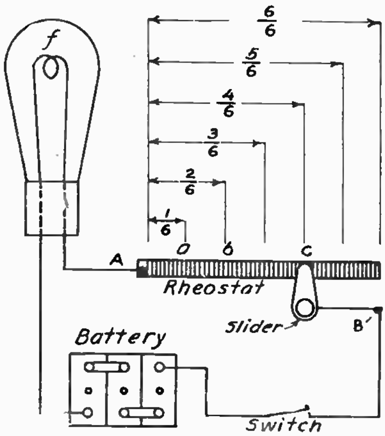

Fig. 1-A

six equal parts, so that counting from the end A, where the slider starts, we can count off or introduce into the circuit as many of these parts as we wish by merely moving the slider to the right. Thus, if the slider is at a, we have one-sixth of the rheostat in the circuit, and since the total resistance of the rheostat is 6 ohms, this means we have 1/6 of 6 ohms or 1 ohm in the circuit. When we move the slider to b we have 2/6ths (which is the same as 1/3rd) of 6 ohms or 2 ohms, in the circuit. Every time we move the slider a sixth we introduce another ohm into the circuit. When the slider is at the point c, we have included in the circuit 4/6ths (or 2/3rds) of the total, and 4/6ths of 6 ohms gives 4 ohms, which is the resistance we need in series with the filament of the tube under consideration.

It makes no difference where we place the rheostat in the circuit, nor any of the other pieces of apparatus, in this case. We can connect them in the circuit in any order we please. The same current will flow in the circuit regardless of the order in which the apparatus is connected. This can be readily appreciated when you consider that when water is flowing through a pipe, whatever water goes into the pipe at one end must come out the other end. This is true of all electrical circuits in which there is only one path for the current to travel—what we will call later, a *series* circuit, in which there is a series of instruments, one behind the other. As far as the amount of current in the circuit is concerned, it makes no difference in a series circuit what the order of the apparatus happens to be.

It must be remembered that *all conductors* have *resistance.* The difference between conductors of various materials, with regard to their resistance, is the *amount* of resist-

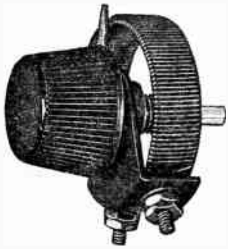

Fig. 2—Filament Variable Rheostat.

ance they have. Every part of the path through which the current flows, in Fig. 1, has resistance, even the battery which supplies the electrical energy. The liquid in the battery, called the *electrolyte,* has a small amount of resistance, perhaps a tenth of an ohm or less. This is so small that we generally neglect it in making rough calculations such as we have done heretofore. The copper wire itself, with which we make the connections from one instrument to another in the circuit, has a small amount of resistance. The amount of resistance in the wiring depends, as we have seen, on the diameter and the length of the wire.

Wire sizes have been arranged by the manufacturers of wire in an orderly manner, which we shall learn later on, but for the present, the wire Table No. I is given for the student's reference. In it are shown the *gauge numbers* by which the various sizes are known, instead of speaking of these sizes as so-many thousandths of an inch in diameter.

Thus we speak of a number 20 wire, which has a certain diameter, as shown in the table. The machinist speaks of drill sizes in a very similar manner, a number 20 drill, meaning a drill with a certain particular diameter. The various gauge systems are different, that is, the system of drill gauges is not the same as the wire gauge. There are also special gauges for special kinds of wire, as, for instance, the "steel wire gauge." In Radio, however, we are for the most part interested in the gauge which applies to copper wire only, so for

Copper Wire Table No. I

Size B. & S Gauge	Diam Bare wire in inches	Ohms per 1,000 ft.
16	.0508	4.009
17	.0453	5.055
18	.0403	6.374
19	.0359	8.038
20	.0320	10.14
21	.0285	12.78
22	.0253	16.12
23	.0226	20.32
24	.0201	25.63
25	.0179	32.31
26	.0159	40.75
27	.0142	51.38
28	.0126	64.79
29	.0113	81.70
30	.0100	103.0

this purpose we use a gauge system known as the Brown & Sharp system, named after a great tool manufacturing concern. It is commonly abbreviated "B & S." It is also known as the "American Wire Gauge" to distinguish it from the British gauge.

It is seen in the table that each wire size has a certain amount of resistance for each foot of wire. Thus No. 20 B & S gauge wire has a resistance of 10.14 ohms per 1,000 feet.

The rheostat has, as we have seen, a rather large amount of resistance, compared with the resistance of the battery and the connecting wires. It has intentionally been made to have this resistance. It consists of a wire wound around a form, and the contact arm, or slider, moves over the edges of the turns of wire so that it can make contact with each separate turn successively. This is done to make it possible to *vary* the amount of resistance included in the circuit. Figure 3 shows a portion of such a rheostat. The points A and B are the same as the points A and B in Fig. 1. When the contact arm is in the position C, the current has to flow through all the resistance wire from A to C and then to B. When the contact arm is in the position D, the current has to flow through only a portion of the resistance and then to B, making the resistance in the circuit less.

Table No. II

Material	Relative Resistance
Silver	0.925
Copper	1.000
Aluminum	1.587
Iron	9.
German-silver	17.3
Manganin	29.3
Constantan	32.
Nichrome	100.

The particular wire used may have many times the resistance per foot of copper wire. Suppose we have a number of wires of different materials, all having the same diameter and length. The resistance of the copper wire will be so many times the resistance of the silver wire; the iron wire will have so many times more resistance than the copper wire. Likewise, it is true with wires of other materials, such as we have mentioned in Table No. II. By referring to this table we can find out exactly how much more resistance a certain kind of wire has in comparison with copper. For instance, the relative resistance of German-silver is 17.3. This means that a piece of wire made of German-silver has 17.3 times the resistance of a piece of copper wire of the same length and diameter. Suppose we have a 1 foot length of German-silver wire, size 20 B & S gauge, and we wish to know its resistance. Look in the table of copper wires.

The resistance of 1,000 feet of No. 20 copper wire is shown to be 10.14 ohms. This means that one foot of the wire would have a resistance 1/1,000th as great, or 10.14/1,000th or 0.01014 ohm, or roughly, one-hundredth of an ohm (0.01 ohm). Now, Table II gives, as the relative resistance of German-silver wire, 17.3. This means that German-silver wire is 17.3 times more resistant to the flow of current than copper wire. So the resistance of our one foot of German-silver wire will be 17.3 x 0.01 or 0.173 ohm per foot.

We can make this quite plain by doing our problem in the form of a table, thus:

	Ohm.
Resistance of 1,000 feet of No. 20 copper wire........	10.14
Resistance of 1 foot of No. 20 copper wire, 10.14/1,000	0.01014
Relative resistance of German-silver................	17.3
Resistance of 1 foot of No. 20 German-silver wire 17.3 x 0.01014	0.173

We now come to the filament of the electron tube. We have seen in the case of the 201-A tube which we studied before, that its resistance is 20 ohms. This high resistance is obtained in such a short piece of wire, by making the diameter of the wire very small. The filament is usually made of

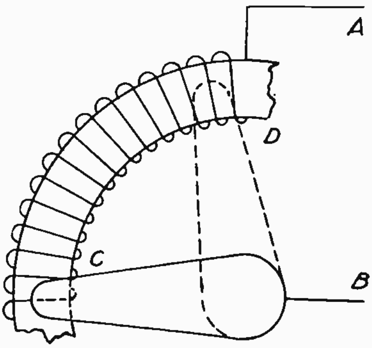

Fig. 3—Portion of a Rheostat Illustrating How the Resistance is Varied.

tungsten, which has a higher relative resistance than copper wire. The higher relative resistance, combined with the small diameter of the wire, enables us to get a lot of resistance in a wire as short as the filament of one of these tubes, which may only be about two inches or less in length.

We have now completely covered the circuit of Fig. 1 with respect to the distribution of resistance in it. But we have more to learn about what resistance does in an electrical circuit. We have learned that resistance in a circuit offers opposition to the flow of the electric current. To what does this opposition lead?

Let us, for the sake of clearness, consider what opposition may do in other fields. Think again of the water pipe. The friction of the pipe against the water flowing in it causes a ioss in pressure. This loss of pressure amounts to the same thing as a loss of some of the energy that is in the water, and the energy so lost is converted into heat. Of course this heat may not be noticeable, for the water continually coming in takes up this heat and carries it off, thus keeping the pipe cool.

Now let us think of another comparison. Suppose we take a file, and rub a piece of brass on it. There is a great friction between the file and the piece of brass, and if we rub hard and long enough, the piece of brass may become so hot that we cannot hold it. This is a very good example of how mechanical energy can be converted into heat energy. We have the same thing happen when sparks fly off a grindstone, or when a car-wheel slides on the car-track.

In a very similar manner, electrical energy in a circuit can be converted into heat energy. The resistance in the circuit, offering opposition to the flow of current, causes some of the energy to be converted into heat. The amount of heat so *generated* depends upon the *amount of the resistance* and

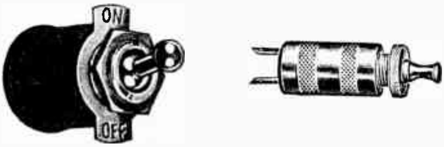

Fig. 4.—Types of Filament Switches.

the *amount of current* flowing through it. When the current is small the amount of heat so generated is small; when the resistance is small the heat generated likewise is small. When it is easy for this heat to flow away into other bodies or be radiated into space, we do not generally notice the rise in temperature of the wire carrying the current.

On the other hand, when a great amount of heat is confined to a small space it is often easy to feel the heat. For instance, a great deal of resistance is confined to a small amount of space in the rheostat. The wire is wound on material which does not conduct heat away very easily. Consequently, if the rheostat is carrying a fair amount of current we can feel the heat by touching our finger to the resistance wire in the rheostat.

As another illustration of this heating effect, take the case of the filament. This is heated to such a degree that the filament becomes luminous. It acts just the same as an incandescent lamp, although to a smaller degree. The heat finds it extremely difficult to escape or flow away from the filament, as the latter is enclosed in a vacuum. This explains why the wire gets red hot and gives off light.

We will find, as we study further, that this heating effect of electrical currents is a very serious thing. It does not worry us much in electric heaters, where we want the heat, but in most cases we do not want it since it means that some of our electrical energy, which we want to use for other purposes,

Fig. 5.—Sketch Illustrating Action of Filament Switch.

is being lost in the form of heat. As we have said before, we must be very careful where we allow resistance to enter into the electrical circuit. This is especially true of the electrical circuits which we have in Radio receivers. There are only a few places in Radio receivers where we actually *want* resistance, such as in the filament or in a rheostat, etc. But when we have resistance in other places where we do not want it, there is always a loss of electrical energy, due

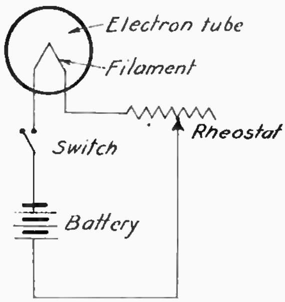

Fig. 6—Filament Circuit of a Vacuum Tube.

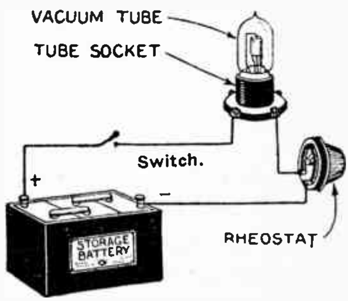

Fig. 6-A—Pictorial View of Apparatus.

to the generation of heat in the wires and conductors. This heat is generally extremely small, so that we cannot notice that it is being generated. But we can notice this loss in other ways. The energy which is in the Radio waves, which the receiver detects and amplifies, is extremely small, and we must be careful not to lose any more of it than we can possibly help. If we lose any appreciable amount of it, we will find that our receiver is not very sensitive. If we have a considerable amount of resistance in the circuits of the receiver, we may be able to receive signals only at a distance of, say, 500 miles, instead of 1,000 miles or more. Of course, the presence of resistance in Radio circuits has more effect than this, but the loss of *sensitivity*, as it is called, is perhaps the most serious effect of resistance.

Figure 1 shows the filament connections of one of the electron tubes which we find in a Radio receiver. The only thing we have not included is a *switch*, which is a device to turn the current off and on as we desire. A photograph of a switch is shown in Fig. 4. This switch may be connected at any point in the simple circuit such as we have in Fig. 1, but it is generally placed in the circuit near the battery. Figures 6 and 6-A shows this arrangement, they are the same as Fig. 1,

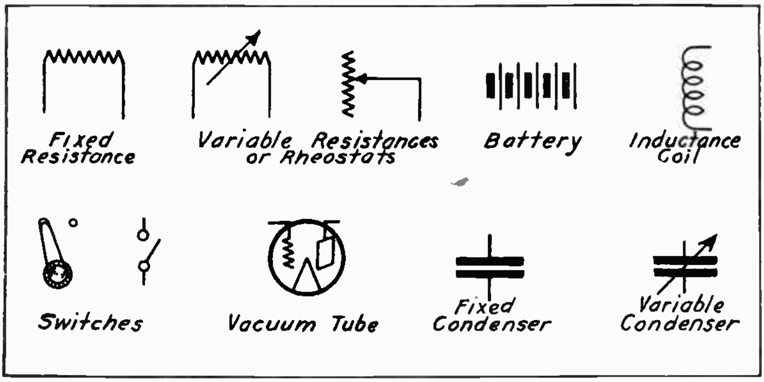

Fig. 7—A Few Radio Symbols.

excepting for the switch. The two diagrams look different because in Fig. 6 we have used a shorthand method of illustrating the various parts of the circuit. The student must become accustomed to using these short-cut ways of representing electrical circuits. They are used continually in Radio engineering.

For instance, an ordinary resistance, which cannot be varied or adjusted, is represented by a kinky line, such as we see in Fig. 7. A resistance which we can adjust is shown in the same manner, excepting that now we cross the kinky line with an arrow, or else indicate one of the connections to it by means of a small arrow head. A *variable resistance* is called a *rheostat*. A battery is represented by a series of long, thin lines in between short thick lines. These represent *cells* of a battery. This is what we have shown in Fig. 7. However, the correct number of cells is not always shown in drawings and diagrams. A switch can be represented in a number of ways, all meaning the same thing, however, since all switches are used for making and breaking electrical circuits at will. Two of these ways of representing switches are shown in Fig. 7 along with other symbols.

PARALLEL CIRCUITS

Now in Radio receivers we generally have several tubes, often as many as six or more. All of the tubes are lighted by the same source of electric current, whether it be from a battery or from the house lighting system, so we must find out how this is done. Let us go back to our old water pipe again, and we shall quickly learn all about it. At the same time let us look at Fig. 8. Here we have a large reservoir which holds a lot of water. We have a number of small tanks, which

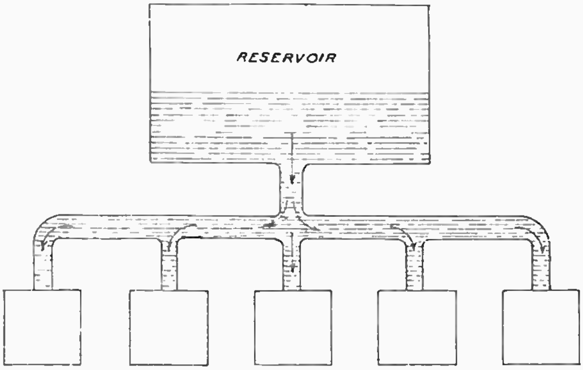

Fig. 8.

we wish to fill with water from the reservoir. We can do this by using an arrangement of piping as we have shown. This arrangement is called a *manifold;* many of you who have worked around automobiles will understand immediately what we mean. The water flows into the piping from the reservoir, as indicated by the arrow at the bottom of the reservoir, and then it divides into the several other channels through which it finally flows into the small tanks at the bottom.

The manner of connecting several electron tubes together so that they can all be lighted by the same battery is very similar to Figs. 8 and 10. The arrangement is shown in Fig. 9, where we have, for example, connected together four tubes. When the switch is closed, the current flows out of the battery and through the rheostat. It then reaches the point "A" where it divides into the various branches in much the same manner as the water divided among the various outlets of the manifold in Fig. 8. Each tube therefore has enough current passing through it to heat it. The four different currents passing through the four tubes unite at the point "B" of Fig. 9, and then continue on in the circuit, going through the switch and back to the battery. Of course, there is not a very close similarity between this electrical circuit and the water system of Fig. 8, but we can get a better idea of this by studying Fig. 10. Here we have a reservoir, but this time it is being emptied by means of the pump. The water divides through the manifold at "A" and then passes through the four small tanks marked "T". These are supposed to represent the four electron tubes. The currents flow of water through the four tanks then unite again at "B" and pass back to the reservoir.

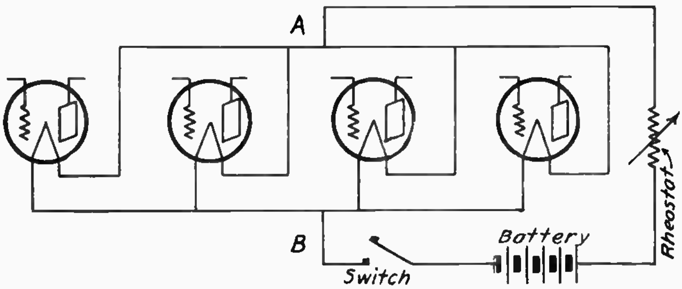

Fig. 9—Four Vacuum Tube Filament Circuits Connected in Parallel

The pressure of the pump in Fig. 10 represents the voltage of the storage battery. The flow of water represents the electric current. We have now learned, in a simple manner, how the tubes of the Radio receiver are lighted and how they are "wired" together so that they may all be lighted by the same battery. We can also see, in Fig. 9, how the brilliancy of all the tubes so connected can be controlled by means of one rheostat. But we shall now learn why this rheostat cannot be the same one which we were talking about before when we learned how to connect up a single tube circuit.

A little earlier in this lesson we learned that when we wish to light a UX-201A tube by means of a six volt supply, we had to add 4 ohms to the circuit in order to limit the current through the tube to 0.25 ampere.

But that was for a *single* tube. Now we have four tubes connected together. The method of connecting them is called a *"parallel"* connection, because all the currents through the tubes come from the same source. Now keep this in mind, and look at Fig. 10 again. Suppose instead of four small tanks there is only one tank for the water to pass through on its journey from A to B. It is clear that the water could not pass as rapidly. Suppose we have two small tanks for the water to pass through. There are then twice as many outlets for the water, and consequently the water can get from A to B with half the difficulty. Then as we add another and then another small tank, until we have four, it becomes easier and easier for the water to flow through.

The same is true with the circuit of the tubes, shown in Fig. 9. Just as the water flows in parallel paths from A to B in Fig. 10, through the different small tanks, so the electric current in Fig. 9 passes in parallel paths from A to B. Since

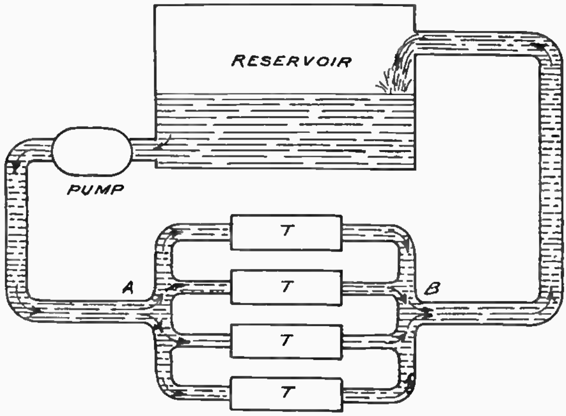

Fig. 10—Illustration Showing a Reservoir Pump and for Tanks Connected in Parallel

there are four of these paths in parallel, it is one-fourth as difficult for the current to flow through. Consequently the resistance between the points A and B of Fig. 9 is one-fourth the resistance of a single tube. Such is the case; when we have a number of parallel paths through which a current may flow, and the resistance of all the paths is the same, the resistance of all of them combined is the resistance of one of them divided by the number of paths.

For instance, we have seen that the resistance of *one* UX-201A tube is 20 ohms. If we have four of them connected in parallel, the *joint* or *combined* resistance is then 20 divided by 4, or 5 ohms.

Now, since it is one-fourth as difficult for the current to get through from A to B naturally four times as much current can flow. In other words, if each tube can take a current of ¼ of an ampere, four tubes in parallel can take 4 times this amount or 1 ampere.

Now we have a six volt battery and we wish to have a total current of 1 ampere flow from it. Using the law we learned before, that is: $R = V \div I$ we find that the resistance we have in the circuit is $R = 6 \div 1$ or 6 ohms, instead of the 24 ohms which we needed when we used only a single tube. Now the four tubes in parallel already furnish 5 ohms, so that now we only need an additional resistance of 1 ohm to be furnished by the rheostat. A six ohm rheostat, however, is the usual commercial size, so that we must use it, and for best operation we should set it about one-sixth of the way around, as can be readily understood by referring to Fig. 1-A. By doing this we shall be certain that the tubes are each carrying a current of ¼ ampere, giving a total current for the four tubes of 1 ampere.

It is not necessary to be able at this early stage of the course, to make such calculations, but it is good to understand how the different things which we find in electrical circuits affect the current and voltage of these circuits.

The student must also become familiar with the names of the various things, and obtain some idea of how great a resistance is, say 10 ohms; perhaps, when you were starting to learn about resistance, when you read that a certain electrical circuit had 20 ohms of resistance in it you did not know what to think. But when you learn that an electron tube, like the UX-201-A has 20 ohms of resistance in it, you begin to understand what an ohm means. You can further appreciate what it means when you think of some of the other good and bad conductors of electricity. For instance, the resistance of a piece of wood, which generally is a very poor conductor when dry, may be twenty or thirty *million* ohms. When damp it may be two or three million ohms. A piece of porcelain may have a resistance of fifty million ohms or more, in fact, it may be so high that we cannot measure it. A piece of No. 20 copper wire has a resistance of only one-hundredth of an ohm to the foot; a piece of No. 20 german-silver wire a foot long has a resistance of about two-tenths of an ohm. So you see that there is an enormous range in the resistance of electrical circuits, all the way from resistances which are too small up to those which are too high to measure. Keep these things in mind, and learn to "gauge" the size of resistance as we meet it in Radio circuits.

SERIES CIRCUITS

When we were learning a little while ago how several tubes are connected together in Radio circuits so that they could be operated by the same storage-battery, we said that they were connected in *parallel.* Now there is another way in which we connect electrical or Radio apparatus together, and we call this the *"series"* connection. Let us see what this is.

First, we all know the general meaning of the word "series"; it merely means a succession of things. That is, when we have a number of things, one following the other, we say we have a series. For instance, if we write 1, 2, 3, 4, 5, 6, 7, 8, 9, we have a series of numbers. So, if we connect a number of pieces of Radio or electrical apparatus together, one following the other, we have a *series* of pieces of apparatus,

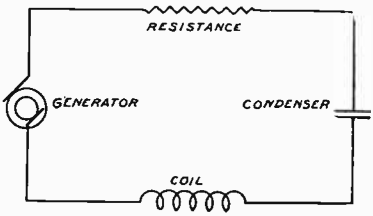

Fig. 11—Drawing Showing Series Connection to Several Pieces of Apparatus Using Symbols.

and this manner of connecting them is called the *series* connection.

In Fig. 11, for example, we have a number of pieces of apparatus connected in series. We have there an alternating current generator connected to a resistance, a condenser, and a coil, all in series. It will be noted that in this diagram we have used a number of symbols, such as we spoke of before. You learned before about the shorthand way in which we pictured a resistance, or a rheostat. In this diagram we also show how we picture a condenser, a coil, and an alternating current generator, in the shorthand method. There are reasons for these shorthand symbols. A condenser consists of two or more metal plates placed near to each other. Hence we represent it by drawing two short lines near each other. A coil consists of a lot of wire wound around a tube of insulating material. Hence we picture it somewhat as an artist would draw a coil of wire. An AC generator has two rings which revolve, and upon which slide pieces of copper or carbon, called the "brushes." Hence we show the two rings and a couple of lines sliding on them. Remember these symbols, for they are very important, being used all the time to draw the wiring diagram of Radio circuits. By means of these diagrams we can show in a few minutes how the most complicated Radio transmitters and receivers are built.

Now let us go back to our electron tube circuit, that is, the single tube circuit, which we saw in Fig. 6. We will reproduce it here in Fig. 12 for your convenience. It is a series circuit, for we have a battery, a rheostat, the filament of an electron tube and switch, all connected in series. One follows the other in succession as we go around the circuit. The current flowing out of the battery has to pass through first one piece of apparatus then the next, and so on, so that the same current must flow through all of them. To show how it all figures out, let us see how much resistance we have in that series circuit.

Suppose, as we saw before, the filament of the tube has a resistance of 20 ohms. Suppose also that we use a six ohm rheostat, and that we have the arm of the rheostat swung all the way around. In other words, all the resistance of the rheostat is in the circuit. In making the connections we had to use a certain amount of wire, depending upon how close together the various parts are located. Suppose the resistance of the wire is 0.1 of an ohm. The whole resistance in the circuit is then all these various resistances added together, including the resistance of the battery, which may be about ½ (0.5) of an ohm. This is:

$$0.5 + 6 + 20 + 0.1 = 26.6 \text{ ohms.}$$

Generally we neglect the resistance of the wiring and the resistance of the battery, because this is usually very small compared with the resistance of the rest of the circuit, so if we would omit these, we would simply say that the resistance of the circuit is 20 plus 6 or 26 ohms. This is accurate enough for most purposes. It is sufficient if the student knows that these other things have resistance.

This is the way in which series circuits work out, at least as far as the resistance is concerned. We have lots of series circuits in Radio receivers, as we shall see. Figure 11 shows a series arrangement that occurs in Radio circuits very often, in fact, in almost all the circuits of a Radio receiver we find a coil, condenser and resistance in series. Oftentimes this resistance is not there in the form of an actual rheostat, but is contained in the very wire of which the coil is made. It is clear that since we have to use wire to wind a coil, and since all kinds of wire have a certain amount of resistance, that the coil must have in it some resistance. When it does have resistance in it, we generally show it in wiring diagrams as being connected in series with the coil, for it is more easily understood then. We shall hear more of this later on.

Now, in order to understand how Radio circuits work, we must at this time begin to tackle the hardest problem of Radio receivers, and that is to understand how and why the condensers and coils work. In our first lesson we learned something about the meaning of *tuning;* we also came upon the idea of *resonance.* Remember the board on the bridge, which we *oscillated* up and down, keeping in time with the water

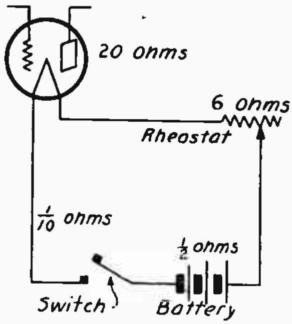

Fig. 12—Filament Circuit of a Vacuum Tube.

waves that flowed underneath. If we did not keep in time with them we would sometimes obstruct their flow. But by keeping in resonance, or keeping in time with them we permitted them to flow underneath unobstructed.

Remember how the violin string vibrated when *tuned* to another violin string which was near it? Remember also that the second violin string would not vibrate unless it were tuned exactly the same as the first one, in spite of the fact that the waves from the first string were striking against it? Well, we have the same thing in Radio. The Radio set at the receiving station, in your home, for instance, must be tuned to exactly the same frequency as the particular broadcasting station which you wish to receive. This tuning, as we have seen before in Lesson No. 1, is done by means of the condensers in the receiver. The tuning could as well be done by means of the coils, but this is not quite as easy, from the practical viewpoint. We will now begin to study what the coils and condenser do in Radio circuits, so that soon we will be able to understand the whole process that goes on in the set, will be well fitted to go out and work on them, and will have quite a broad knowledge of the idea of Radio so that the lessons which follow will be quite simple.

We will start our study with the condenser. An electrical condenser is a fairly simple piece of apparatus. It merely consists of a metal plate located rather close to another metal plate, and in between the plates we may have air, mica, or any good insulating material. The wires leading to this condenser are attached, or soldered to the metal plates. Such a condenser is shown in Fig. 13. This is the simplest form of condenser. In Radio circuits, as we have seen, a condenser is represented in a simple manner by drawing two short lines parallel to each other, and rather close together of equal length. This is shown in Fig. 11.

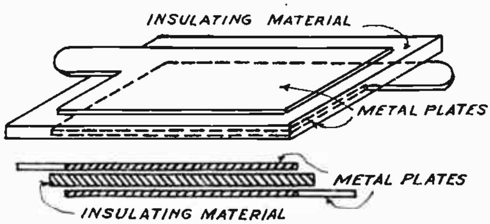

Fig. 13.—Constructional Details of a Simple Condenser.

Now suppose we have such a condenser connected to a battery, and a switch, as shown in Fig. 14. There is also connected in the circuit a *galvanometer*, a very sensitive instrument which indicates the presence of a current whenever one flows in the circuit. We will not worry now about how the galvanometer operates, for we will study measuring instruments later on. For the present remember that we have connected in the circuit a very sensitive instrument for detecting a flow of electric current.

At first, before we close the switch of the circuit in Fig. 14, there is no current flowing in the circuit. The battery has a voltage, or an electromotive force, but since the circuit is broken at the switch, no current can flow. Suppose now we close the switch. The voltage of the battery will cause a current to flow, which tries to find its way completely around the circuit. But when it comes to the condenser it finds a piece of insulating material in its path, through which it cannot easily flow. Consequently, after flowing out of the battery to the condenser, which takes only a thousandth or a millionth of a second perhaps, it stops flowing, and if we were to measure the voltage across the condenser—that is—the force which exists between the condenser plates which tries to make a current flow through the insulating material from one plate to the other—we should find it to be the same as the voltage of the battery.

In other words, by connecting the condenser to the battery, it has acquired a voltage, and this voltage is the same as the voltage of the battery.

Now, keeping all this in mind, let us look at it from another angle. We learned in Lesson No. 1 that all materials are composed of an enormous number of extremely small electrical particles called *electrons*. These electrons exist in the battery, in the wiring and in the condenser, as shown in Fig. 14. The chemical processes which are going on in the

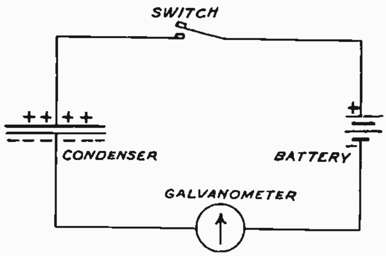

Fig. 14—Illustrating How a Battery Charges a Condenser.

battery cause a certain arrangement of the electrons within it which causes one terminal of the battery to *attract* other electrons to it, and the other terminal of the battery to *repel* other electrons from it. The terminal of the battery which repels the electrons is called the negative terminal or *pole* of the battery, and the terminal which attracts electrons is called the *positive* terminal or pole. In circuit diagrams, such as the one shown in Fig. 14, the positive pole of the battery is marked + (plus) and the negative pole is marked — (minus).

No energy is being taken from the battery until it is connected to an external or outside circuit such as the wiring and the condenser. The electrons are distributed through the wiring and the battery, and on the plates of the condenser, but are not moving in any particular direction. As soon as we close or complete the circuit by pressing the switch, the positive pole of the battery attracts the electrons which were on the plate of the condenser connected to it, and the negative pole of the battery repels the electrons near it onto the other plate of the condenser. There is, therefore, an increase in the number of electrons on the one plate (marked —) and a decrease in the number on the other plate (marked +). This was exactly the condition we had in the battery before the switch was closed, but now this condition has been permitted to advance along the wiring to the plates of the condenser.

The galvanometer will indicate this very small flow of current if it is able to act quickly enough, but as we have seen, all this takes place in an extremely small interval of time.

Now let us open the switch and see what happens. Doing this, we open the circuit; we may just as well remove the battery from the circuit, for this amounts to the same thing. But we have not as yet touched the plates of the condenser. Now suppose we take a piece of wire and touch it to one plate of the condenser. Then we bring the other end of the wire up to the other plate of the condenser and just lightly touch it. Look at Fig. 15. Just at the instant we touch the second plate (short circuit it) we will see a small spark, providing the voltage of the battery that was formerly connected to it, was high enough.

Now how about this? There was originally no electricity, or electric charge in the condenser, as far as we knew. If we had *short-circuited* the condenser before we connected it to the battery we would not have been able to get a spark. The condenser apparently has taken some electrical energy from the battery, and has *stored it up*, until we wanted to release it. When we furnished a path over which the electrons on one plate could rush over to the other plate this electrical energy was released, and became used up by creating the spark and by slightly heating the short-circuiting wire.

It will be remembered there were more electrons stored on one plate of the condenser than on the other. Consequently we could mark the two plates of the condenser in the same way as the terminals of the battery, that is (plus) and (minus). Now suppose, instead of short-circuiting the condenser by a mere piece of wire, we had connected in this wire another extremely sensitive instrument for not only detecting a flow of current, but which could also indicate which way the current was flowing. (See arrows, Fig. 16.) At the instant the path between the two plates is completed the electrons rush around in the direction of the dotted arrows from the negative to the positive plate. Since there are more electrons on the negative plate than on the positive plate, they try to get where there is least crowding.

In their haste to get around, more of them get on the upper plate than can comfortably stay there. As a result the upper plate, which was formerly positive, becomes negative, and the lower plate, which was formerly negative, becomes positive. But the lower plate is now *less* positive than the upper one was before, and the upper plate is now *less* negative than the lower one was before. However, the electrons *discharge* again, this time going in the other direction, and go through the whole process many times.

If we continue to hold the short-circuiting wire in place the same thing will occur again and again; the electrons oscillate back and forth, the polarity of the condenser reverses

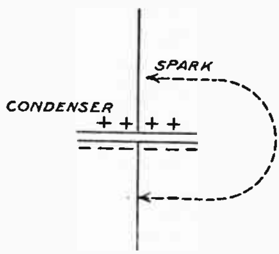

Fig. 15.

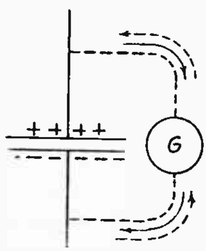

Fig. 16.

each time, and its voltage becomes less and less, until finally all the energy is converted into heat in the wiring and the voltage is zero, whereupon the condenser is totally discharged.

If you will remember, we stated in Lesson No. 1 that a flow of electrons is the same as a flow of current, and the direction in which the electrons flow determines the direction of the current. So we have in Fig. 16, a rapidly changing current, first flowing in one direction and then in another, continually growing less and less. This is a true Radio current, the *oscillating current* we spoke of in the first lesson. Each reversal of the current is called an *oscillation*. These reversals, or oscillations, take place very rapidly, each one requiring perhaps only a millionth of a second. The reason they finally die away is because their energy is gradually used up as they travel back and forth, as there is no battery or generator in the circuit of Fig. 16 which can supply it with energy to take the place of that consumed.

So now we have an oscillating current, although this oscillating current dies away quite rapidly. Furthermore, this current is quite small in the circuit we have just described. However, if we can find a means of preventing the current from dying away so rapidly perhaps we can make some practical use of it. Besides that, we can find a way of making this current oscillate at any particular rate that pleases us. In other words, we should be able to tune the circuits just like we tuned the violin string.

You remember in the paragraph given heretofore, that the electrons rushed from one plate to the other, during the discharge, with such zeal that the polarity of the condenser was reversed. Perhaps, if we slowed down the electrons in their rush, dampen their ardor, so to speak, we could delay the reversal of polarity.

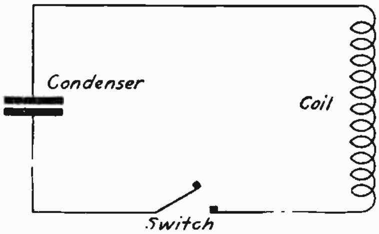

Fig. 17

This is exactly what we do in Radio circuits; it is in this way that we tune the circuits. By delaying the discharge of a condenser we can make the reversals as slow as we please, that is, we can make the frequency anything we want, by delaying the discharge in the right amount. We do this by placing in the circuit along with the condenser, a coil of wire.

Look at Fig. 17. In this circuit we have a condenser which we will assume is charged. We also have a switch, which is open, and a coil in series with the two. Let us close the switch and see what happens.

At the instance on closing of the switch the electrons rush out of one condenser plate in order to get on the other. But before they can get to their destination they have to pass through the coil. Now, you know when they pass through the coil, they establish a magnetic field, and it takes energy to do this. So they are retarded in their flight, and the electrostatic energy which they had while on the plate of the condenser becomes converted into electromagnetic energy in the coil.

When all their energy is thus converted and the magnetic field of the coil has attained its greatest strength, this field begins to collapse, for you know it requires a *movement* of electrons (or a current) to maintain an electromagnetic field in the coil. So the coil begins to give back to the circuit the energy it had taken from it. The electromagnetic energy is converted back into electrostatic energy, and the electrons finally complete their journey, reversing the polarity of the condenser.

Then they start all over again, and begin to discharge in the opposite direction. The coil again retards them, and the magnetic field is again established, but this time *its* polarity

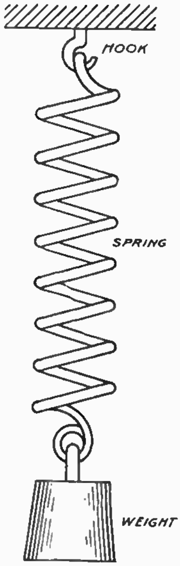

Fig. 18.

is reversed, for the discharged current is now flowing in the opposite direction. So the reversals continue, until finally they die away as they did before. This time, however, it took a great deal longer for the oscillations to die away than it did when there was no coil in the circuit. The greater we make this coil, that is, the greater the number of turns of wire, the slower will the reversals occur, and the longer will it take for the current to die away, *provided*—and this is important—provided that we do not increase the resistance of the circuit when we increase the number of turns on the coil. Resistance, you know, causes a loss of energy, and this would help to make the current die down rapidly. The only part of the electrostatic energy of the condenser, which the coil can turn into electromagnetic energy, is that part which is not converted into heat energy by the resistance of the circuit. Part of the resistance is in the coil, part in the condenser, and a small part in the connecting wires.

We can get the idea a little better perhaps by looking at Fig. 18. This illustration shows a heavy weight hung on a spring. Suppose we pull the weight down and let go. What happens? The weight *oscillates* up and down. But have you ever considered what goes on during this oscillation? When we pulled the weight down we had to exert a certain force, and this produced a tension in the spring, due to our stretching it. Now, when we let go of the weight, the tension in the spring pulls up the weight. In pulling up the weight, the spring gives up all of its energy excepting a small part, which is lost in friction with the air. The weight finally gets to the top of its journey and no longer moves upward. It is clear that since the spring no longer pulls the weight upward that it has lost all of its energy. Where has this energy gone? The answer is, all the energy that was not lost in friction has been given to the weight. It is clear that this must be so, for at that instant the weight begins to move downward, due to its *weight*. In moving down, the weight gradually returns its energy to the spring by stretching it, for soon the weight stops moving downward as the spring is stretched to its limit and then moves upward again, repeating the whole process. But gradually the system oscillates more and more slowly until finally it comes to rest, after all the energy in the system has been used in friction with the air, or from other causes.

The coil and condenser act in a very similar manner, as we have seen. The tension in the spring may be likened to the charge (or voltage) of the condenser. The original charge which we gave the condenser (see Fig. 14) takes the part of the *pull* we gave the weight when we started it oscillating. The coil takes the part of the spring. The up and down motion of the spring and weight is like the to and fro motion of the electrons in the electric circuit.

Now that you have finished Lesson 2, lay down this textbook for a moment and review in your mind what you have read. Recall the three fundamental measurements of electricity; the ampere, the ohm, the volt. What do each of these represent? Go over the lesson mentally as far as possible.

Then take up the lesson again, and be sure you have not missed any of the important principles. Now you are ready to answer the Test Questions on this page.

TEST QUESTIONS

Number Your Answer Sheet 2—3 and add Your Student Number

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What is an electrical conductor?
2. Name several insulators.
3. How do we find the current in a circuit when we know the pressure and the resistance?
4. What is the resistance of a circuit when the voltage is 8 volts and the current is 2 amperes?
5. What is the purpose of a rheostat when used in the filament circuit of an electron tube?
6. How many times greater is the resistance of iron wire than that of copper wire?
7. Draw a diagram showing how a six volt storage battery, a rheostat and the filament of an electron tube are connected together so that the rheostat will control the current flowing through the tube.
8. Draw a diagram showing how a battery, one rheostat and the filaments of four electron tubes are connected in parallel so that the rheostat will control the current flowing through the four tubes.
9. Show by a drawing how several pieces of electrical apparatus are connected in series.
10. Why do the oscillations finally die out in the discharge of the condenser in Fig. 16?

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LESSON TEXT No. 3

(3rd Edition)

TUNING RADIO RECEIVING CIRCUITS

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Washington, D. C.

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Be regular. Be systematic. Have a schedule for studying and live up to it. Some students assign a certain part of each day for study and a few really do accomplish it. A better plan is to use the week as a basis and decide upon the number of hours in each week which are to be used for study. Then if you see that you are running behind your schedule, give an hour or two extra each day to your studies until you get on your regular schedule again.

Remember that your studies are extremely valuable to you, and that you cannot afford to give up to anything else the time that belongs to them. You can make better progress on your studies in the early morning than you can in the evening when you are all tired out. If possible, get up a little earlier in the morning and give this extra time to your studies and you will find that you will be greatly benefited by it. Only fifteen minutes in the morning spent in reviewing the work done the night before will greatly help to fix it in your memory.

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

TUNING RADIO RECEIVING CIRCUITS

It is intended, in this practical radio course to present the first six lessons in such a manner, that when the student has finished studying them he will have a very fair working knowledge of radio. After these first six lessons, we shall begin the study of the details of the theory of radio and the construction of apparatus. By studying the course in this way, the student will have an advantage over others who have attacked the subject from a different angle. It is to be expected that the study of these details is a little more difficult than merely obtaining a "bird's-eye view" of the radio *situation.* But by the time the student comes to these advanced radio subjects, he will be better prepared for them,

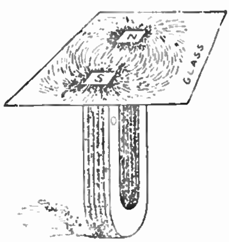


Fig. 1—Illustration Showing How Iron Filings on a Piece of Glass Arrange Themselves When a Magnet is Placed Under it.

by reason of having this all-around conception of radio; the phrases which will be introduced will not be new to him, and the ideas presented will be merely the details of what he has learned before.

We have succeeded in giving to you, in the first two lessons of this course, an idea of what radio is about; you have learned what "tuning" means, and you have learned something about the flow of electrical currents in electrical circuits.

Probably, the only thing about all this that is not yet clear is *how* the coil takes the energy from the circuit, during the discharge of the condenser. We shall now explain how this is done, but you must not forget what we have just said. We shall come back to it in a little while, but for a few moments we will start on another path of thinking.

Do you remember, in our first lesson, when we were talking about the door-bell circuit, we learned that if we had a current flowing in a wire, and an ordinary compass needle were held next to the wire, the compass needle would turn around, and rest at right angles with the wire? Well, we know that if we had two compasses, and placed them near each other, the needles would *attract* each other, and we would find the point of one needle pulling on the opposite point of the other needle. You must clearly understand that the wire carrying an electric current is acting just like a magnetic compass. We can illustrate this in several other ways; look at Fig. 1. This shows an ordinary horse-shoe magnet, which is being held up to a pane of glass. Upon the pane of glass we have sprinkled a lot of iron filings, and by tapping the glass we can see these iron filings gradually arrange themselves in the manner shown in the illustration. They seem to form lines from one pole of the magnet to the other pole. None of these lines cross each other, but all seem to go in the same direction.

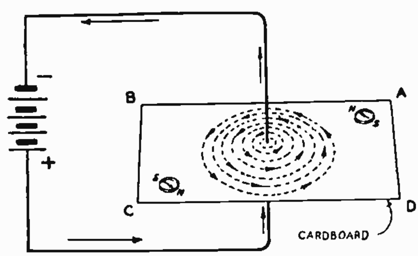


Fig. 2—Using Compasses to Illustrate the Magnetic Field Around a Wire Carrying an Electric Current.

MAGNETIC EFFECT OF CURRENTS

In Fig. 2 we see a sheet of cardboard, through which passes a wire carrying a heavy electrical current. On sprinkling iron filings on the cardboard and tapping it gently, the iron filings will arrange themselves in circles about the wire, the wire being at the center of the circles. The wire with the electric current is acting just like the magnet, excepting in the shape of the lines formed by the iron filings. If, instead of using a horse-shoe magnet for our illustration we had stretched the horse-shoe out and had made a simple bar magnet out of it, and then had placed just one of the poles under the glass, we should have obtained circles of iron filings very similar to the ones formed about the wire carrying the current.

You now know that a current flowing in a wire gives rise to *magnetism*. If we would take the wire in Fig. 2 and wind it up into the form of a coil, we would find the magnetic effect greatly increased. We have done this in Fig. 3, and have slipped into the coil another piece of cardboard sprinkled with iron filings. On tapping the cardboard gently the iron filings arrange themselves in the pattern shown in the illustration, showing that the magnetism comes out of one end of the coil, goes around and returns to the coil at the other end. The space around a wire which carries an electrical current, and within

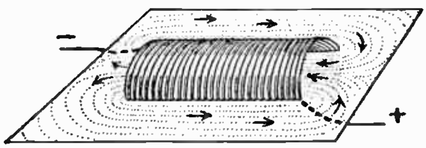


Fig. 2-A—The Sketch Above Illustrates the Magnetic Stress Surrounding an Inductance (Coil of Wire).

and around a coil carrying a current, and the space near a magnet, is called a *magnetic field*. It is called so because *magnetic energy* resides in this space, or *field*.

When a current, therefore, flows in a coil, that part of the electric energy in the current which is not used up in the resistance of the coil, is utilized in establishing a *magnetic field* in and about the coil. The energy which it so takes, in order to establish this magnetic field, is *stored* in this field in the form of *magnetic energy*, or the energy of magnetism.

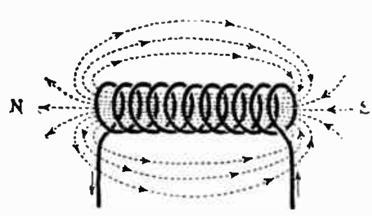


Fig. 3—Lines of Force About a Coil of Wire.

The *strength* of the magnetic field, or the amount of magnetism in the field, depends upon the strength of the current, and the number of turns of wire in the coil. The greater the strength of the electrical current flowing in the coil, the stronger will be the magnetic field; the greater the number of turns to the coil, the greater will be the amount of magnetic energy stored in the field in and about the coil.

We are now in a position to understand how the coil takes energy from the circuit during the discharge of a condenser in the circuit. The flow of electrons from one plate of the condenser to the other forms an electrical current. As the current flows through the coil which is connected to the condenser, some of the energy in the current is taken by the coil in establishing the magnetic field. But we must now learn how this coil gives back this energy to the circuit when the current is decreasing, that is, when the condenser discharge slows down.

Suppose we try the same stunt with the coil and iron filings shown in Fig. 3, but this time do not have any current flowing in the coil. We can tap the cardboard till doomsday, trying to make the iron filings arrange themselves in any certain pattern, but they will not do so. They simply travel to where we make them travel by tapping the cardboard. Therefore it is plain, there are no magnetic effects

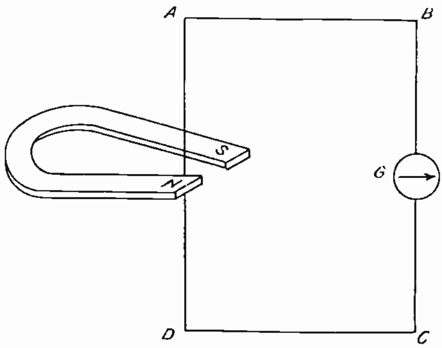


Fig. 4

excepting when the coil carries a current. It is also clear that if the coil was first carrying an electric current, and had a magnetic field established in it, when we stopped the current by breaking the circuit, the magnetic field must certainly disappear. In other words, the energy in the magnetic field of the coil had gone elsewhere. But where? That is the next question.

It will be a very simple matter to reason in this manner: certainly, if a current flowing in a wire or in a coil can establish a magnetic field, then a magnetic field ought to be able, on the other hand, to establish an electric current in the coil. Such is the actual case, excepting that you must always remember there must be *motion* of some kind. In order to create a magnetic field, the electrons in the wire or coil must be in motion—that is, a *current* must be flowing. On the other hand, in order for a magnetic field to create a current in a wire or in a coil, the *magnetic field* must be *moving,* not necessarily from one point to another, but at least must be changing in strength.

We have a state of affairs like this in an ordinary electric dynamo or generator. There is a magnetic field established by a current flowing in some coils. Another set of coils is rotated in this magnetic field by a machine of some kind. As the coils are rotated in the field a voltage is created in the moving coils, and an electrical current made to flow in them.

Suppose we had a simple wire circuit, A, B, C, D, such as we see in Fig. 4, and in this circuit we had a very sensitive instrument, G, for detecting a flow of current. On quickly moving a magnet up to the wire, the instrument would indicate that a small current was flowing as long as we had the magnet in motion. On withdrawing the magnet, that is, upon pulling it away rapidly, it would be seen that a current is again flowing, but when we merely hold the magnet still, no current would flow. A current will flow only when the strength of the magnetic field *is being changed.*

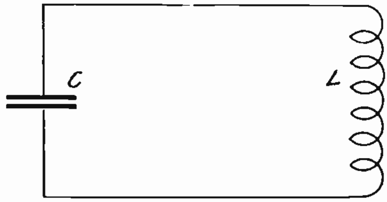


Fig. 5—Closed Circuit Consisting of a Condenser (C) and Inductance Coil (L) Connected in Series.

Now, if we have a coil carrying an electrical current, having a magnetic field established in and around the coil, and then when we stop the current by breaking the circuit the magnetic field disappears, it is clear that the strength of the magnetic field has changed. It has changed from the strength it had *down to nothing.* Consequently, this change will cause a voltage to be established (or *induced*) in the winding of the coil, and this voltage will cause a current to flow, even for a very slight instant after we break the circuit. Sometimes, if the current in the circuit is strong enough, or if the magnetic field is sufficiently intense, we shall see a small spark at the point where we break the circuit, indicating that the current flows for a very short time after the break.

At any rate, it is not necessary to entirely break the circuit, or to have the current entirely stop flowing, in order to obtain this effect, for even a small change of the magnetic field will *induce* a voltage in the coil.

Now we are able to see more clearly what is going on in the circuit of Fig. 5, which shows a condenser "C" in series with a coil "L." The condenser has been charged, and begins to discharge. At the beginning of the discharge there is a rush of current from one plate to the other. As the current flows it establishes a magnetic field inside and outside the coil. While the magnetic field is being *built up* in strength, its strength is changing, and consequently it *induces* a voltage back into the circuit which *opposes* the original current, trying to make it flow more slowly, so that it will last a longer time. When the current has reached its greatest strength the magnetic field strength is greatest; then the current begins to decrease, and with it the magnetic field begins to decrease in strength. As it decreases in strength it again induces a voltage back into the circuit, but this time it is in the *same direction* as the current, so that it tries to *keep up* the current as it decreases. Thus, once again we see that the coil tries to make the current continue flowing for a longer time. When the current reverses, that is, when the condenser begins to discharge again in the opposite direction, the whole process repeats itself, over and over again, until the oscillations finally die away.

Let us go back to the spring and weight illustration in Lesson Text No. 2. Suppose we did not have the spring to hold up the weight by its tension. The weight would then simply drop to the ground, and there would be no oscillations. Suppose again, that we did not have the weight hanging on the spring. If we would then pull down the spring and let go, it would simply fly up, and probably jump off the hook; again there would be no oscillations. The same is true of the coil and condenser circuit of Fig. 5. There can be no electrical oscillations unless we have both the condenser and the coil.

Let us think what would happen if we give a little push to the weight and help it along in its travels up and down. That is, when the weight is traveling upward, we give it a little push upward, and when it is traveling downward, a little push downward. Evidently, the weight would continue to oscillate, and would not slow down. The slight amount of energy that is lost in friction or in fanning the air, would be made up by the pushes my hand gives the weight. Not only that, but the pushes will actually cause the weight to oscillate *more strongly*. That is exactly what happens when we *tune* a radio circuit. We adjust the coil and condenser, either separately or together, to *naturally* vibrate at the same rate as incoming radio signals so that as the current oscillates in the radio receiver circuits, the incoming oscillations give them a *boost* each time, making the oscillations continue, as well as make them stronger. As we have seen before, the adjustment of the circuit so that it oscillates at the same rate as the incoming signals, is called *tuning to resonance*. You now see the reason for this tuning, and understand fairly well how it is done.

CAPACITY

We have said before that a condenser is composed of a number of plates of metal placed alongside of each other. Look at Fig. 6. Here we have a condenser formed by two plates, and these plates are connected to a source of electrical energy, which in this case is represented by a simple battery. *You must remember*, that batteries are not used in radio receivers for the purpose of charging condensers, but we shall

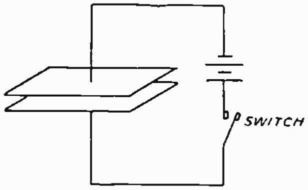


Fig. 6—Circuit Consisting of Condenser Battery and Switch Connected in Series

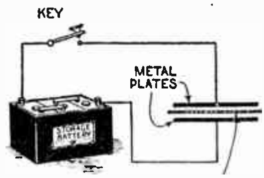


Fig. 6-A—Pictorial View of Apparatus in Fig. 6 Connected Together.

use them frequently in our explanations in order to simplify these explanations. We have seen that when a condenser is connected to a source of electrical energy like this, that the electrons in the circuits and on the plates of the condenser, become re-arranged in the circuit. One of the plates of the condenser acquires quite a few of these electrons, and the other plate loses just as many. The question to be answered is, "How many electrons are stored up on the one plate and lost by the other?"

This is a very complicated question to answer, so we will not try to answer it directly. But we will try to find out something about it. You remember that when the condenser is so charged, a voltage is established between the plates of the condenser. When the circuit is first closed by pressing the switch a considerable current flows in the circuit, which after a very short interval of time decreases and finally stops altogether.

This is called the charging current. At any instant during the time this charging current is flowing there is a certain charge taken by the condenser. How great this charge is depends on several things, the main ones being the size of the condenser plates and the voltage of the battery.

Now suppose, after say, one ten-thousandth of a second the size of the plates and the voltage of the battery were such that a voltage of 3 volts was established on the condenser plates. On opening the switch the charge will remain on the condenser, as we explained before. Suppose, again, that the condenser plates were suddenly made twice the size. We

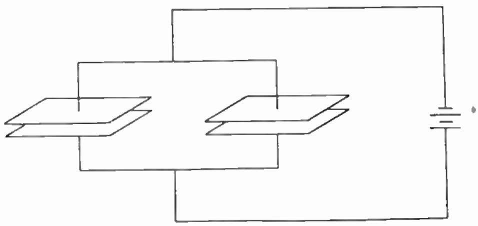


Fig. 7—Two Condensers Connected in Parallel and Connected in Series with a Battery.

originally had a certain number of electrons on the plates, and these produced the voltage in the condenser. Now, when we double the size of the plates, these electrons are only half as crowded as they were before, so that the voltage of the condenser at this instant is now less than what it was. In other words, the condenser now has a greater *capacity* than it had before; its *capacity* to hold a charge is greater; it can hold a greater charge at the same voltage, or even at a lower voltage. This word "*capacity*" is used to indicate the ability of the condenser to hold a charge. Just think of a water tank; the larger

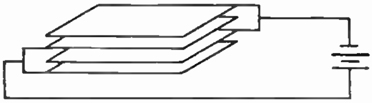


Fig. 8—Illustrating How Alternate Plates of a Condenser are Connected Together.

it is the greater the amount of water it can hold. The same thing is true of condensers; the larger the plates of the condenser the greater the charge it can hold.

Now, suppose that instead of making the plates twice as large, we used the same size of plate, but had twice as many of them, as shown in Fig. 7. Notice that the plates are connected in *parallel*. The same effect is found as before; the charge divides equally between the two sets of plates, and the capacity of the condenser is doubled by doubling the number of plates. There is one thing peculiar about this arrangement, however, and that is the outsides of the two outside plates are not used. The electric charge is held on the insides of the plates, on the sides which are next to each other. Now look at Fig. 8. In this figure we have taken the two sets of plates shown in Fig. 7 and have sandwiched the plates in between each other. Each set of plates is connected in parallel, which gives us a condenser which has quite a large capacity, but occupies only a small space, instead of spreading out, as in Fig. 7.

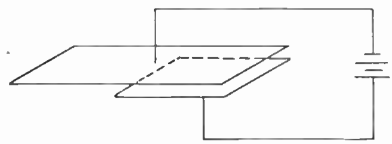


Fig. 9—Illustrating the Useful Overlapping Area of Condenser Plates.

The useful part of the condenser is the part that *overlaps*. For instance, in Fig. 9, the part of the upper plate that *does not* overlap the lower plate is useless, as far as furnishing capacity to the condenser is concerned. The capacity of the condenser is determined by the *overlapping area* of the plates. Consequently we can easily make a condenser whose capacity we can change or *vary*. This can be done very simply by having a set of plates which can be moved in and out of another

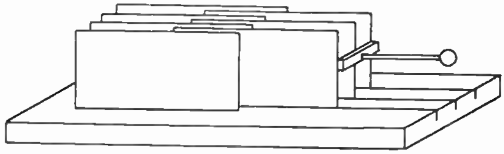
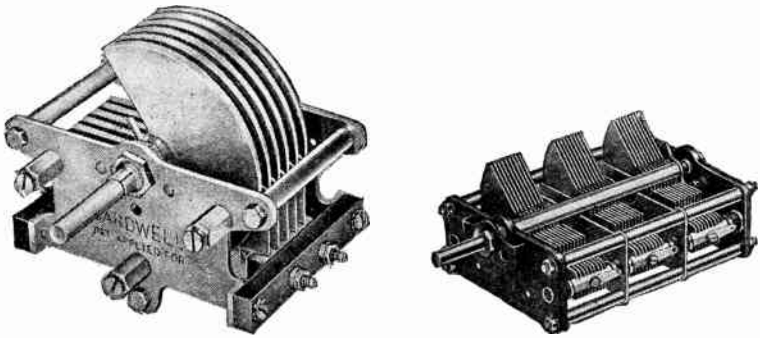


Fig. 10—Early Form of Variable Condenser.

set of plates. A picture of one of these condensers is shown in Fig. 10. This is composed of a set of plates anchored in a base of insulating material, such as dry wood, and another set of plates, which do not touch the others, slides in and out in grooves in the wood. This is one of the earliest forms of variable condenser which was used in radio receivers. Of course this style of *variable* condenser is large and clumsy, so that nowadays condensers are made so that one set of *rotor* plates moves between another set of *stator* plates. Such condensers are shown in Fig. 11. These styles occupy much less space, and provide a much greater capacity for the same space.

The variable condensers shown in Fig. 11 are made of semi-circular plates. There are other shapes of plates used for special purposes in radio receivers, but we will reserve the study of these until later on. In the semi-circular plate condenser, it is clear that if we move the rotor plates a certain distance and then move them the same distance again, that we increase the *overlapping area* of the plates and consequently have increased the capacity of the condenser. In other words, the capacity increase is in proportion to the area of the rotor and stator plates enmeshed.

Now just keep all this in mind, and we shall see how the coils can be made to change the conditions in the radio circuits.



Variable Condenser. Three Gang Condenser.

Fig. 11

Of course, it is not necessary to vary both the condenser and the coils, as the same effect can be produced by varying one or the other, as if produced by varying both, but we shall have to consider this in order to learn how the coil acts.

INDUCTANCE

In this lesson we learned that when a coil carries an electric current, that this current establishes what is known as a *magnetic field* in and about the coil. We also learned that if we had a magnetic field to begin with, and that if this magnetic field was changing, or if we passed a coil through it, that a voltage would be *induced* in the coil, due to the energy in the magnetic field.

Now suppose we had a magnetic field of a certain strength, and that we passed rapidly through it a coil of a certain number of turns. There would be a certain voltage induced in the coil. Suppose again that we passed another coil through the same magnetic field, but that the second coil has just twice as many turns of wire as the first coil. It would be found then that the voltage induced in the second coil would be just twice that induced in the first coil. It is clear then that the number of turns of wire in the coil determines how it is going to act. There are other things, however, which must be taken into consideration, and some of these are the diameter, size of wire, and so forth. We shall learn more about this later. The subject of coils is a rather difficult one, perhaps a little more difficult than the subject of condensers, so the student will have to take many things for granted at the present time, until we get to the lesson in which we shall study them in detail.

At any rate, there is a certain property of coils which we called *"inductance."* The amount of inductance of a coil gives us an idea of the ability of this coil to create a magnetic

Fig. 12—Various Types of Fixed Condensers.

field when a current flows in it, or—just the opposite—the ability a certain magnetic field has of creating or *inducing* in the coil a voltage, when the coil is passed through it or when the magnetic field varies in strength. The greater the number of turns, the greater the *inductance* of the coil; the greater the diameter of the turns, the greater the inductance; the smaller the wire, the greater the inductance.

In the case of condensers, the larger the plates, the greater the capacity; the closer the plates the greater the capacity. There are other things which determine the inductance of coils and the capacity of condensers, and these are the materials inside them. If we place a sheet of glass between the plates of a condenser, instead of merely allowing them to be separated by air, the capacity of the condenser will be very much increased. If we place an iron core inside a coil of wire, the inductance of the coil will be very much greater than if we had only air—that is, inside the tube upon which the coil is wound.

As a rule, air core coils are used in tuned radio circuits, and the condensers used for tuning do not have anything but air between their plates. But there are small condensers used in modern receivers, known as *fixed* condensers, which have mica sheets between the plates. These are called fixed condensers, because the plates cannot be moved. Several of these are shown in Fig. 12. We shall learn what these are used for later on.

With regard to condensers and coils, therefore, you must remember the following:

The capacity of a condenser increases as

(*a*) *the overlapping area of the plates is increased;*

(*b*) *the distance between the plates is decreased;*

(*c*) *and depends upon the material between the plates.*

The material between the plates is called the *dielectric.* It may be air, mica, paper, glass, bakelite, or any good insulating material.

The inductance of a coil increases as

(*a*) *the number of turns of wire is increased;*

(*b*) *the diameter of the coil is increased;*

(*c*) *the diameter of the wire is decreased;*

(*d*) *and depends on the material of which the core is made.*

The core material may be air or iron. Iron causes the coil to have a great deal more inductance than if an air core is used. Furthermore, it depends on the kind of iron used. Permanent magnets are made of hard steel. The cores for electromagnets, which we want to be magnetic only when a current is passing through the coil, are made of soft iron. Often these cores are made of thin sheets laid upon each other called *laminations. Silicon steel* is the grade of steel often used for these laminated cores. We shall learn a great deal about this later on when we study transformers and choke coils for Power Supply Units, etc.

To get back to the ideas of tuning. Remember, in our previous lesson, we described how a weight hung on a spring oscillated up and down after it was once started? Well, we have the same picture in Fig. 13. Let us give the weight a downward push, and count how many times a minute it oscillates up and down. Now let us take off the weight and put in place of it a heavier one. Then start it going and count once again. You will find this time that the heavier weight oscillates more slowly than did the lighter one.

Let us try something else. Suppose instead of changing the weight, we let it alone, and changed the tension of the spring. That is to say, suppose we used a spring which had been coiled up more tightly and had more tension. We would find that increasing the tension of the spring, or its "springiness," as it were, would cause the weight to oscillate more rapidly. Its *frequency* would be greater. In other words, it is possible to control the frequency of oscillation by changing either the load on the spring, or its elasticity (or tension) or both.

Now, to go a step further in our analogy, suppose, instead of the weight, we had a can hung on the end of the spring, and we also had a lot of lead shot that we could pour into the can. Let us pour a little bit in—an amount sufficient so that if we started the can oscillating it would do so at the rate of say, twenty times a minute.

Now we will go a step further. With the can at rest, let us start our hand oscillating up and down, away from the can and spring, at the rate of say, fifteen times a minute, or with any frequency which is different from that at which the can and spring oscillate by themselves. While keeping the hand thus oscillating, bring it closer and closer to the can; eventually it will touch the can and cause it to start on its downward journey. (Don't let the hand follow the can on its journey, but merely give it a push.)

Now, remember, the can oscillates *naturally* 20 times a minute, while the hand is oscillating fifteen times a minute. It is clear that the can will return on its upward journey before the hand has completed its downward journey. It is clear then, that the two motions will interfere, and the hand will prevent the weight from going through its motions as it should.

Now add some lead shot to the weight in the can. The can will oscillate more slowly. Keep on adding the shot until you find that the can oscillates *naturally* at the same rate as the hand—fifteen times a minute. When you have it just right you will find that every time the hand starts its downward journey, the can is starting its downward journey also, so that there will be no interference between the two at any time. Each time the can goes downward, so does the hand; the hand gives the can a slight push or boost, as it were, and helps the can along in its journey. As a matter of fact, we can make the can oscillate as strongly as we please by pushing it as hard as we please, but we must always push at the right instant. When the rate of pushing is exactly the same as the natural rate of the can there will be no interference between the two. We have *tuned* the can and spring to the frequency of the hand, by loading it up with lead shot. Once the can is started going, it is an easy matter to keep it going, but it is quite difficult to keep it going when the two frequencies are not the same.

Let us see what this has to do with radio. The weight represents the coil's inductance. The spring represents the capacity of the condenser. The rate at which the can is vibrating (or oscillating) is the frequency. The hand represents the radio waves being received by the radio receiver. This received wave may have any frequency; that is, up to the

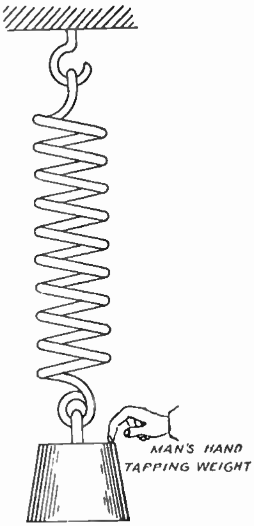


Fig. 13

station sending the waves. We must make the receiver capable of oscillating at the same frequency by tuning it. Just as we loaded up the weight on the spring by adding shot, or by changing the elasticity of the spring, in order to tune it to the same frequency as the hand, so in the radio circuit we can change the inductance (which corresponds to the weight), or the capacity (corresponding to the spring). Or, if we please, we can change both of these a little. Generally, we are content to change only the capacity of the condenser, as this simplifies the construction of the receiver.

So now we know the process of tuning. At least we have an idea of what it is all about. The radio waves are sent out by the broadcasting station, which cause electrical oscillations, or electrical currents which reverse in direction with great frequency. The radio receiver is tuned so that it is capable of oscillating at this same frequency, and when so tuned the incoming waves cause it to respond with little difficulty. It is clear that the smaller the losses (or the resistances) in the circuits, the weaker need be the incoming waves in order to make the receiver respond. This means that when the losses are smaller, the receiver can respond to weaker signals, which may be coming from a broadcasting station farther away.

Having covered the subject of tuning, by coils and condensers, we must learn something about the electron tubes. We learned that these electron tubes have a filament, just like the filaments in an incandescent lamp. Of course, the filaments in the electron tubes are very much smaller, and do not give out much light. The filaments are heated by electric currents, just as are the filaments of the incandescent lamps, but the voltage required to light them is very much lower, from 1.5 to 7.5 volts, instead of 110 volts.

The current required to heat the filament may be obtained from storage batteries, as you learned in a previous lesson, although in most modern receivers they are heated by the alternating current obtained from a transformer which is connected to the house lighting circuits. This matter was also explained in a preceding lesson, and will be discussed more at length later on. The student must remember that the filament can be heated by either method, because for the present, at least in these earlier lessons the circuit diagrams, as Fig. 14 will show, storage batteries for heating the filament in order to simplify matters.

When studying our first lesson you learned that there were such things as electrons, and you also learned that these electrons exist in everything, no matter where this thing may be, or its condition. Whether hot or cold, soft or hard, electrons are contained in it. In fact, the latest theory of the scientists is that everything is made of electrons, and the number of electrons, and the way they are arranged makes the difference between various materials, as, for instance, lead, iron, salt, air and so forth.

We also learned before that an electric current is the same thing as a flow or movement of these electrons. The problem in radio, therefore, is to make use of these electrons by making them flow where we want them to flow, and make them do what we want them to do.

It is well known that when materials are heated to a sufficiently high temperature, perhaps a few hundred degrees, that they let go of the electrons which they have in them. For instance, the very filament in the electron tube which we are studying, has electrons in it, and when we heat up this filament by passing through it an electric current from a battery, its electrons jump away from it. They jump away in the thousands, perhaps the millions, in a second. They fill the space around the filament within the glass walls of the bulb in which the filament is located.

But now that we have gotten these electrons out of the metal of the filament, the next thing to do is to make them work for us. As learned a little way back when we were studying about condensers, when we have a lot of electrons, they can be attracted to the positive pole of a battery if this battery is connected to the place where the electrons are crowded. In other words, the electron is supposed to be *an extremely small negative electric charge,* and according to the law of electricity, *opposites attract.* Therefore, if we connect the positive pole of a battery to the place where the negative electrons are, the positive pole will attract the negative electrons, and we will have an electrical current flowing. This is actually what we do in an electron tube.

ACTION OF THE VACUUM TUBE

In Fig. 14 we have an electron tube, the glass bulb having in it a filament and a plate. The glass bulb is known as the *envelope* of the tube. The plate is thin and small and may be made of tungsten, or nickel, or some other metal. The filament is lighted by means of the filament six volts lighting battery. This battery is known as the "A" battery. There is another battery, called the "B" battery, which has its positive terminal connected to the plate.

What has been said about the filament of the tube being heated by either direct current as furnished by a battery or by alternating current as furnished by a transformer, applies as well to the "B" supply, although this must always be direct current and *not* alternating current. When the power for the "B" supply is obtained from a transformer in the form of alternating current, this must be rectified by means of a special rectifier tube, and the *ripples* or *hum* must be filtered out of it. This has been explained in an elementary manner in a preceding lesson, and will be discussed in great detail later on. Although, for the sake of simplicity, the diagrams in this lesson show "A" and "B" batteries for their source of power supply. It must be remembered that these can be, and are generally, replaced by a *power-pack*, which includes a rectifier and filter, operated directly by the A. C. house lighting power.

The filament, being heated by the "A" battery, shoots off a great multitude of electrons, and the plate, which is located in the space where these electrons are, and being charged positive by being connected to the positive terminal of the "B" battery, attracts the negative electrons. Now since the electrons come from the filament, and pass on to the plate, they must keep on passing somewhere, as they cannot pile up as they

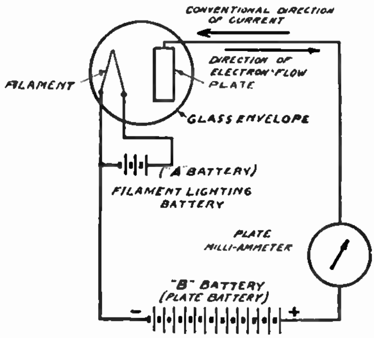


Fig. 14—Filament and Plate Circuit Connections of a Two Element Vacuum Tube.

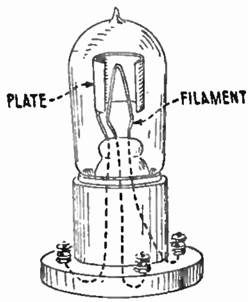


Fig. 14-A—Pictorial View of a Two Element Vacuum Tube, Showing Connections to Filament and Plate (Cut Away) Through Socket and Tube Base.

do on the plates of a condenser. The small plate in the tube is too small to hold many of them. Furthermore, we want these electrons to flow around through a complete circuit so that we can make them work for us. And finally, if we did not furnish some means of replacing the electrons that are taken from the filament, the filament would soon lose all the electrons it had. So we connect the negative pole of the "B" battery to the filament.

The electrons, therefore, flow in a complete circuit; they jump out of the filament into the space within the tube; then they are gathered up by the plate with its positive charge; next they pass through the "B" battery, and finally come back to the filament. They continue going over and over this path without a stop, as long as the filament is lighted and as long as the batteries hold out. The electrons lost by the filament are supplied by the "B" battery, and it is this that gradually uses up this battery. There are also the resistance losses in the system, which must be taken care of by the "B" battery. So now we have a source of electrons, the electrons themselves, and a means

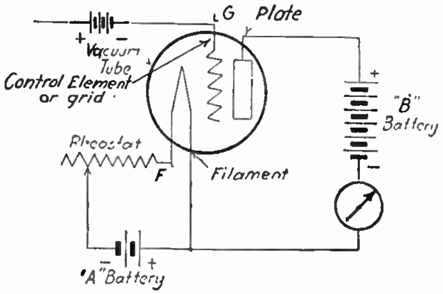


Fig. 15—Illustration Showing Position of Filament, Grid and Plate in a Vacuum Tube.

of making them work for us. We now have to see how they can be made to do work for us in a radio receiver, so that we can receive very weak signals.

It is clear that Fig. 14 is not by itself a radio circuit; there are no condensers or coils in it, and these are necessary for tun-

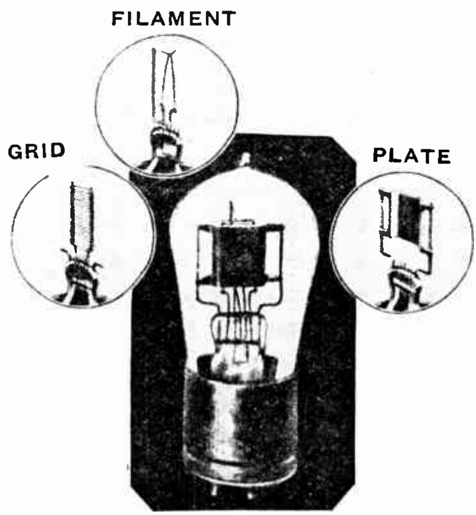


Fig. 16—Picture of a Vacuum Tube Showing Details of Grid, Filament and Plate.

ing. We must include this electron tube, with its "A" and "B" batteries in a tuning circuit with a condenser and coil. But before we do this we must find out how we can *control* the electron flow.

Glancing at Fig. 15, we see how this can be done. If we had another plate, or one or more wires in between the filament and the plate, we might make this *rob the plate* of some of the electrons, or even make it *help the plate* get more electrons. In other words it will act as a control *element*, and such it is actually called. But the popular name for it is "*grid*," since it is constructed like a grid. This is shown in Fig. 15. A photograph of an actual electron tube—and the three elements—is shown in Fig. 16.

Now let us see what this control element or grid does in the electron tube. Ordinarily, although the grid is right in the path of the electrons as they travel from the filament to the plate of the electron tube, it does not obstruct or block the passage of many of these electrons, since nearly all of them can

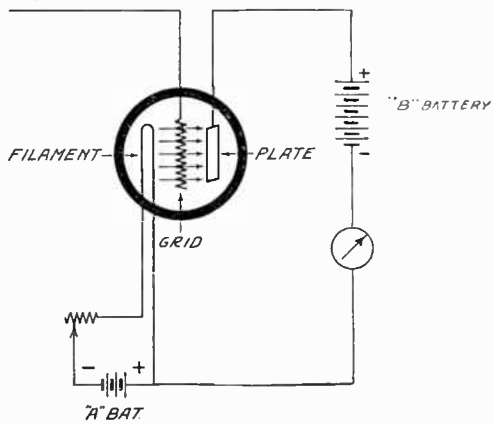


Fig. 17-A—Illustrating the Electron Emission from the Filament to the Plate of a Vacuum Tube.

pass through the open spaces of the grid. The construction of the grid makes this possible, since it consists of nothing more than an open network, or mesh, of fine wires. It does, however, gather in some of the electrons, so that it usually acquires a slight negative charge, just as any piece of conducting material when electrons collect on it. But at the present time this effect is not important; we are now mainly concerned with the fundamental operation of the tube, and will come back to the other later on. For the present let us suppose that *all* of the electrons normally go *through* the grid on their way from the filament to the plate.

This being the case, there will be a certain current flowing in the *plate circuit* of the tube, that is, the circuit (see Fig. 15) from the filament, to the plate, through the "B" battery and the current indicator, then the "A" battery and the rheostat to the filament.

NOTE:—*Before the discoveries were made that led to the electron theory, physicists believed that the current flowed from the positive terminal of a circuit, back to the negative terminal. These two theories are, therefore, in contradiction to one another, but due to the fact that the whole foundation and operating principles in the development of electrical engineering were founded on the old theory, this custom cannot well be changed in all cases, so we must still speak of the current as flowing from the positive terminal to the negative in some cases, covering the action of motors, generators, transformers, batteries, etc., but it is well to bear in mind that the thing that really flows in the wire or circuit is a stream of negative electrons from the negative to the positive terminal.*

It is hoped that this will clear up in the student's mind the much talked of contradiction which has sprung up regarding the flow of current in radio circuits.

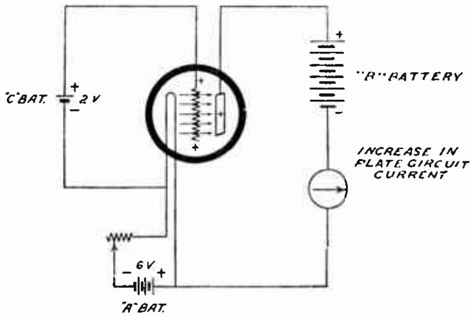


Fig. 17-B—Illustrating the Result of the "C" Battery Placing a Positive Charge on the Grid.

At any rate, let us say that we have a certain amount of current flowing in the plate circuit of the tube, due to the *emission*, or sending forth, of electrons from the filament to the plate. We have represented this in the diagram, Fig. 17-A, where we have also shown the way in which the electron tube is generally drawn in wiring diagrams. The number of arrows drawn from the filament to the plate represent a number of electrons traveling that way. All of them pass through the grid, and we have a certain amount of current flowing through the current indicator, in the plate circuit.

Now suppose we place a positive charge of electricity on the grid, or control element, of the tube. See Fig. 17-B. As we have said before, opposite charges attract, so that this charge on the grid will attract more electrons from the filament. Some of these electrons will stay on the grid, since the positive charge will try to hold them, but the greater part of them will fly through the open spaces of the grid to the plate. There is, therefore, a much greater number of electrons passing from the filament to the plate, and as a consequence the current in the plate circuit is increased.

Now, on the other hand, suppose we had a negative charge of electricity on the grid. (See Fig. 17-C). Since opposites attract, it is clear that charges which are *like* or the same, must repel each other. Therefore, the grid with its negative charge repels many of the electrons from it. Some of these are forced back into the filament from which they came; others are scattered out into the space within the glass bulb. When this happens, the current in the plate circuit of the tube must be less than it was before.

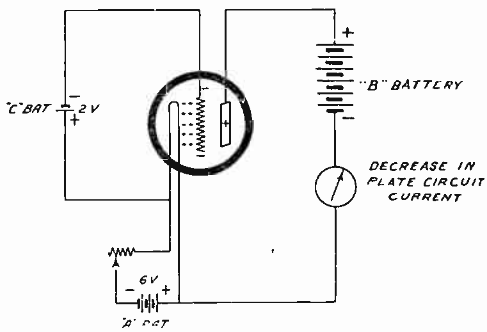


Fig. 17-C—Illustrating the Result of the "C" Battery Placing a Negative Potential on the Grid.

Now we see that the current in the plate circuit of the tube can be controlled by the charge on the grid. These changes in the plate current can be made to work for us, for it is a simple matter to place a pair of headphones, in the plate circuit, instead of the current indicator or galvanometer and hear what is going on. This is the principle of radio reception, so you see that we are rapidly making progress in our study, and things are gradually becoming clearer and clearer.

There are two ways to change the amount of current flowing in the plate circuit of a vacuum tube.

First, by increasing or decreasing the voltage applied to the grid of the tube.

Second, by increasing or decreasing the voltage applied to the plate of the tube.

Either of these two methods will cause a change in the plate current. This is very important because the *amplification factor* of a vacuum tube, represents the maximum number of times the tube is capable of amplifying the signal that is impressed upon its grid. The value of the amplification factor varies according to the ratio of the change in plate voltage, to the small change in grid voltage which produces an equal variation in plate current. By using the proper measuring instruments in the grid, filament and plate circuits it can be found that a very small negative or positive charge on the grid of the tube will produce quite a large change in the plate current. The reason for this can be explained as follows: Suppose we have 90 volts in our "B" supply. This is the same thing as saying that the positive terminal of the "B" battery or unit is 90 volts higher than the negative terminal.

Now, since the plate of the tube is connected to the *positive* and the filament of the tube to the *negative* terminal of the "B" battery, we must have the same voltage between the plate and the filament, that is 90 volts. In other words, the plate is 90 volts higher than the filament.

This being the case, the positive charge on the plate, of 90 volts, can attract just so many electrons, and produce only a certain amount of current in the plate circuit.

Now suppose we increase the plate voltage by 5 volts, making the total plate voltage 95 volts, and that this change of voltage increases the plate current by say 1/1000th of an ampere, which is usually called a *milliampere,* this change of 5 volts in the plate circuit will cause only a slight change in the plate current.

However, a change of 5 volts, say for example, from — 5 to 0 or from 0 to + 5, applied to the grid of the tube will cause a very great change in plate current. Suppose this 5 volts change in grid voltage causes a change of 10 milliamperes in plate current, we might find it necessary to increase the plate voltage to 40 volts (90 + 40) to obtain the same plate current change obtained by only a 5 volt change of grid voltage.

Thus it would require eight times the change of plate voltage as of grid voltage to obtain the same result in plate current change. The amplification factor of such a tube would be 8. To find the amplification factor of a tube we divide the number of volts change of "B" supply required to produce a certain increase in plate current by the number of volts change on the grid to produce the same increase of plate current. The quotient is the amplification factor of the tube in this case $\frac{40}{5}$ equals 8.

The amplification factor of different tubes is different, varying from about 3 to 20 or even higher, depending upon the construction of the tube in regards to the spacing of the elements and the size of wires in the grid, that is, the closer the spacing the greater the screening effect of the grid. In later text books more information will be given on the characteristics of vacuum tubes.

Now we have next to learn where and how we get the positive and negative voltages, so that we can place them on the grid of the tube. You will remember that the tuning circuit of a radio receiver consists of a coil having inductance, connected in series with a condenser having capacity. An electric current flows in this circuit whenever a signal is picked up by the antenna or aerial, and this charges and discharges in and out of the condenser, the energy being transferred during each reversal of the current back and forth from the condenser to the coil and vice-versa. This happens many times a second, depending upon the frequency of the current, or the wave length of the radio waves.

You have also learned that when a condenser becomes charged it has a voltage established between its plates; that is, each time the condenser is charged, one plate is so many volts higher than the other plate. One plate is therefore *positive* and the other is *negative*. When the condenser charges in the opposite direction, after the current has reversed, the voltage is reversed; the plate of the condenser which was negative is now positive, and the plate which was positive is now negative. So you see that we have here in the condenser the positive and negative charges which we can place on the grid of the electron tube.

You will see what we have now if you look at Fig. 18. We are fast approaching a complete wiring diagram of a radio receiver. We have a coil L connected in series with a condenser C. As the current in this circuit reverses with great *frequency,* the voltage in the condenser C reverses in step with the current. At one instant, therefore, we have the grid connected to a plate of the condenser which is positive, and the next instant that plate is negative, so that the voltage between the grid and filament reverses each time the high frequency radio current in the tuning circuit reverses. At one instant, therefore, when the grid is positive, the plate current increases, and the next instant, when the grid is negative, the plate current decreases. These increases and decreases of plate current are in step also with the high frequency radio currents in the tuned circuit. Furthermore, this varying current in the plate circuit is much greater than the current in the tuning circuit, due to the amplification by the tube.

FUNDAMENTAL RADIO CIRCUIT

The circuit shown in Fig. 18 is the fundamental circuit of the radio receiver. Although many circuits differ from one another in details, the tuning circuits in all radio receivers are based on this diagram. The grid and filament connections to the tube are called the *input* connections, and the plate and

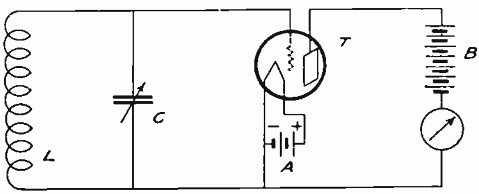


Fig. 18—Fundamental Vacuum Tube Circuit of a Radio Receiver.

filament connections are called the *output* connections of the tube. There is often a *tuned circuit* connected to the input of the tube. The output of the tube may be connected to several different circuits, depending upon how the tube is being used. If you will remember, we spoke of detector tubes and amplifier tubes in our first lesson, and we also spoke of two kinds of amplifiers—audio and radio frequency amplifiers. The radio frequency amplifiers amplify the high frequency radio currents. The detector tube operates on these high frequency currents so that it is possible to hear them when we pass them into headphones or a loud speaker. If these are yet too weak to hear comfortably we can amplify them still further in an audio frequency amplifier. The operation of the tube in all these cases is very much the same, as we shall see when we study these various operations separately and in detail.

Now let us see how far we have gone. First we have the radio wave sent out by the transmitting station. This radio wave when passing over the antenna of the receiving station establishes or *generates* a voltage in the antenna which causes a current to flow in it. This current is a *high-frequency* current, that is, it oscillates back and forth in the circuit at a very high frequency, this frequency corresponding to the frequency of the radio waves. We have seen that in order to *tune* the circuits to this frequency, we must have a tuning circuit composed of coils and condensers. Then the high frequency current in this tuning circuit causes a voltage to be established between the terminals of the condenser, and this voltage is then applied to the input of an electron tube. The electron tube *amplifies* these voltages, which reverse in polarity each time the high frequency current reverses, and we have in the output circuit of the tube a highly magnified current which oscillates at the same rate as the original currents in the antenna.

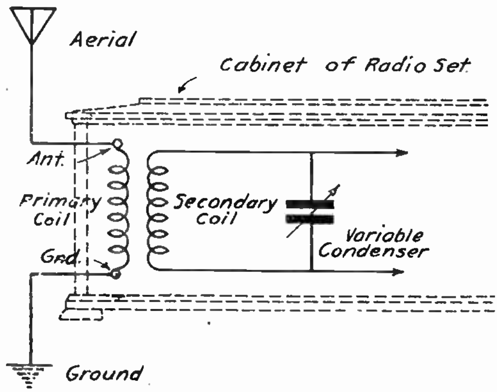


Fig. 19—Antenna Circuit of a Radio Receiving Set, Including Primary Coil, and Showing Connections to Secondary Coil and Variable Condenser.

AERIAL AND GROUND CONNECTIONS

But we have passed over a "missing link" in our story, and that is to find out how the current in the antenna causes a similar current to flow in the tuned circuit. Let us look at Fig. 19. We have shown in that figure an antenna, using the usual shorthand method of representing it, connected in series with a small coil. This is the complete antenna circuit, as generally used in up-to-date radio receivers. This may not look very much like a complete circuit to you, but you will soon see that it is. As a matter of fact the antenna is a condenser, or at least it is one plate of a condenser, and the ground or earth is the other plate. The antenna which is generally used for receiving broadcast concerts is merely a single wire, from 40 to 100 feet long, connected to two insulators and stretched above the roof of a house, or between two poles or trees.

Located somewhere inside or on the cabinet of the radio receiver are two binding posts labeled "ant" and "gnd". These abbreviations stand for antenna and ground, and show where the wires from the antenna and from the ground are to be connected.

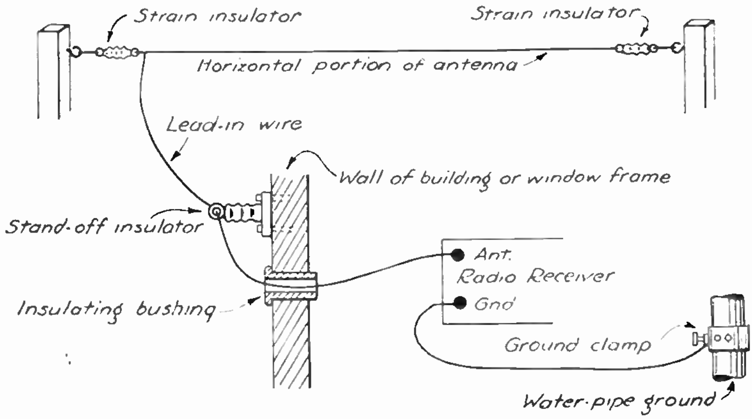
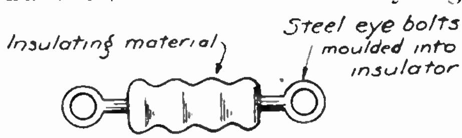


Fig. 20—Illustrating Connections from Receiving Set to Antenna and Ground.

COMPLETE AERIAL INSTALLATION

Figure 20 shows a complete installation, all excepting the batteries. The wire from this horizontal portion of the antenna is called the "lead-in" wire. This ground wire is connected to a cold-water pipe by means of a "ground-clamp" or it may be soldered to the pipe.

The insulator shown in Fig. 21 is made of some material, like glass or bakelite, which has extremely high resistance.



Strain Insulator
Fig. 21

As we stated before, when the radio waves pass over the antenna they "*induce*" a voltage in the antenna which causes a current to flow in it. A coil is connected in the antenna circuit of the radio receiver. We also stated that the antenna wire and the earth form a large condenser, the wire acting as one plate of this condenser and the ground acting as the other.

This is shown in Fig. 22. We can see that this is a simple series circuit the only thing left out of it being the radio waves themselves. We cannot at the present time explain how the waves act on this circuit, as it is a long story, but we will devote some time to it later on, so you must take it for granted, for the present at least, that the radio waves act like a generator or dynamo connected in series in this

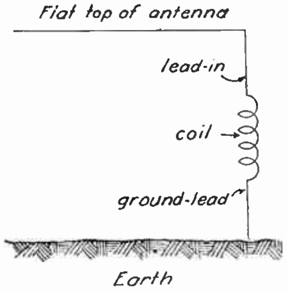


Fig. 22

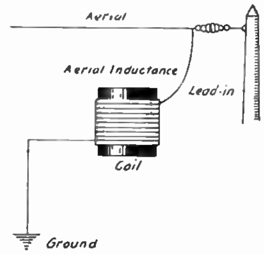


Fig. 22-A—Pictorial View of Circuit as Shown in Fig. 22.

circuit. The whole antenna circuit therefore acts like the circuit shown in Fig. 23, and since it contains both a condenser and a coil, it acts just like the tuned circuits we were discussing a little while before.

Having a generator, or a source of electrical energy, acting on the circuit, a current will flow in the circuit. This current must likewise flow through the coil in the circuit. Now we come back to the old idea that when we have a current flowing through a coil, and this current is varying or changing, that a magnetic field is established in and about the coil which changes in strength corresponding to the current. We have just such a situation here. The current in the antenna is changing at a great rate, not only in strength, but also in direction, since it is a high-frequency radio current. Therefore, the magnetic field of the coil is varying likewise. Now, as we learned before, if we place a wire, on another coil of wire, in this changing magnetic field, a voltage will be *induced* in this second coil which will cause a current to flow through it when the circuit is completed.

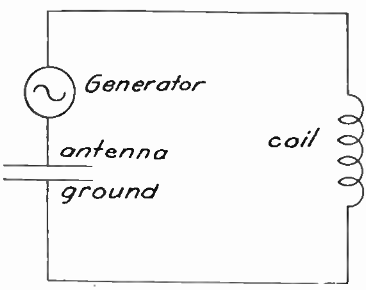


Fig. 23

We have the whole thing shown in Fig. 24. The antenna is connected to a small coil called the "*primary*" coil. The changing current in this coil establishes a changing magnetic

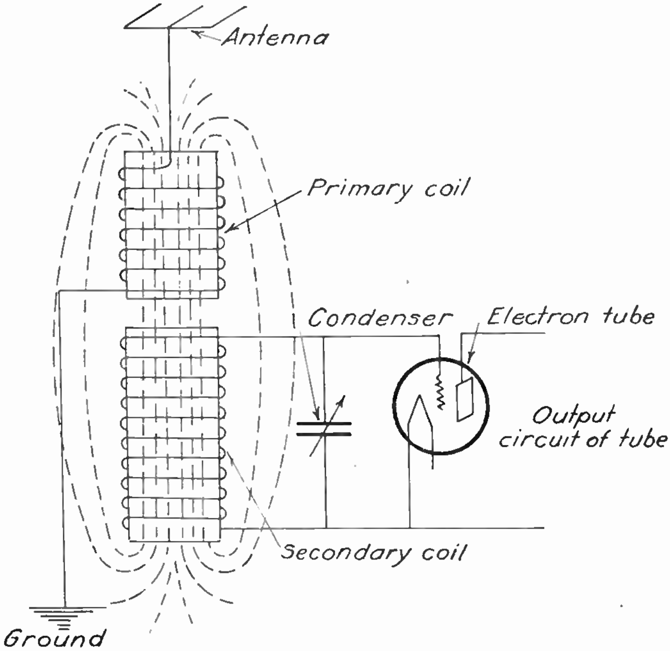


Fig. 24

field as shown by the shading in the picture. This magnetic field "cuts" or "links" another coil, which is called the *secondary coil.* The changing magnetic field *induces* a voltage in the

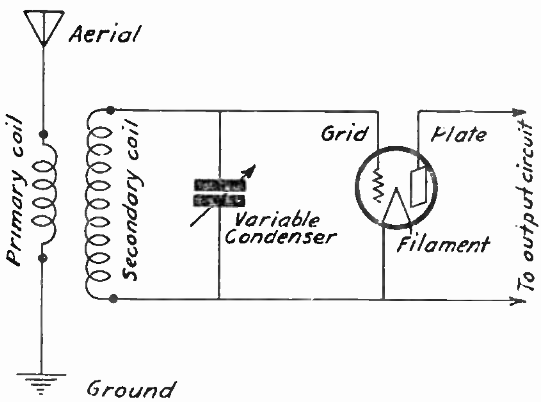


Fig. 25—Usual Way of Representing Circuit Shown in Fig. 24

secondary coil, and when the circuit of this secondary coil is completed, say, by connecting it to a variable condenser (as shown in Fig. 24), a current will flow in this circuit.

Now we have brought the radio oscillations from the antenna and into the tuned circuit; next they pass on to the electron tube, where they are amplified, and so we have oscillations of greater strength in the output circuit of the electron tube.

We have now covered a great deal of ground in our study, probably more than you at first expected to cover in three lessons. We have a great deal more to learn however, so carefully absorb all that you can from each lesson.

TEST QUESTIONS

Number Your Answer Sheet 3—3 and add Your Student Number

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Upon what does the strength of a magnetic field of a coil depend?
2. What is the effect on the capacity of a condenser when the size of the plates is increased?
3. What happens when a coil of wire is passed through a magnetic field?
4. State two ways in which the inductance of a coil may be increased.
5. What metals may be used for the plate of an electron tube?
6. What is the effect on the plate current of an electron tube when a negative charge is placed on the grid?
7. Draw a diagram illustrating the fundamental circuit of a Radio receiver.
8. Explain the purpose of the coils and condensers in a Radio receiver.
9. Draw a simple diagram showing how the connections to the antenna, lead-in wire, receiver and ground should be made. Also show where the insulators should be placed.
10. Draw a diagram showing how the primary and secondary coils and the electron tube are connected in a complete circuit.

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LESSON TEXT No. 4

(3rd Edition)

RADIO AND AUDIO FREQUENCY AMPLIFYING CIRCUITS

Originators of Radio Home Study Courses

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Washington, D. C.

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Circumstances are the creatures of men."*
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Some persons not accustomed to studying find it extremely difficult to do so successfully in the midst of confusion, or even with another person in the room. If you are disturbed by street noises, piano playing, interruptions by other members of the household, etc., you should have a place where you can be alone while you are engaged in your studies.

If you cannot do this, you must nevertheless continue with your studies and you will soon pass unnoticed the things that first attracted your attention. Let your study time be sacred to its purpose, and have it understood in the home, or wherever you live, that you are engaged in a serious piece of work and must not be interrupted.

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

RADIO AND AUDIO FREQUENCY AMPLIFYING CIRCUITS

At the beginning of this course we learned that the energy in the radio waves is very small; in fact, it is *extremely* small. Therefore, it is not possible to use these waves directly since the work they could be made to perform would be likewise extremely small. In the electron tube we have amplified these weak oscillations somewhat, but they may be still too weak to do any considerable amount of work, such as operate a loud-speaker. So we must, in many cases amplify them still further.

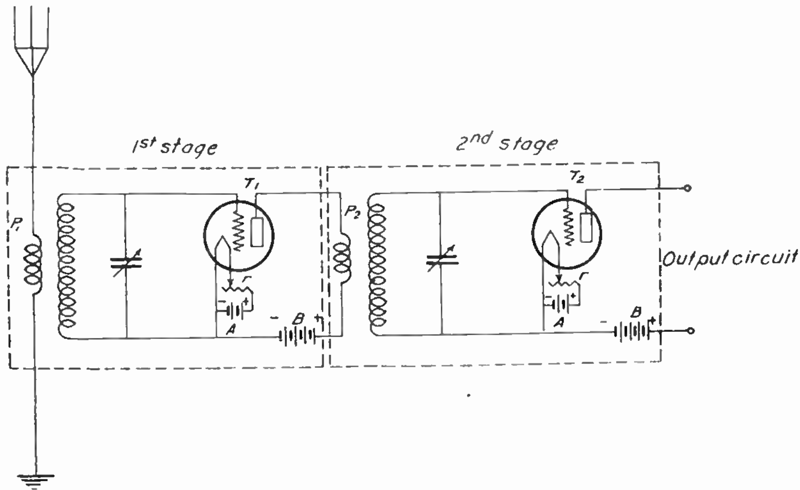

Fig. 1—Two Stage Radio Frequency Amplifier Using Separate "A" and "B" Batteries to Simplify Circuits.

In order to do this we may go another step further, and add onto the output circuit of the electron tube another circuit of the same kind. For instance, looking at Fig. 1, we see that we are attaching together two stages or steps of amplification, such as shown in Fig. 25, Text-Book No. 3. The two stages of Fig. 1, are exactly alike, according to the way in which they are connected, that is, their wiring diagrams are exactly alike. But the individual pieces of apparatus may not be exactly alike. For instance, the primary coil in the first stage, marked P_1 may have a different number of turns of wire than the primary coil of the second stage, marked P_2, we will learn why this is so later on. But the wiring is the same for the two stages.

But the thing looks rather expensive, doesn't it, especially from the battery point-of-view. In Fig. 1 we show two sets of "A" batteries and two sets of "B" batteries. Isn't it possible to cut out some of this expense? It certainly is, and that is one reason why, in the second lesson, we learned how to connect several electron tubes together so that they may all be operated by the same "A" battery. We can go much further than this, however, for we shall find it possible not only to use a single "A" battery for the entire receiver, but also a single "B" battery as well. It is not quite practical to use the same batteries for performing the duties of both "A" and "B" batteries so that is all the further we shall go for a while.

Of course, as we stated in previous lessons, it is a common practice now to obtain the voltages for operating the receiver from a power pack which is operated by the electricity in the house lighting system. The circuit arrangement of the receiver, however, is very much the same as when it is operated by batteries. For example, if, instead of connecting the wires which go to the two terminals of the "A" battery to the proper terminals of the power pack, and do likewise with the two terminals of the "B" battery and use the proper vacuum tubes we would have an A. C. operated set without making any other changes in the circuit of Fig. 2. So, for simplicity, we shall for a short while, continue to show batteries in our elementary circuit diagrams. All you have to remember for the present, is that the different batteries "A," "B" and "C" are replaced by corresponding sources of voltage in the power pack.

We learned in the second lesson, that in order to operate several tubes on the same "A" supply, we could simply connect the tubes in series or parallel. It is the general practice to connect them in parallel, that is, for one side of all the filaments to be connected to one "A" supply terminal, and the other side of the filaments to the other "A" supply terminal. This is shown in Fig. 2. You will note that it is also possible to combine the several rheostats, marked r, in Fig. 1. For example, we can still use a separate rheostat to control the filament current in each tube, or we can control the filament current in all the tubes at the same time by properly using one rheostat. In Figure 2 we have so arranged the circuit that we can use just one rheostat.

In connection with Fig. 2 there are several things to discuss. The first is a little more of the shorthand way of representing radio circuits. You will notice that we have lines crossing each other at several points in the circuit. This indicates that at these points the wires are fastened together, either by soldering or by clamps. At other points in the circuit, you will notice little loops seeming to jump over another wire. These indicate that there is *no* connection at the point between the wire which has the loop in it and the wire which it crosses.

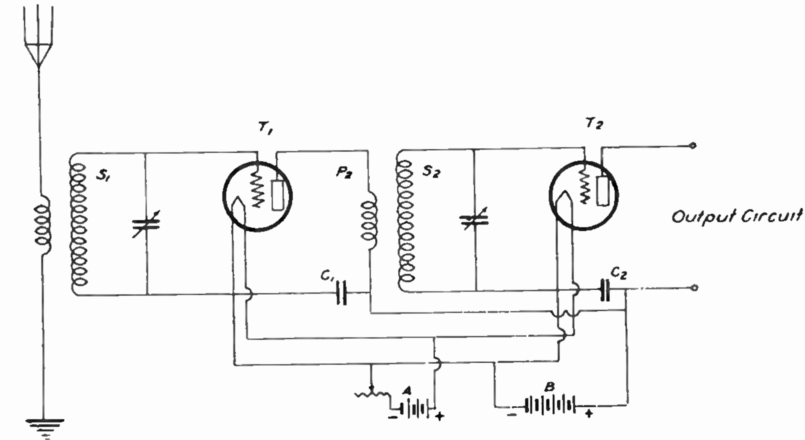

Fig. 2—Circuit Diagram of a Two Stage Radio Frequency Amplifier, Using Only One "A" and One "B" Battery.

Now, if you will follow the lines from the filament of electron tube T_1 you will find one going directly to the "A" battery, (+) and the other one goes first through the rheostat and then to the other side of the "A" battery (—). Following the wiring from the filament of electron tube T_2, we have an exactly similar state of affairs.

We have a more complicated proposition in connection with the "B" battery. You learned that the plate of the electron tube is to be connected to the positive (+) terminal of the "B" battery. Starting out from the + terminal of the "B" battery, you will find that it is connected to the plate of the first tube, but not directly. The current from the "B" battery must first pass through the primary coil P_2, and then to the plate of the first tube. The same is true for the second tube; passing from the + terminal of the "B" battery, the current must first go through whatever is connected to the output of the second tube and then to the plate of the second tube.

Sometime ago you also learned that the negative (or minus) terminal of the "B" battery is connected to the filaments of the tubes. This is shown for a single tube back in Fig. 14, Text Book No. 3. We have so made the connections that the minus terminal of the "B" battery is connected to the filaments of both tubes in Fig. 2. If you trace out the wiring you will see that this is so.

There is one other thing in connection with Fig. 2, however, that we must not pass over, and that is the small fixed by-pass condensers marked C_1 and C_2, in the first and second stage. In some receivers these fixed condensers are not absolutely necessary, but it is always best to use them. The batteries are generally placed at some distance from the receiver, perhaps on the floor, or in a space at the bottom of the console, if you have that type of cabinet. At any rate, the high frequency electron flow which travels in the plate circuits of the two tubes would have to travel from the plate, through the primary coil, P_2, or through the circuit connected to the output, then through long wires to the "B" battery and then through another long wire back to the filament. In passing over this great amount of wire, a lot of the high-frequency energy may be lost, and we said before that we cannot afford to lose very much of it, since we have not much energy to start with. If we had there would be no need to amplify it several times.

In order to avoid making the current pass over this long circuit, we place in the receiver the condensers C_1 and C_2, which are called *by-pass condensers,* because, when used in this manner, they offer a short path to the weak high frequency currents from the end of the primary coil to the filament circuit away from the long wires to the "B" battery circuit.

RADIO FREQUENCY AMPLIFYING CIRCUITS

Figure 2 is the actual circuit of part of a popular receiver. The part shown is called the *"radio-frequency amplifier."* Its purpose is to take the weak high-frequency (or radio-frequency) signal voltages, and amplify them, making them strong enough to satisfactorily operate a *detector* or *rectifier tube* which is connected to the output circuit of the amplifier.

Sometimes when two stages are not quite sufficient, we often use three stages when we wish to build a radio receiver that will receive signals from very great distances. Sometimes one is contented with only a single stage. How many stages we use depends upon the conditions at the receiving station, upon the sensitivity of the individual stages, and upon how far we wish to receive. So far it has not been practical economical to use more than three stages of this kind, as difficulties arise in the design which we shall consider later on.

You may have wondered a little while ago, when you were studying Lessons 2 and 3, how long it would be until you learned what was inside of a radio receiver. You probably wondered why we were telling you about electrons, about water waves, buzzers, condensers and coils; you may have asked, "Why don't you open the cabinet of the radio receiver and tell us what happens from beginning to end?" Well, you see the reason now. If we had tried to do it that way you

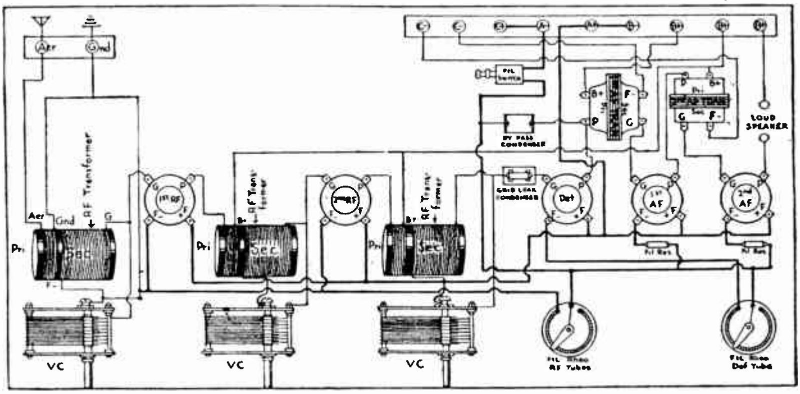

Fig. 3—Wiring Diagram of a Receiver Employing Two Stages of R. F. Amplification Detector and Two Stages of A. F. Amplification.

would have probably been all mixed up before we had quite begun. But by approaching the subject in this manner, you have obtained a very good idea of what radio is about, and you have gone so far as to be able to understand quite a complicated wiring diagram. And this diagram represents a most important part of the radio receiver. You are not only able to understand the diagram, but can explain how each piece of apparatus in it works. Not only that, but you can actually wire up such a radio-frequency amplifier. Look at Fig. 3. We have shown here, in picture form, the same circuit that we have in Fig. 2 with the addition of a detector and two stages of audio-frequency amplification. Just trace out the wiring for yourself. Let us give you a start in it.

First we have the antenna lead-in probably coming through a window. We fasten this to the antenna binding post (A). Next we take a short piece of wire, and solder one end of it on to the antenna binding post and the other end on a terminal of the primary coil. To the other end of the primary coil we solder another piece of wire, and the other end of this wire goes to the ground binding post (G). Then, we connect a piece of wire from this binding post to the ground, and our antenna circuit is complete.

In connection with this let us say that there are many ways of making the coils. Sometimes the primary winding is on a separate tube inside or outside of the secondary, and sometimes they are wound on the same tube of insulating material. Even when wound on the same piece of tubing they may differ, for the primary may be wound at either end of the secondary or perhaps in the middle. Generally the *primary winding* has only a few turns, say from 4 to 35 and the *secondary* may have, say 50 to 100 turns.

Following out the circuit further, we next solder a wire onto one terminal of the secondary coil G and the other end onto one terminal of the variable condenser. We join this same terminal of the condenser to the grid terminal on the tube socket in a similar manner. The other end of the secondary coil F—and the other terminal of the condenser are joined together, and these connected to one filament terminal on the tube socket and ground.

SOUND WAVES

Next we must study the *detector,* or the *rectifier tube,* as it is called. But let us first find out why a detector tube is needed at all. In the first lesson of this course we spoke about sound waves, and used these to illustrate some things about radio waves. Now we must come back to the sound waves again, for perhaps the most important thing that has to be done in a radio receiver is to take the electrical oscillations and turn them into air oscillations or sound waves. In other words we have to make the air vibrate, and the rate at which it vibrates depends on the musical note we are to hear. For instance, in order to produce a sound like we would have if we were to press the middle key on the piano keyboard, that is, middle "C," the air will have to vibrate at the rate of 256 times a second. That is, the frequency of vibration of the air must be 256 *cycles per second.* If we are to hear a rather high pitched note, the air must vibrate much more rapidly than this, say 1,000, 2,000, or, perhaps up to 8,000 times a second. When we hear very low notes, the air is vibrating very slowly, say, 50 or 100 times a second. The lowest note that we can hear as a musical tone has a frequency of about 25 or 30 cycles per second, and the highest note may be anywhere from 8,000 to 20,000 cycles per second, depending on the sharpness of the particular ear that is listening to the sounds.

Radio-frequency oscillations, at least those that we receive from broadcasting stations, have a frequency of from 550,000 cycles per second to 1,500,000 cycles per second. Remembering our old rule, where we get the wave-length by dividing the frequency into the number 300,000,000, we have the frequency 550,000 cycles corresponding to

$$\text{Wave-length} = \frac{300,000,000}{550,000} \text{ or 545 meters} \qquad (1)$$

$$\text{and Wave-length} = \frac{300,000,000}{1,500,000} \text{ or 200 meters} \qquad (2)$$

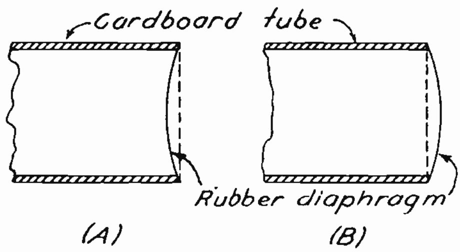

Fig. 4

A meter is slightly greater than a yard in length, or about 39½ inches. In other words, the wave-lengths used in broadcasting range from 200 meters to 545 meters, and the range of frequency is from 550,000 to 1,500,000 cycles per second. (Reduce to Kilocycles by dividing by 1,000.)

Since the highest frequency that a human ear can recognize as a sound is about 20,000 cycles per second, it is clear that the human ear could never respond to a frequency of 550,000 cycles or higher. The reason for this will be plain enough when we consider what is in the ear. In the human ear there is a very thin sheet of some material, stretched like the head of a drum, and when the air waves strike this, it vibrates back and forth, as shown in Fig. 4. This illustration shows a tube of cardboard which has a sheet of rubber stretched over its end. Suppose some sound waves hit this rubber *diaphragm* as it is called. While the air is in motion in one direction, the diaphragm will be stretched inward, as shown at (A). When the air is in motion in the opposite direction, the diaphragm will be stretched the other way as at (B). This is the way the air waves act. There are pressures at certain distances apart, depending on the wave-length, and there are regions of less pressure in between. Now when the air waves hit the rubber diaphragm, they cause it to vibrate at the same frequency as that at which the air waves are vibrating.

Suppose the rubber is rather thick, and that it will not stretch very easily, or, suppose that the frequency of the sound waves is very high. Then the rubber diaphragm cannot vibrate fast enough for the air waves; before the rubber has had a chance to stretch in one direction, say to the right, the other part of the sound wave comes along and tries to make it stretch in the opposite direction, to the left. As a result the diaphragm does not stretch at all, but remains still, just as it would if no air waves were hitting it.

Well, the same thing is true in radio. We want to use a loud-speaker at the output of our receiver. A loud-speaker may be made in several ways, but all loud-speakers, and all telephone receivers operate according to the same electrical principles. You have learned sometime ago that when a current is passed through a coil, a magnetic field is established. You also learned that if we were to place a core of iron in this coil, the magnetic field would be much stronger. You were also told an arrangement like this, called an *electromagnet,* will act the same as the ordinary compass needle or the ordinary horseshoe magnet, that is, it will attract to it pieces of iron.

Suppose then we take an electromagnet, and place close above it, an iron diaphragm, supported on a ring. See Fig. 5. Then if we send an alternating current into the coil, that is, a current which reverses its direction of flow regularly so many times a second (say 60 times a second), the iron diaphragm will be attracted to the magnet and repelled from it just as often as the current reverses. If the frequency is extremely high, the diaphragm could not respond, as we saw before. When the diaphragm vibrates, it makes the air in front of it vibrate at the same rate, and it is in this way that the loud-speaker acts. Of course, in order to make the loud-speaker act more effectively we always place over this diaphragm some kind of a horn, or some large surface that can set a large amount of air in vibration.

Now, if we were to connect the loud-speaker directly to the output of the radio frequency amplifier, shown in Figs. 1 and 2, it is clear that it would not respond, for the frequency of the radio oscillations is extremely high, far above the highest frequency at which the iron diaphragm will vibrate. There are other reasons why it will not vibrate, as we shall learn later on, but this will be sufficient for the present. The problem then is to reduce or lower the frequency, or at least to make it act as if its frequency were lower, and this is the job that the rectifier or the detector has to do. How does it do it?

Before we learn exactly how the detector tube does this, we have just a few more things to consider. One of these is the nature of the radio waves as they are sent out by the

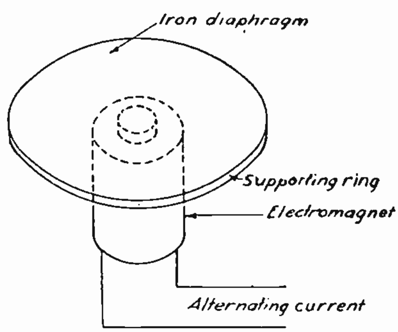

Fig. 5

broadcasting station. A transmitter of radio waves is a very complicated arrangement; it consists first of a generator of radio oscillations. These oscillations have the frequency which is desired, that is in a 300 meter wave-length, the oscillations of the transmitter have a frequency of 300,000,000 divided by 300 or 1,000,000 cycles per second. These oscillations are continuous, and their strength is always the same.

The radio wave sent out by this *oscillator* is called the *carrier-wave*. The meaning of this name is evident, for this wave sent out by the transmitter is for the purpose of *carrying* the *voice waves* which we desire to transmit. For reasons which we will learn later, it is not possible to *transmit* the voice waves directly on account of their low frequency, so we have to use a *carrier* which has a very high frequency to do this.

While this carrier is being *radiated* or transmitted out into space by the transmitting station, the voice waves are combined with it in a certain manner. These voice waves are not constant; they vary in frequency from one instant to another depending upon the musical note we are transmitting, or upon the strength of this note. The combination of the carrier wave and the voice waves results in a very complicated wave, which has an extremely high frequency—too high to act directly on a loud-speaker. Actually the frequency of the combination wave changes from one instant to another, but the change is not very great. For instance, when receiving a carrier wave of 1,000,000 cycles per second when it is being combined with a voice wave of say, 1,000 cycles, the combination wave varies in frequency from 999,000 to 1,001,000 cycles per second. But we shall hear more of this later. For the present all that we have to know is that the resulting wave radiated by the transmitting station is a combination of a carrier-wave of very high frequency and the voice waves of rather low frequency, and that the combination wave still has a very high frequency—too high to hear directly. The carrier-wave is said to be *modulated* or changed by the voice-wave. Consequently the voice frequency is often called the *modulation frequency*. The resulting wave is called a *modulated wave*.

DETECTOR CIRCUIT

Since it is impossible to make this modulated wave act directly on a loud-speaker, it is necessary to *demodulate* it, as it is called; that is, we have to use something that *separates* the carrier-wave and the voice-waves, so that we can throw away or discard the carrier (or very high) frequency, and use the modulation (or voice) frequency to operate the loud-speaker. This is what the detector tube does. The actual details of how the detector does this will not be discussed here, for it is a long and complicated story. We will reserve this subject until a later lesson, when we will be more prepared to study it. For the present, the detector tube (or rectifier tube, as it is often called), is used to *demodulate* the modulated wave, that is to separate the carrier-wave from the voice-waves.

One way in which the electron tube can be connected so as to do this is shown in Fig. 6. *It will be seen there is no difference between this circuit and the circuit of the radio-frequency amplifier, excepting in two respects. First, there is a small condenser, called the grid condenser connected to the grid of the detector tube. There is also connected in* *parallel with the terminals of this grid condenser, a rather high fixed resistance, called a grid-leak resistance. The grid leak and grid condenser make it possible for the tube to act as a demodulator, or as a separator of the carrier and the voice waves.*

There is another very important difference between the way in which a detector tube and an amplifier tube are connected, and that is in the connection of the *grid-return*. Look at Fig. 6 again. Starting at the grid, we can follow the circuit to the grid condenser and grid leak, then through the circuit connected to the input of the tube and finally return to the filament. It will be seen that the return wire from the grid in the case of the detector tube (Fig. 6) is connected to the *positive* side of the "A" battery, whereas in the case of the amplifier (Figs. 1 and 2) the grid-return is connected to the *negative* side of the "A" battery. You will learn the rea-

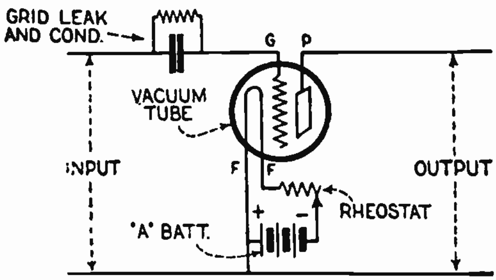

Fig. 6—Input and Output Connections for a Detector Tube.

son for this in a later lesson. These connections must be made properly, else the tubes will not operate exactly as they should. Remember then, that in an amplifier using the 201A type of tube, the grid-return is to be connected to the *negative* terminal of the "A" battery; and in a detector, using the same type of tube, and a grid condenser and grid leak, the return is to be connected to the *positive* terminal of the "A" battery.

Now we can go a step further in building up the complete circuit diagram of the radio receiver. We can take the detector tube of Fig. 6 and connect it to the output of the radio-frequency amplifier of Fig. 2. But we cannot do this directly, so we must furnish a path for the current to flow in the output of the radio-frequency amplifier, by *coupling* the two circuits together by means of a tuned circuit. The complete circuit of the detector tube is shown in Fig. 7, where the input of the detector is connected to a tuned circuit.

All we have to do to complete our circuit is to add this circuit of Fig. 7 to the output of the circuit of Fig. 2, and we have a complete receiver that will work. This complete receiver is shown in Fig. 8. In this complete diagram we have so made the connections that we can use the same set of "B" batteries and the same "A" battery for all three tubes. We have also placed the pair of head-phones in the output circuit of the detector tube, for now since the wave has been demodulated or *rectified* it is possible for the current in the plate circuit of the detector to operate a magnet and diaphragm. But note that we have used a pair of head-phones and not a loud-speaker. The reason for this is that although the circuit will work as it now stands, we will not get signals out of it that are strong enough to operate a loud-speaker. So we must be content for the present to hear the concerts or the signals on a pair of head-phones.

Later on in this lesson, we will learn how to add two more tubes to the circuit that will make the signals strong enough to operate a loud-speaker. What we shall add will be an audio-frequency amplifier of two stages or steps. We have now separated the carrier from the voice-waves by allowing the detector tube to demodulate the combination wave, so that the signals are now in a condition to be heard. But they are still weak, so we must further amplify them. In the audio-frequency amplifier which we shall add, we will not have to consider high frequencies any more, for we shall have only frequencies which can be heard—that is, voice frequencies. That is why this amplifier is known as an *audio* amplifier—it amplifies frequencies which are *audible,* that is, that can be heard by the human ear.

We must point out another change which we made when combining the detector circuit with the radio-frequency amplifier. You will note that in Fig. 2, showing the diagram of the radio-frequency amplifier, we have used two *by-pass* condensers, C_1 and C_2, in order that the high frequency currents will not have to travel a long distance out into the battery wires and back again to the filament circuit. If you look closely and follow out the wiring, you will see that the condenser C_1 is connected on one side to a wire which comes from the negative (minus) terminal of the "B" battery, and on the other side to a wire coming from the positive (plus) terminal of the "B" battery. The same is true of the other condenser C_2. These two condensers are, therefore, connected in parallel, so it is not necessary to use two separate condensers. We can just as well use a single by-pass condenser of twice the capacity.

This is what we have done in Fig. 8. The condenser C in Fig. 8 takes the place of the two condensers C_1 and C_2 in Fig. 2. This condenser has both terminals connected to wires which come directly from the two sides of the "B" battery, just the same as before. It is used to *by-pass* the radio frequency current. In Fig. 8 you will also notice that the two tubes in the radio-frequency amplifier have the currents in the filaments controlled by a single rheostat, marked R. This is the same as we did in Fig. 2. But you notice that we have added an additional rheostat, in order to control the filament current in the detector tube. The reason for this is that sometimes it is thought advisable to be able to control the detector filament current by itself, so that when we adjust

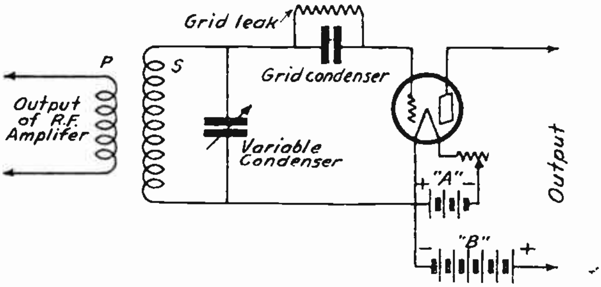

Fig. 7—A Vacuum Tube Detector Circuit.

the rheostat of the radio-frequency tubes, we will not be affecting the detector tube.

It is the function of the audio-frequency amplifier to take the signals, which have been put in such shape by the detector that we can hear them by connecting a pair of head-phones to the output of the detector tube, and make these signals strong enough to operate a loud-speaker. There is no pleasure to be derived from straining our ears listening to very weak music, or by suffering the discomfort of having to wear head-phones continually, so fortunately we have a means for making them as loud as we please in the audio-frequency amplifier.

QUALITIES OF SOUND

Before we go into the study of the amplifier proper, we must learn a few things about sound. Many of you play some sort of musical instrument, or, if you do not you have heard musical instruments played many times. Not only that, you can all sing, and you have all heard others sing. You are acquainted with the fact that there are qualities in sounds that are very different from each other.

For instance, a man may have a deep voice, or he may sing a very deep tone. Or, take a bass horn for instance; this produces a very much deeper tone than a shrill piccolo or a flute. Think of a woman's voice, singing a very high tone; compare this with a tone sung by the same woman but not quite so high. It is clear that there are differences between these tones that she sings, otherwise we should not be able to distinguish the difference by hearing these tones. These differences enable us to tell one voice from another, or to recognize a person, without seeing him, simply by hearing him talk. Now what are these differences that enable us to distinguish one sound from another.

The qualities of sounds that enable us to distinguish them are *pitch, quality (or timbre), and intensity.* Let us first find out what we mean by intensity, for this is the simplest idea of the three. The intensity of a sound is merely its *loudness.* You learned in the first lesson that sound waves are waves in the air, which vibrate. It is not the frequency of these air vibrations, that is, the number of times the vibrations occur in a second, but the *strength* of these vibrations which determines the loudness of the sounds that we hear when these air waves strike the ear. The strength of the waves is also called their *amplitude.* Remember this word *amplitude* for it is the name given to the strength of any kind of an oscillation, for instance, an oscillating current. The strength of the current is its amplitude.

Next we have to consider the *pitch* of a sound. A little while ago we pointed out the difference between the tone given out by a bass horn and the tone given out by a flute; one tone was very much higher than the other. But it might be possible to make these two tones just as loud as each other, that is, we might make their intensities or their amplitudes the same, and yet the one tone would still be higher than the other. The difference between these tones is their *pitch,* whether they are loud or soft tones.

The high tone (of the flute) is said to have a *high pitch,* and the low tone (of the bass horn) is said to have a *low pitch.* It has been found that the high tone has a *high frequency* and the low tone has a *low frequency.* In other words, the pitch of a tone depends on its frequency. Any two tones which differ from one another in pitch, have different frequencies, the higher tone having the higher frequency.

We have therefore, so far, two qualities of sounds, intensity and pitch. Thus we may have loud tones and soft tones, and we may have high tones and low tones. But there is another thing that enables us to still further distinguish sounds from one another. Suppose we had a cornet and a trombone, both playing a tone of the same pitch, and each of the performers trying to make the loudness of his tone exactly the same as the loudness of the other performer's. It is clear then that there would be no difference between the two as far as intensity and pitch are concerned. But there would still be a difference between them that would enable us

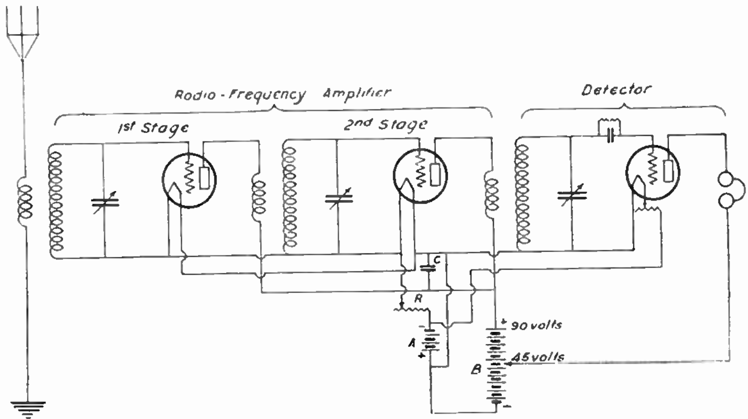

Fig. 8—Circuit Diagram of a Two Stage Radio Frequency Amplifier and Detector.

to pick out the one from the other without seeing the instruments.

This remaining difference is known as the *timbre,* or the *quality* of the sound, and this is determined only by the instrument producing the sound. For instance, brass instruments are often said to have a *brassy* sound, a brilliant sound. A wooden instrument, as for instance the flute, has a mellow, more subdued sound. This is the reason a composer when writing a musical composition, writes certain parts for the brass instruments; for example, the cornet, trombone, and so forth, play the brilliant parts of the composition, the brass reed instruments will play another, the string instruments another, and the wood instruments still another.

The difference between the different instruments is due to the *overtones* of these instruments. No instrument, and this includes the human voice, is capable of producing a *pure tone*, that is, a tone which is only a single tone with a single frequency. Nearly all tones are complex, that is, the tones that we hear are combinations of several tones; one of these tones is more prominent than all the others, and we call this the *fundamental* tone; the frequency of this fundamental tone is called the *fundamental frequency*.

The other tones which are in the sound we hear are much weaker in intensity than the fundamental. The amplitudes of these other tones are smaller than the amplitude of the fundamental. They are so much weaker, in fact, we cannot hear them as separate tones, but we know they are there only because they give a certain *quality* or *timbre* to the sound. The frequencies of these other tones are also different from the fundamental frequency, and are an exact number of times this frequency.

If for example, we have a sound which has a fundamental frequency of 1,000 cycles per second, there may be mixed with this tone, another which has a frequency of twice 1,000 or 2,000 cycles per second; or, there may be one with a frequency three times 1,000 or 3,000 cycles per second, or it may even be as high as 10 times or 10,000 cycles per second. The other tones, which are called *overtones* by musicians, and *harmonics* by scientists, are always an exact number of times the frequency of the fundamental tone, and the number of these harmonics and their strength or amplitude, determines the quality or timbre of the sound we hear.

To show how this works in the musical instruments, the brass instruments always have quite a few of these harmonics or overtones that are quite strong. That is why the brass instruments are so brilliant. On the other hand the wood or reed instruments have few of the harmonics and, then, only weak ones. That is why these instruments give out subdued or soothing sounds.

Now suppose we have some music coming from the head-phones. Or perhaps, it may be simpler to think of only a certain note. Suppose that some one is playing a certain tone on a violin at the broadcasting station, and that he continues to play this tone, that is, he *sustains* it. We listen in to this tone, with a pair of head-phones connected to the output of the detector tube. It is not very loud, but we can easily distinguish that it is a violin being played. We can do this because we have previously had the experience of listening to a violin and we know how it sounds. Although we cannot hear or distinguish the separate overtones or harmonics in the sound, we do know subconsciously that they are there, for it is by that means that we can tell a violin from a cello or from any other instrument.

It is clear that if we want to amplify this note, so that we can hear it coming out of a loud-speaker, and if we still want it to sound just like a violin note, just as we heard it at the output of the detector, we shall have to amplify the fundamental note and all the harmonics in the same amount. That is, if there are a certain number of harmonics in the note, and these harmonics each have a certain strength, in order to keep the sound "true" we shall have to amplify all of these together the same number of times, say 20 times or a thousand times. We cannot amplify the second harmonic 10 times

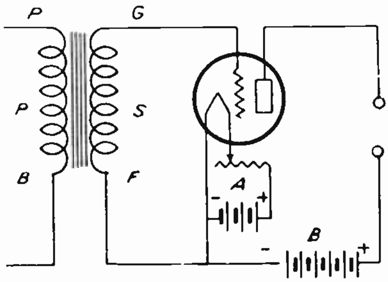

Fig. 9—Circuit Diagram of One Stage of Audio Frequency Amplification.

and the third harmonic 20 times and expect the sound to be exactly as it was originally. We must amplify everything by exactly the same amount, both the fundamental and all the harmonics.

It is plain, therefore, that we are not to have tuned circuits in the audio-frequency amplifier like we had in the radio-frequency amplifier. If we had we would simply pick out certain frequencies which we would amplify, just like we tuned in the different frequencies or wave-lengths with our tuned circuits in the radio-frequency amplifier. We have to permit *all the frequencies* to come through, and the amplifier must act the same on all the currents of these different frequencies.

We cannot use a tuned circuit; therefore there is no tuning condenser in the audio-frequency amplifier. Further than this, we do not have the enormously high frequencies that we had in the *radio-frequency amplifier.* There we had the frequencies of the radio waves ranging from 550,000 *to* 1,500,000 *cycles per second.* Now, in the *audio-frequency amplifier* we are dealing only with frequencies that the average human ear can hear, that is, from say 30 *cycles to about* 10,000 *cycles per second.*

On account of the fact that the frequencies are fairly low, we do not have to use coils which have air-cores. We can use coils which are wound on iron-cores advantageously; in fact, we are required to use iron-cores in the *audio-frequency transformers,* and we are also required to use a great many more turns of wire in them.

AUDIO FREQUENCY AMPLIFYING CIRCUITS

An audio-frequency amplifier is connected exactly the same way that we connect a radio-frequency amplifier, with the exception that we leave out the tuning condensers. Figure 9 shows how the connections are made. The transformer consists of a primary and a secondary winding, wound on an iron-core, represented by the several parallel lines drawn between the two coils marked "P" and "S." The amplifier tube is connected to the secondary of this transformer, as shown in Fig. 9, and the "A" and "B" batteries are connected to this tube in the same manner as we connected all the other tubes. The only difference is that in all the amplifiers, as you will remember, we connect the grid-return wire to the negative (minus) terminal of the "A" battery, and in the detector we connected it to the positive (plus) terminal of the "A" battery. The "B" battery is connected in the circuit as usual, and the loud-speaker is connected to the output of the amplifier.

In Fig. 10 we have a photograph of some audio-frequency amplifier transformers and in Fig. 11 the constructional details of one. The transformers have markings at the different terminal wires, that is P, B+, G and F—. These markings tell us the proper way in which to connect the transformer in the circuit of the amplifier, for the way in which it is connected depends upon the way in which the coils of the transformer have been wound.

These letters are shown in the Fig. 9, which explains what they mean. The letter "G" for instance, indicates that this terminal of the transformer is to be connected to the grid of the amplifier tube. The letter "F—" means that this particular terminal of the transformer is to be connected to the filament (negative terminal) of the electron tube. The letter

"B+" means that this terminal of the transformer is to be connected to the positive terminal of the "B" battery of the preceding tube (in this case the detector tube.) The letter "P" means that this terminal of the transformer is to be connected to the plate of the preceding tube.

Figure 12 shows how the detector tube and the audio frequency amplifier tube are connected together. Note that we have used the same "A" battery for both tubes, and likewise the same "B" battery. If you will trace out the wiring of the grid-returns you will note that the grid-return of the detector tube, marked (a) is connected to the *positive* side of the "A" battery, while in the amplifier, the grid-return, marked (b) is connected to the negative side of the "A" battery.

If on adding this audio-frequency amplifier to the circuit, we do not get sufficient *volume* of sound out of our loud-speaker, it is a simple matter to add another stage to the

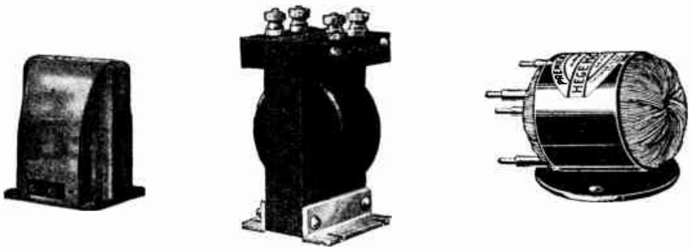

Fig. 10—Several Types of A. F. Transformers.

amplifier. This has been done in Fig. 13, which shows a complete two stage audio-frequency amplifier. You will note that in this case, we have used a single rheostat to control the current in the filament of both tubes.

In Fig. 14 we have a combination of the complete detector circuit and the two stage audio-frequency amplifier, in which the same rules have been followed. In Fig. 15, we have the complete wiring diagram of the five tube receiver which we started out to study. In these two diagrams, Figs. 14 and 15, the rheostats marked R_1 control the filament current of the detector tube, and the rheostats marked R and R_2 control the filament current of the audio-frequency amplifier tubes. The rheostat marked R_3 in Fig. 15 controls the filament current of the radio-frequency amplifier tubes. The latter rheostat is often used as a *volume control.* The smaller the current flowing in the radio-frequency amplifier tubes, the less will be the volume output of the loud-speaker. There are other ways of controlling the volume in various receivers, but we shall come to these systems later on.

Figure 15 may look rather complicated at first glance, but if you will study it for a while you will see that it is very simple. At the left you see the two stages of the radio-frequency amplifier. These are wired exactly alike, consisting

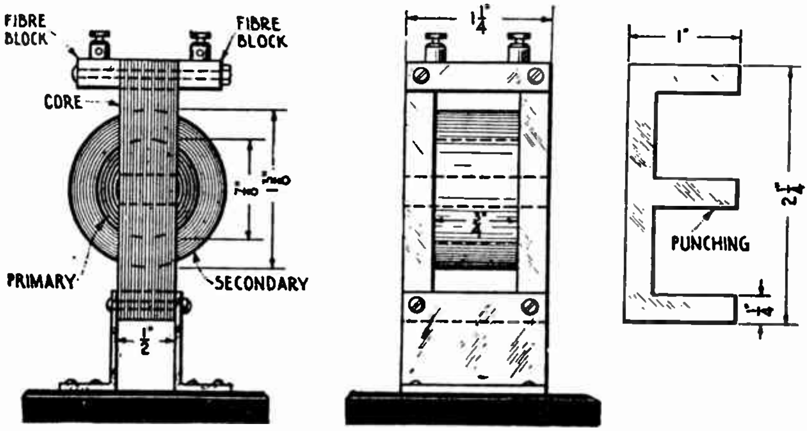

Fig. 11—Dimensions and Constructional Details of the Shell Type of Audio Frequency Transformer.

of a tuned circuit in each stage and an electron tube. The tuned circuit consists of an air-core coupling coil, usually called a radio-frequency transformer, and a variable condenser. Next we come to the detector circuit, which is very

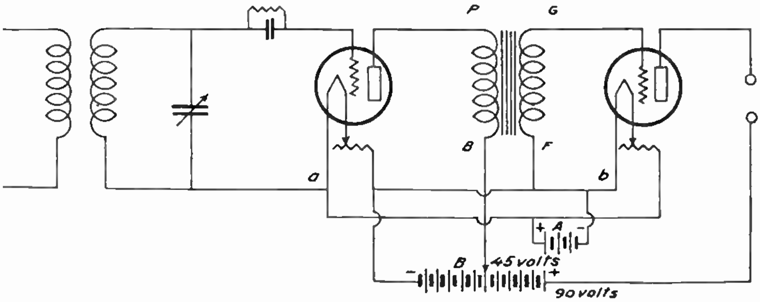

Fig. 12—Circuit Diagram Showing Connection to Detector Circuit and One Stage A. F. Amplifier.

similar to the circuit of the radio-frequency amplifier, with the exception of the grid leak and grid condenser, and the connection of the grid-return wire. After that, on the right of Fig. 15 we have the audio-frequency amplifier of two stages. The wiring diagram of this part of the receiver is also very similar to the wiring of the other parts, excepting that now we are using iron-core transformers, and no tuning condensers.

We shall now look into some variations of these circuits, as they may be called. The first variation we shall begin with is the detector circuit. The detector circuit we have studied is the one that is used mostly, but there is another detector

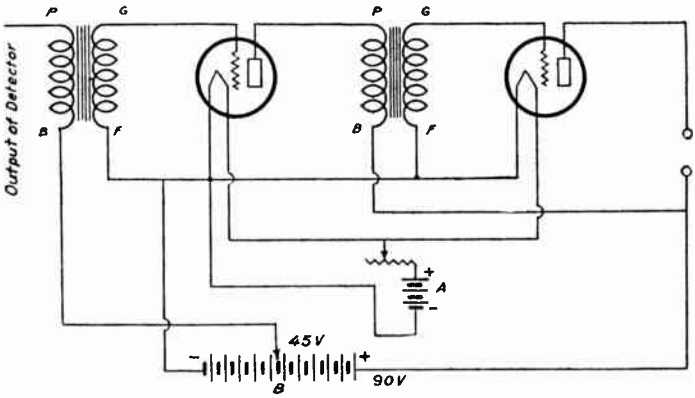

Fig. 13—Circuit Diagram of Two Stage Audio Frequency Amplifier.

circuit which is sometimes used. This is the "C" battery detector. You see we already have two sets of batteries, called by the first two letters of the alphabet; the "A" battery is the filament battery, and the "B" battery is the plate battery.

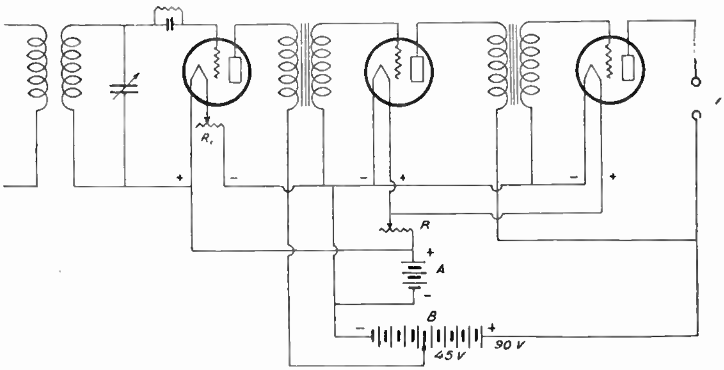

Fig. 14—Circuit Diagram Showing Connection to Detector Circuit and Two Stage A. F. Amplifier.

When we add another battery to the circuit we call it by the next letter of the alphabet, that is, the "C" battery. This "C" battery is the grid battery.

Look at Fig. 16 and you will see what we mean. In that illustration all the batteries are shown, the "A," "B," and "C" batteries. The "C" battery is placed in the input or the grid circuit of the electron tube. When the proper voltage is used in the "C" battery, the circuit of Fig. 16 is that of a detector, but differing from the detector we studied before both in the circuit and in its manner of operating. Although you will not be able to appreciate what these terms mean at the present time, it will be well to tell you the names that are given to these two different kinds of detectors. When a grid condenser and leak are used, the action of the detector is known as *"grid rectification."* When a "C" battery detector is used, the action of it is called *"anode (or plate) rectification."* Just remember these names, so the next time you meet them in our course they will not seem strange to you.

The detector with the grid leak and grid condenser is generally used more than the "C" battery detector. But this type of detector is likely to be *overloaded* by strong signals.

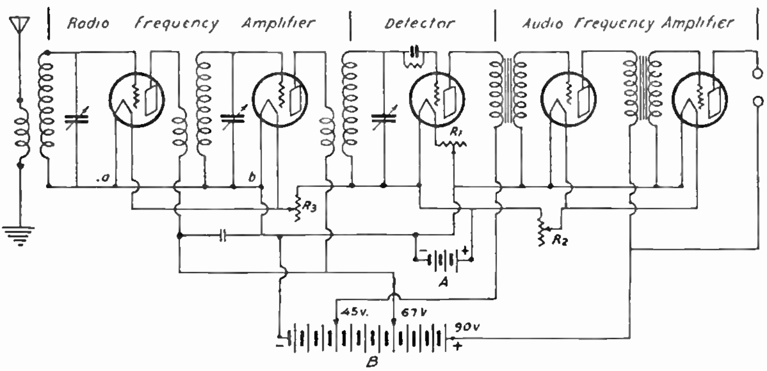

Fig. 15—Circuit Diagram of a Complete Five Tube Radio Receiver Employing Two Stages of R. F. Amplification Detector and Two Stages of A. F. Amplification.

This means that when we receive strong signals, as from a local broadcasting station, the signals may be too strong for the detector to handle without spoiling the *quality* of the music. On the other hand, the "C" battery detector will handle considerably stronger signals before overloading occurs.

The "C" battery is also used in the audio-frequency amplifier, see Fig. 17, in a similar manner. But there is another reason why the "C" battery is used in the audio-frequency amplifier, and that is because it reduces the amount of current flowing out of the "B" batteries. This makes the "B" batteries last much longer than they would ordinarily. The connection of the "C" battery in the audio-frequency amplifier is the same as in the "C" battery detector. In both of these circuits the negative (minus) terminal of the "C" battery is toward the grid of the tube, and the positive (plus) terminal is connected to the filament of the tube (that is, the negative side of the filament). Note this difference between the detectors carefully. In the detector which uses the grid condenser and the grid leak, the grid-return was connected to the *positive* side of the filament. In the "C" battery detector, the grid-return is connected to the negative side of the filament, and in audio and radio-frequency amplifiers, the grid connection is to the *negative* side of the filament.

It will be interesting to see why the introduction of the "C" battery in the audio-frequency amplifier causes the plate current, or the current out of the "B" batteries, to be reduced. The negative charge on the grid, put there by the "C" battery, reduces the number of electrons passing from the filament to the plate, and consequently the plate current is less than it would be if the "C" battery were not

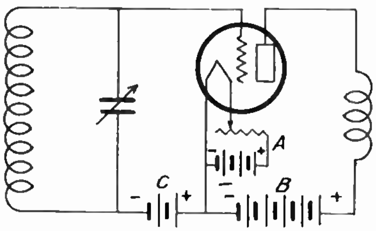

Fig. 16

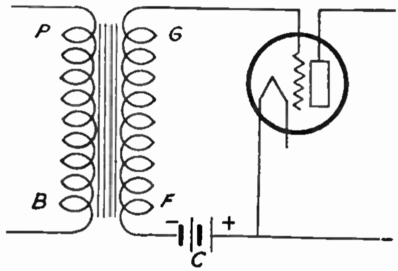

Fig. 17

there. This saving in the power taken out of the "B" batteries is sometimes very great, especially when *Power Tubes* are used in the audio-frequency amplifier, as is frequently done nowadays. Power tubes are special tubes made for handling very strong signals without becoming overloaded, and these tubes generally require rather high plate (or "B" battery) voltages. In the case of the UX-171-A power tube, the full voltage to be used on the plate of this tube is 180 volts. On account of this, if a "C" battery were not used, there would be quite a large current in the plate circuit, drawn out of the "B" batteries, if they are used for supplying the power, and they would not last very long. But when we use a "C" battery of the proper voltage, in this case about 45 volts, the current taken by this tube from the "B" batteries is less. The decrease in the plate current when using the "C" battery in the amplifier may be about 20 milliamperes or less, whereas if we did not use a "C" battery the current might be as high as 30 to 45 milliamperes in the UX-171-A tube.

In the typical set the amplifiers are UX-201A tubes. The first audio-frequency amplifier tube generally is operated at a "B" battery voltage of 90 volts, and the second tube at 135 volts. The two tubes will therefore require different values of "C" battery voltage. The first tube will generally operate well with a "C" battery between 3 and 4.5 volts, and the second tube will operate satisfactorily with a "C" voltage of 7 to 9. The complete circuit of a "C" battery detector tube and two stages of an audio-frequency amplifier is shown in Fig. 18.

There are several new features brought out in the circuit of Fig. 18. In the first place you will see that we have connected the plate or output circuit of the radio-frequency amplifier (at the left) to the 67.5 volt tap on the "B" battery. This is because many of the radio receivers are made to operate this way. The receivers can be designed to work on many different voltages, so that you must become acquainted with the manner of connecting them to these voltages properly. Sometimes the radio-frequency amplifier works on 90 volts, sometimes on 45 volts, and sometimes on 67.5 volts, depending upon the design of the receiver.

The next thing to notice is that we used but a single "C" battery in the audio-frequency amplifier. The two voltages, which are marked on the diagram, are obtained by connecting the grid-returns of the two A. F. tubes, one at the end of the battery and the other at a tap near the middle of the battery. This particular battery would be a 7 to 9 volt battery, but you may use any battery that has taps at the proper places. The same is true of the "B" batteries. You may use any combination that will give the voltages that you require in the receiver.

This brings us to the subject of connecting batteries to the receiver. A sketch of two 45 volt "B" batteries is shown in Fig. 19. By connecting these two 45 volt batteries in series we can obtain a voltage of 90 volts between the wires A and B. By connecting to the point between the batteries, we can obtain a voltage of 45 volts as between the wires A and C, and by connecting an additional wire as shown we can obtain a voltage of 67.5 volts between the wires A and D. Usually there are other taps on these batteries, as shown in Fig. 19, so that it is possible to get many combinations of voltages. The polarity (that is, plus or minus) is always marked on these batteries.

In Fig. 20 we have shown a small "C" battery on which are taps by means of which we can obtain voltages of 3, and 4.5 volts. There are "C" batteries of different sizes, which will furnish voltages of 1.5, 3, 4.5, 6, 7.5 and 9 volts upwards. The connections to these battery terminals are made according to voltage required by tube or tubes so that they will operate properly.

A standard six volt storage battery is shown in Fig. 21. There is not much that can be said at this time about storage batteries, as we shall study them in detail later on, but you must always be careful to keep the proper amount of liquid (called the *electrolyte*) in them. This battery furnishes a voltage of 6 volts for operating the filaments of the electron tubes. The condition of the battery is determined by using a hydro-

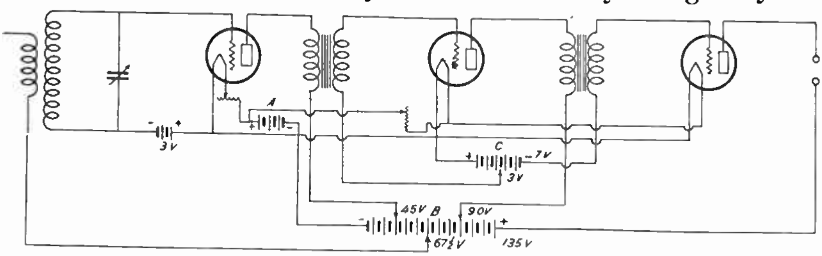

Fig. 18—Circuit Diagram of Detector Using "C" Battery and Two Stages of Audio Frequency Amplification.

meter, which is nothing more than a glass tube, into which a rubber bulb sucks electrolyte out of the battery, and in which another glass tube floats. This inside tube is weighted at the bottom so that it floats upright, and the height at which it floats tells us the condition of the electrolyte in the storage battery. A scale is marked on the inside float. When a battery is fully charged, it will float up until the number at the level of the liquid is about 1280 or more. When it reads 1150 or less, the battery needs charging.

Before closing this lesson, and because we have reached the point where we can understand the complete circuit diagram of a simple receiver, we shall show more in detail the manner in which a receiver may be operated on power taken from the A. C. house-lighting systems. Figure 22 shows a complete diagram of an A. C. operated receiver, without going into the details of the power supply; that is, the rectifier, filter, and power transformer. Let us analyze this circuit and see what we have in it. You will see how similar it is to what we had in Fig. 15.

All the tubes used were designed specifically for operation on alternating current, except the last, which is the UX-171A, or CX-371A. This tube works as well on A. C. as on D. C. when used in the last audio stage. The two radio-frequency amplifier tubes are UX-226's, which consist of the

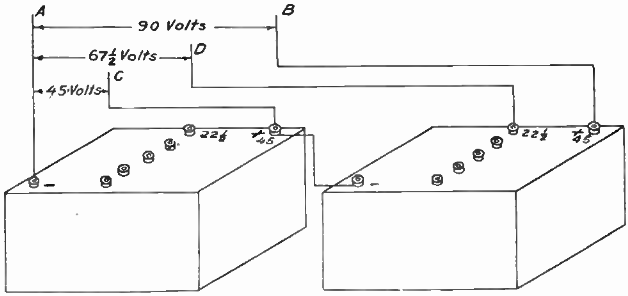

Fig. 19—Showing Connections to "B" Batteries to Obtain Various Voltages.

usual grid, plate and filament. The detector tube is a UY-227 tube. It consists of a grid, plate and filament, just like other tubes, but in addition it has another electrode called the *cathode*. The filament, in this tube, is called the *heater*, because all that it is used for is to heat the cathode. Remember, in order to cause electrons to be expelled from any electrode, it is only necessary to heat it. Whether it is heated by pass-

Fig. 20—Small "C" Battery.

Fig. 21—Storage Battery.

ing current through the cathode itself (which is the filament in the case of the other tubes), or whether we heat the cathode indirectly, as we do in the UY-227, electrons will be expelled just the same. We use this type of tube for the detector because the hum from the alternating current would be too great if we used the other type of tube as detector.

The filaments of the 226's are lighted by an alternating voltage of 1.5 volts; the heater of the 227 by an A. C. voltage of 2.5, and the filament of the 171A by an A. C. voltage of 5 volts. These three alternating voltages are obtained from a power transformer which contains several windings. For simplicity, in Fig. 22, the three windings supplying power to the filaments and heater are indicated as separate transformers, T_1, T_2, and T_3. The complete transformer is shown as a separate sketch in Fig. 22. In addition to the three windings mentioned there are two other secondary windings. One of these furnished power for lighting the filament of the rectifier tube, and the other furnishes the high alternating voltage which is to be rectified.

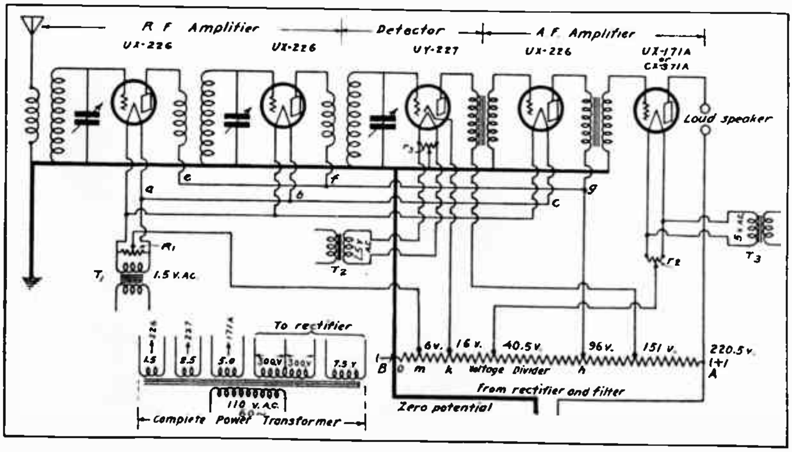

Fig. 22—Circuit Diagram of an A. C. Operated Radio Receiver.

The direct or constant voltage supplied by the rectifier tube and filtered in the power supply apparatus, is impressed across the terminals of a heavy resistor AB, called the voltage divider or output resistor. There is a total voltage drop (difference in voltage) in this resistor of 220.5 volts. The heavy line in the diagram represents the ground, or chassis, which we shall call the point of *zero potential.* Since the grids of the R. F. amplifier tubes are connected to ground through the R. F. transformers, they may be considered as having a negative D. C. potential.

These R. F. grids must have a bias of 6 volts, that is, they must be six volts, *negative with respect to the filaments* of the R. F. tubes, which is the same thing as saying that the filaments must be 6 volts *positive with respect to the grids.* So we connect the filaments of the R. F. tubes to a point on the resistor which is 6 volts above ground. This is done at the center-tapped resistor R_1, which is connected across the filament leads.

Six volts is the grid bias required when we have a voltage of 90 volts between plate and filament, so we connect the plates of the R. F. tubes to the output resistor to a point which is 96 volts above ground. The voltage between plates and filaments is then 96—6 or 90 volts. We now have a voltage of —6 on the grids and 90 on the plates, with respect to the filaments of the R. F. tubes.

Since these voltages are satisfactory for operating the first A. F. amplifier tube, we have connected the grid-return of that tube to ground, the same as the grid-returns of the R. F. tubes, and have also connected its plate to the same point on the output resistor.

Next we come to the detector. This is a "C" bias detector, requiring let us say, 16 volts negative on the grid, and a plate voltage of 135 volts. The grid-return is again connected to ground, or is at negative potential. Therefore, the cathode is connected to a point 16 volts above ground, and the plate to a point 151 volts above ground. The voltage of the plate is then 151—16 or 135 volts *with respect to the cathode.* You will note that we always make measurements or calculations *with respect to the cathode or filament.*

Finally, we require a grid bias of —40.5 volts and a plate voltage of 180 volts on the 171A. So, if we connected the grid-return to ground, as before, we must connect the filament to the output resistor at a point 40.5 volts above ground. Then the plate is connected to a point 180 + 40.5 or 220.5 volts above ground, which is the end point of our resistor.

The center-tapped resistors are used for two main reasons: first, since all the plate current of a tube passes through the filament of the tube, by making the B— connected to a point mid-way between the filament terminals, the plate current passes equally through both sides of the filament. We are thus not overloading either side of the filament. The resistors R_1 and R_2 are connected in this way.

The other reason for using the center-tapped resistors is that by this means the hum, which we always have in electric sets, is kept much lower than it would be with other arrangements. We shall learn more about this in a later lesson. For example, the main function of the resistors R_1 and R_2 is to keep down the hum voltage of the set.

Once you get the idea of these circuits, and learn how the various voltages can be obtained from batteries and voltage-dividers, the whole thing will be greatly simplified.

Of course, there are some things that we have neglected in this short discussion; but we will come to them in later lessons. The principles of radio various circuits must be studied very carefully, and it is not well to try to absorb too much at one time.

TEST QUESTIONS

Number Your Answer Sheet 4—3 and add Your Student Number

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Draw a circuit diagram of a two stage radio-frequency amplifier, using only one "A" battery and one "B" battery.
2. What is the purpose of a radio-frequency amplifier?
3. How many turns of wire are generally used in the primary and secondary coils of a radio-frequency amplifier such as shown in Fig. 3?
4. What are the differences between a detector tube (or rectifier tube) circuit and a radio-frequency amplifier circuit?
5. What is the function of the audio-frequency amplifier?
6. What is the range of frequencies amplified in an audio-frequency amplifier?
7. What are the qualities of sounds that enable us to distinguish them?
8. Draw a diagram of a five tube receiver having two stages of radio-frequency amplification, a detector and two stages of audio-frequency amplification.
9. What is the advantage of the "C" battery type of detector over the grid leak and grid condenser type?
10. Draw a diagram showing how and where a "C" battery should be connected in an audio amplifier.

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LESSON TEXT No. 5

(3rd Edition)

AUDIO-FREQUENCY AMPLIFIERS AND RADIO-SPEAKERS

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Physical fitness depends a great deal on the regularity of the bodily functions. Physicians tell us that we should eat our meals at regular hours, that we should set aside a certain period each day for exercise and recreation. In this way we attain our maximum health. Mental regularity is not so easily achieved, although it can be acquired. There are many disturbing influences. It is difficult to have a fixed time and place for study and then stick to it. But once it is accomplished, study is easier and more efficient.

Reliability is the direct result of regularity. The man who is regular in his habits can be depended upon. Others can predict what he will do and when he will do it. He can depend upon himself. Students fail to get their work done because they cannot rely upon themselves to study when the time comes. Make yourself regular to make yourself reliable. Mental and bodily regularity will go a long way in determining your success.

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Complete Course in Practical Radio

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AUDIO-FREQUENCY AMPLIFIERS

The usual audio-frequency amplifier uses iron-core transformers to couple the tubes together. But there are several ways in which the several stages can be connected together without using transformers. The first of these methods which we will consider is the resistance-capacity coupled amplifier, or as it is called more generally, the *resistance coupled amplifier.*

RESISTANCE COUPLED AMPLIFIERS

A circuit diagram of this type of amplifier is shown in Fig. 1. For the sake of clearness we have omitted the "A" batteries, for these are always connected in the same way.

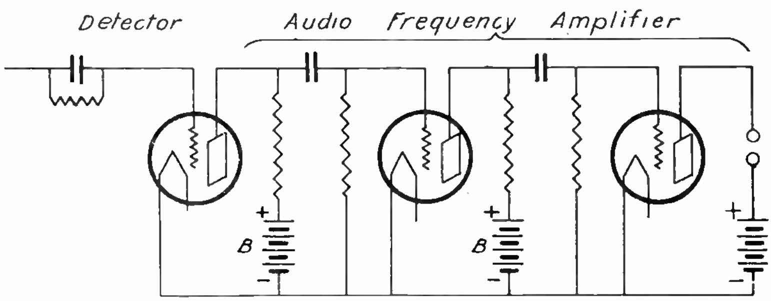


Fig. 1—Elementary Circuit Diagram of a Two Stage Resistance Coupled A. F. Amplifier.

We have shown the amplifier connected to the output of a detector tube. Now let us see how this amplifier works. In order to do this, we will have to start with an electron tube, and build up the complete amplifier. Then we will know the reasons for the different things in the circuits. Suppose we start with an electron tube, having its filament lighted by an "A" battery, so that it emits electrons, and we place in the plate circuit a resistance of about 100,000 ohms and a "B" battery. We have shown this part of the circuit in Fig. 2-(A). Now suppose we have a signal voltage (that is, an alternating or oscillating voltage) impressed on the input of the tube. This is indicated by the letter "v."

As we learned before, when we have such a state of affairs there will be a similar current in the plate circuit of the tube, but of course made stronger or amplified by the tube. In other words, there will be a rising and falling voltage established between the points "a" and "b" of Fig. 2-(A), which we want to make work for us. The idea is now to take this voltage between "a" and "b," and impress it on the input of another electron tube so as to amplify it still further. Suppose we were to connect the points "a" and "b" directly to the input (this is, the grid and filament) of another electron tube. We have shown this in Fig. 2-(B). What will happen? The answer is that the second tube will not work at all. The reason for this is clear, for we are using a voltage of 90 volts, or perhaps 135 volts in the "B" battery, and this is connected in Fig. 2-(B) just like a "C" battery, that is, in the grid-return of the second tube. Having such a high positive grid voltage, the plate current in the second tube will be so greatly increased that the tube will not work. Under such conditions the tube will be *saturated,* by which we mean that when the grid or "C" voltage is so *positive,* a weak signal voltage on the grid will produce no corresponding voltage change in the plate or output circuit.

What we must do is to get rid of this high voltage on the grid of the second tube. This is easily done by placing a fixed condenser in the grid circuit of this tube, as shown at Fig. 2-(C). This condenser is marked "C." A constant voltage, such as furnished by the "B" battery will not pass through the condenser, but a varying voltage, furnished by the radio signals, will pass through easily. Therefore the condenser C *blocks* the voltage of the "B" battery off the grid of the second tube. For this reason, the condenser, when used in this way is called a *blocking condenser.* But remember that it allows the signal voltage to pass through onto the grid of the second tube, where we want it to go.

Now we can ask again, "Will this work"? The answer is again "No." Why will this system not work yet? This brings up something which we referred to in our previous lesson, but which we said we would explain a little more in detail later on. You will remember that the grid of an electron tube is directly in the path of the electrons which are travelling from the filament to the plate of that tube. On account of this, if the grid were left "free," that is, not connected to anything which furnishes a complete path around to the filament, it would collect a number of these electrons, and so acquire a large negative charge. In an ordinary circuit this charge could pass off the grid by flowing around through a coil and back to the filament. In other words there would be no chance for a fairly large negative charge to accumulate on the grid.

But when we place the blocking condenser in series with the grid of the second tube in Fig. 2-(C), we are preventing these electrons, and the negative charge which they cause on the grid, from flowing off the grid. As a result the grid becomes highly charged negatively. Now you remember what happened a few moments ago before we placed the blocking condenser in the circuit. The "B" battery placed such a large

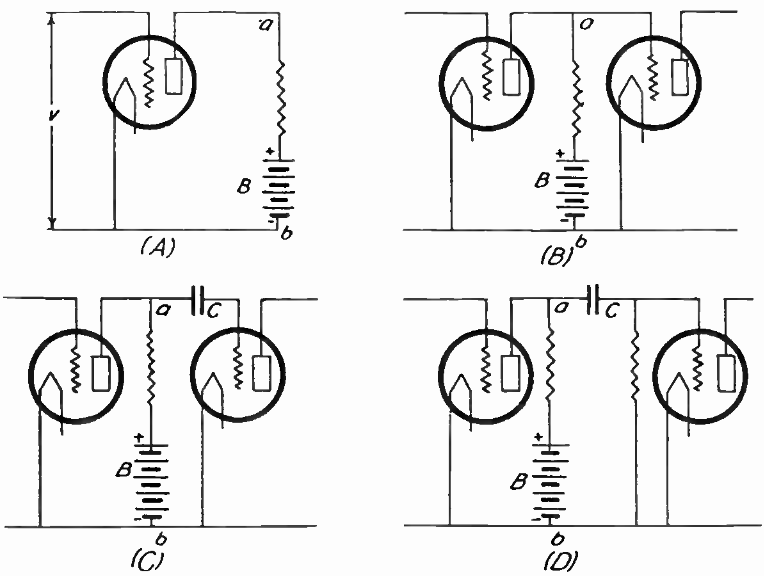
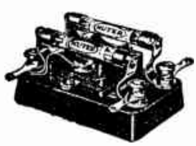
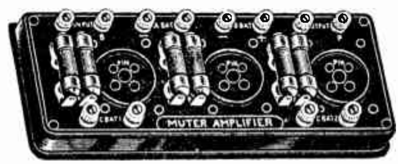


Fig. 2

positive charge on the grid that the plate current was increased so much as to saturate the tube so that it would not operate. The opposite occurs when the negative electrons charge up the grid. The plate current is reduced so far that the tube will not work. Naturally we cannot expect the tube to work with hardly any current in the plate circuit. But suppose we furnish a path over which these electrons can escape from the grid back to the filament from whence they came? That is just exactly what we have to do before the system will work well. We can do this by inserting another resistance between the grid and filament of the second tube, but this time it must be a very large resistance. If it is not large, a considerable part of the signal voltage will be used up in it. In actual practice, this resistance is about 500,000 ohms. The resistance used in the plate circuits of the tubes is about 100,000 ohms, and the capacity of the blocking condenser may be anything from about .01 to .1 microfarad. (A microfarad is one-millionth of a farad). It is not well to use less than this, as the low tones will be lost in the amplifier, and if we use too large a capacity, there will be other ill effects encountered. We will learn more of this later on.

We can now see the complete circuit, as shown in Fig. 1, more clearly. This is a combination of several stages of the circuit explained in Fig. 2. Going a little farther, we have in Fig. 3, the complete circuit, where only one set of "B" batteries is used. This circuit can be used to replace any other kind of audio-frequency amplifier that may be used in the receiver. But you must also know that whereas two stages





Resistance Coupled Unit and a Three Stage Resistance Coupled Amplifier.

are all that are required in an amplifier which uses transformers, there are generally three stages required in a resistance coupled amplifier. For this reason three stages are shown in Fig. 3. Even when three stages are used, the amplification in a resistance coupled amplifier is generally less than that obtained in a transformer coupled amplifier, but it is often claimed that better quality of reproduction can be obtained by using a resistance coupled amplifier. This may be true when the amplifier is properly designed, but when not properly designed, the resistance coupled amplifier may give as poor quality of reproduction as the poorest transformer coupled amplifier.

A "C" battery is generally placed in the grid circuit of the last tube to prevent distortion and reduce "B" battery consumption, because no high resistance is in the plate circuit and therefore it receives practically the full applied "B" voltage.

IMPEDANCE COUPLED AMPLIFIERS

We will now go further into the different kinds of audio-frequency amplifiers. We have so far studied the transformer coupled and the resistance-capacity coupled amplifier. The next type that we shall take up is known as the *impedance coupled amplifier*. The complete circuit of this amplifier is shown in Fig. 4. With a little study you will be able to see

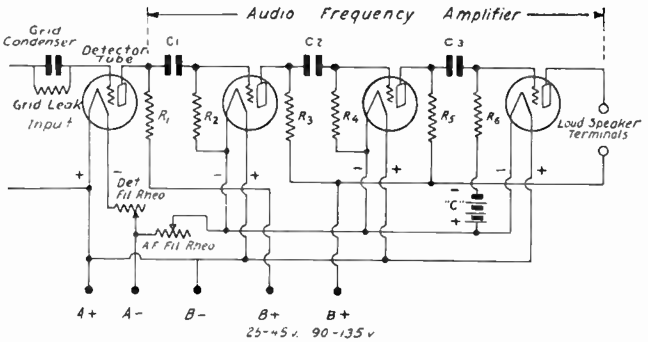


Fig. 3—Circuit Diagram of a Three Stage Resistance Coupled A. F. Amplifier.

that this circuit is exactly the same as the circuit for the resistance-capacity coupled amplifier. The difference is not in the wiring diagram, but in that we use an *impedance coil* in the plate circuits of the three tubes, instead of resistances. There is still the blocking condenser, and there is also the grid-leak resistance, just as in the resistance coupled amplifier.

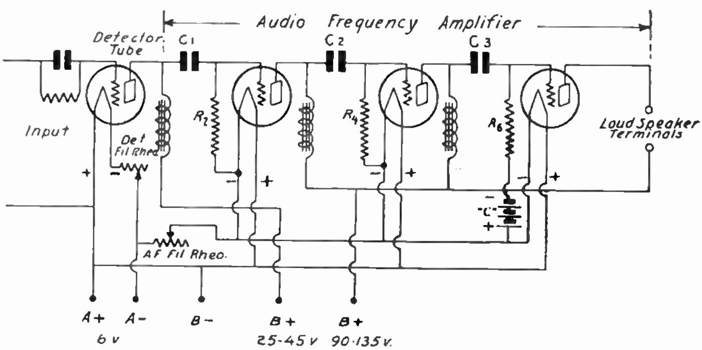


Fig. 4—Circuit Diagram of a Three Stage Impedance Coupled A. F. Amplifier.

fier. The simple circuit of the impedance coupled amplifier is shown in Fig. 5-(A), and in Fig. 5-(B) the resistance-capacity coupled amplifier, so that you can see the difference between the two systems.

Since there is no difference in the circuit arrangement, it is to be expected that there will be no difference in the operation of the set. This is true to a great extent as there is no difference in the operation of the two systems excepting in one respect. You will probably remember that we have said before that the resistance does not change as the frequency of the current changes. There is this much in its favor, that no matter what the frequency may be, when we have a certain voltage impressed on the input of the first tube, we shall always have a similar voltage established across the terminals of that resistance in the plate circuit of the tube.

In other words, if we have a certain voltage "v," as in Fig. 5, impressed on the input of the tube, there will be a certain voltage between the points "a" and "b" in the plate circuit of that tube. This will be the same thing, whether the frequency of the impressed voltage "v" is 50 or 5,000 cycles per second. This is because the resistance does not change with the frequency.

But there are difficulties encountered in using resistances in the plate circuits of the tubes. In order to operate the electron tubes properly it is necessary to have a certain voltage on the plates of these tubes. Now you will see, if you look again at Fig. 5-(B), that the "B" battery is connected in series with this resistance, so that the electrons flow from the filament to the plate through the resistance, then from the battery back to the filament. In order to obtain a considerable amount of amplification in each stage it is necessary to use a large resistance in the plate circuits, perhaps 100,000 ohms. This is the value of the resistance often used.

As part of the "B" battery voltage is used up in this large resistance, *it is generally necessary to use somewhat higher "B" voltages in resistance coupled amplifiers than in transformer or impedance coupled amplifiers.*

To come back to the impedance coupled amplifier, let us first find out what is an *impedance coil.* One of these is shown in Fig. 6. You will see that an impedance coil is nothing more than a transformer which has only one winding instead of two. In other words, an impedance coil consists of a core of iron, over which is wound a great many turns of fine wire. There may be as many as 5,000 turns of No. 36 wire, or there may be more turns. In many cases the wire may be as small as No. 40 B. & S. gauge.

Now we have said before, that when an alternating current is passed through a coil of wire, a varying magnetic field is created which cuts back on the turns of wire, and *induces* a voltage across the terminals of the coil. What we do then, in the case of the impedance coupled amplifier, is to take this voltage across the terminals of the coil, at the points "a" and "b" in Fig. 5-(A), and impress it on the input of the next tube, through the blocking condenser. You remember in the case of the resistance coupled amplifier, we had to place this blocking condenser in series with the grid in order to keep the high voltage of the "B" battery away from the grid; then, after

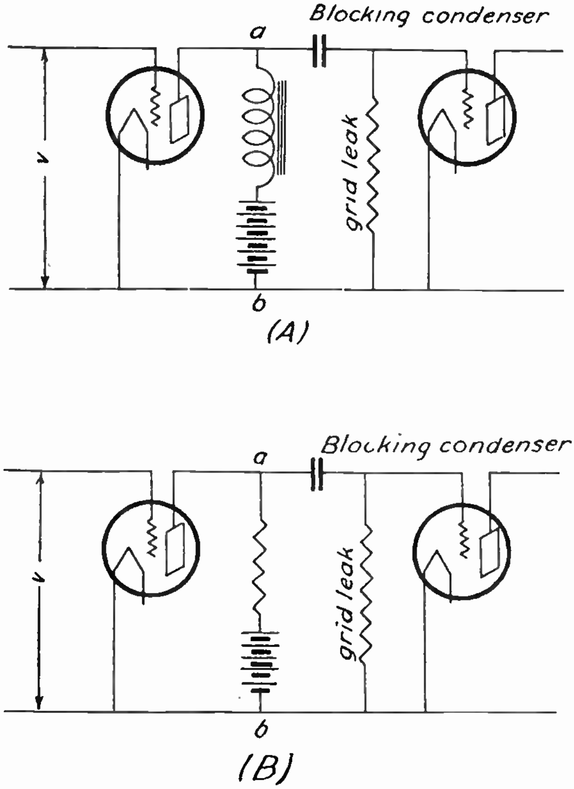


Fig. 5

doing this we had to add a grid leak resistance to the circuit so that a large negative charge would not collect on the grid. The same is true of the impedance coupled amplifier.

But now we have an impedance coil instead of a high resistance, in series with the "B" battery. The impedance coil has only a small resistance compared with the other, say about a couple of hundred ohms, so that it is not necessary to use a very high "B" battery voltage in order to get the proper amount of current flowing or to get the proper voltage on the plate of the tube.

The varying voltage, which is due to the signal put into the amplifier and continuously *varies* in strength, will produce a relatively large voltage between the points "a" and "b" of Fig. 5-(A). You see, we have to draw a very distinct line between varying and constant currents. A constant current has very little effect on an impedance coil, and this is due to the small resistance of the coil. The smaller this is, the better the coil. But the varying current has a large effect on the impedance coil, and furthermore, this effect is different at every frequency. The lower the frequency the smaller is the effect, and the higher the frequency the greater is the effect.

On account of the fact that the effect of the signal voltage is small at the lower frequencies, say from 200 cycles per second down, it is difficult for the amplifier to amplify sounds which have such low frequencies. The quality of reproduction, therefore, is made poor on this account. Just to give you an idea of what we mean, suppose you think of a man playing a piano, and suppose that this man has a weak left-hand and a strong right-hand. The low notes of the piano will come to your ears very softly then, and his playing will not sound well. But if his hands are equally strong the music will sound very much better.

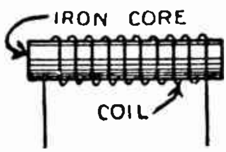
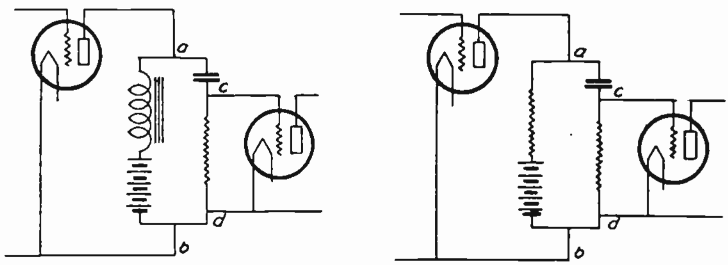


Fig. 6—Impedance Coil.

So, in any kind of amplifier, if we should lose the low notes the quality of reproduction will be poor. Both impedance coupled amplifiers and transformer coupled amplifiers have this one defect in common; they are both poorer on the low notes than on the high notes. But if the primary winding of the transformer, or the winding of the impedance coil, has a great many turns of wire, and the iron core used in these is large enough, it is possible to make this weakening of the low notes hardly noticeable. In other words, in order to make the quality of reproduction good, it is necessary to use rather large impedance coils and transformers. Of course, we have to draw the line somewhere, and strike a happy medium between perfect reproduction and the size and cost of the coils.

In addition to these things, you will remember that we once said that some of the strength of the low-frequency notes is also lost in the blocking condenser, and that this must be made fairly large so that the loss is not noticeable. All these things must be considered together when designing or building an amplifier, for it is clear that it would be a foolish trick to buy a very large and expensive impedance coil in order to get good quality, and then spoil it by using a small blocking condenser. The blocking condenser in either the resistance coupled amplifier or the impedance coupled amplifier should never be less than .01 microfarad, and preferably should be greater.

We must now consider another defect of these two systems; this defect leads us to another type of amplifier called the *dual impedance* amplifier, which has been devised in the effort to correct this defect. Although we connected the grid



(A) Fig. 7 (B)

leak resistance in the circuit so that the grid of the tube would not accumulate an excessive negative charge, there are two things that this grid resistance may do. The first of these is that when we are receiving a very strong signal, as from a local broadcasting station, the grid may collect quite a large negative charge in spite of the leakage path provided by the resistance. When this happens, the tube is said to be *blocked,* and the quality of reproduction will be badly spoiled. Of course, it is possible to reduce the volume of the loud-speaker by any of the means provided in the radio receiver, but the operator of the set does not always want to do this, especially if the receiver does not give sufficient volume in the first place.

The other effect which we mentioned is a little more complicated and we must study it carefully. Suppose we look at Fig. 7. The circuit diagrams in this figure are the same as the circuit diagrams in Fig. 5, only they have been drawn a little differently. You can see that they are similar by comparing the two sets of diagrams, line for line. The same points "a" and "b" have been marked on these diagrams as were marked on Fig. 5.

Now you remember we had a certain voltage between the points "a" and "b" due to the signal voltage. This voltage is across the terminals of the plate resistance or the impedance coil, depending upon which type of amplifier we are using. As you can see in the diagrams of Fig. 7, this same voltage is at the same time across the blocking condenser and the grid resistance, since these two are connected to the same points. But also notice that the second tube is only connected across the grid resistance, and we want the voltage input to this tube to be as great as possible. It is clear that part of the voltage between the points "a" and "b" is used up in the blocking condenser, and this cuts down the amount of voltage that we can get on the input of the second tube.

In order to increase this voltage, two things might be done, though both of these lead to difficulties. The first is that we may use a very large blocking condenser, as we suggested before, but a very large condenser leads to still other difficulties. The second thing that we might do would be to increase the grid leak resistance. But this will lead to the same difficulty we tried to avoid by putting the grid leak there in the first place. If the grid leak resistance is too high it will be difficult for the electrons to leak off the grid, and consequently the grid will become highly charged.

So, in trying to avoid these difficulties, the grid leak resistance is removed, in the *dual impedance* amplifier, and another impedance coil substituted in its place. The circuit diagram of the dual impedance system is shown in Fig. 8. By using the second impedance coil instead of the grid leak resistance, there is hardly any chance for a charge to collect on the grid of the second tube, no matter how great we make this impedance. The greater we make it the greater will be the amplification up to a certain point. And also the greater we make it, the better will it amplify the low notes. This impedance, as well as the one in the plate circuit, still has that same defect of passing on the low notes less effectively than the high ones. But if the system is properly designed it is possible to make the reproduction good enough to satisfy very discriminating ears.

There is an important thing that must be remembered in connection with all these kinds of audio amplifiers, and that is, that first, there is a certain amount of amplification in the tube itself, as we learned quite a way back. In the transformer there is also a certain voltage *"step-up,"* so that the transformer coupled amplifier can furnish a considerable amount of amplification.

On the other hand, although we still have the same amplification in the tube itself, in the other systems, such as the resistance or impedance or dual impedance systems, there is never a voltage step-up in the instruments connected between the tubes. In fact, there is always a step-down, or a loss of amplification in these systems. Consequently the amplification obtained in any stage of these types of amplifiers, is always slightly less than that which the tube itself furnishes.

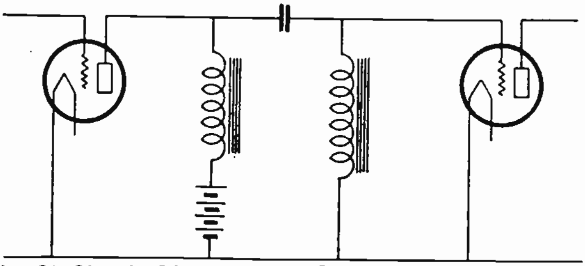


Fig. 8—Circuit Diagram of a Dual Impedance Amplifier.

In spite of this small amount of amplification as compared with that which the transformer coupled amplifier will give, and also in spite of the fact that three stages of resistance, impedance or dual impedance amplification are required to give a fair amount of volume, as compared with two transformer coupled stages, it is often claimed that the improvement in the quality of reproduction is worth the additional stage. It is safe to say, however, that any one of these systems, transformer coupled or otherwise, can be made so good, when properly designed, that there will be little to choose between in the matter of quality of reproduction.

To go a little farther in our discussion of amplifiers, there is another type which is a combination of the dual impedance and the transformer coupled amplifier. No special name has been given to this type, but it is shown in Fig. 9. It consists of a transformer having two windings exactly alike; in other words, the *turn-ratio* of this transformer, as it is called, is *one to one*. There is also a blocking condenser C shown in the circuit of Fig. 9. However, the grid charge can easily leak off through the winding of the transformer marked S. This type of amplifier has been found to give slightly more amplification than the resistance or impedance types, and there is little or no chance of blocking the tubes.

You have probably noticed the great similarity among all these types of amplifiers. The circuit diagrams of all, with the exception of the transformer coupled amplifier, are exactly the same; that is, the scheme of connections is exactly the same. To review briefly some of these similarities and differences therefore:

(a) The filament circuits of all the tubes are the same with the exception of the detector tube, when using a grid condenser and grid leak. In this case the grid-return is made to the positive side of the "A" battery. When using a "C" battery detector the grid-return goes to the negative side of the "A" battery.

(b) All the radio-frequency amplifier stages are wired alike.

(c) The wiring scheme of the radio-frequency amplifiers is almost the same as that of the audio-frequency amplifier stages, the main difference being that there are no tuning condensers in the audio-frequency amplifier.

(d) All the stages of the audio-frequency amplifier are alike, excepting in the case of the "B" battery voltages. The first stage of the audio-frequency amplifier is generally operated on 90 volts of "B" battery and the second stage either on 90 or 135 volts or more. When plate voltages higher than 45 are used, it is necessary to use "C" batteries in the grid circuits of the tubes. A "C" battery is often used even where only 67.5 volts are used on the plate. The following "C" battery voltages may be satisfactorily used, when using the UX-201A type of tube:

"B" battery voltages	67.5	90.	135
"C" battery voltages for above values......	3.	4.5	9

It is often necessary to use appropriate "C" voltages on the various tubes in audio-frequency amplifiers, whether they be of the transformer coupled type or of the type that we have been discussing. The method of applying the "C" voltages in the transformer coupled amplifier has been shown in a previous lesson. The manner of applying the grid bias (or "C" voltage) in impedance and resistance coupled amplifiers is shown in Fig. 8-A. The "C" voltage is simply connected to the resistance or impedance which furnishes the path over which the electrons leak off the grid. There is no loss of voltage in the grid leak, on account of the fact that the "C" voltage on the grid is always negative and no current is flowing through the grid leak. There is simply a "charge" placed on the grid by the "C" battery. Without any current flowing through the resistor, there cannot be any voltage drop, hence there is no loss of voltage in it, and the

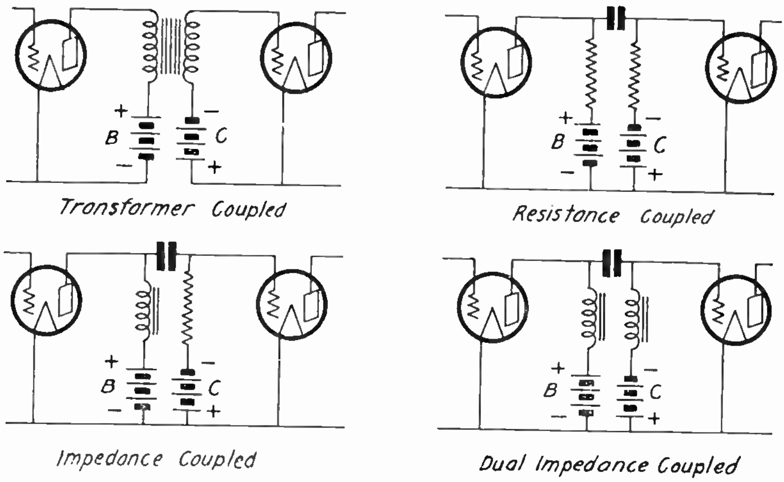


Fig. 8-A.

"C" voltage at the grid is the same as the voltage of the "C" battery.

(e) With the exception of the transformer coupled amplifier. all other types of audio-frequency amplifiers are wired exactly alike. The only difference is the substitution of an impedance for a resistance, either in the plate or in the grid circuit, or in both circuits.

(f) The wiring of the "B" batteries remains the same, the positive terminal of the "B" battery always being connected to the plates of the tubes, and the negative terminal connected either to the negative or to the positive side of the filament, depending upon the particular design of the radio receiver. When connecting up a radio receiver it is advisable to try either connection, and to use the connection which gives the best results. But when making the trial, be sure that you have the tubes out of the sockets, otherwise you are apt to burn them out. First remove the tubes, then connect the batteries. Next place your fingers across the two springs of the tube socket which make contact with the filament prongs of the tubes. If you do not feel a slight electric shock (which will not hurt you) you may put the tubes in the sockets with safety.

We have by this time, gone a considerable distance in our general study of radio. You will probably remember that the main purpose of these first six lessons of the course is to give you a bird's-eye view of the whole radio situation. It must be clear to you that it is impossible to completely cover the whole study of radio in six lessons. But the idea is that when you come to the lessons that will follow the first

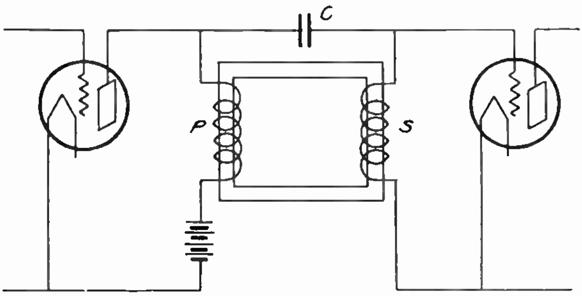


Fig. 9—Circuit Diagram of a Combination Dual Impedance and Transformer Coupled Amplifier.

six, you will find them much easier and more understandable than they would be if you had not already learned what it was all about. Besides all this, this course in radio is a *practical* one; we must train you in as short a time as possible, so that if you wish, you may actually go into the radio business, after the first few lessons have been learned, and during the rest of the course you may "Earn as You Learn."

For these reasons, there are several things which we have not yet met in our study, which we must introduce here, in spite of the fact that we will not be able to go into them very deeply at present. Later on whole lessons will be given over to these ideas separately; but in the meantime you will know what it is all about, and you will actually be able to work with these various kinds of receivers, and, if you wish, do servicing or constructional work, or perhaps selling of such receivers.

REGENERATION

The thing we are going to learn about now is called "*regeneration.*" In order to introduce it to you we shall have to go back to our old idea of the water tanks and pumps, and the rest of it. The scheme shown in Fig. 10 may probably be a very useless one in connection with pumping systems, but it will serve well to explain what we have in mind.

Suppose, then, we have a stream of water which enters the tank on the left at the point marked "a." If the valve at the bottom of this tank is properly adjusted, we can get the water to rise in the first tank to a certain level, as indicated at m, m, and then after that the valve can be regulated so that the water flows out at the bottom of the tank (at b) just a little faster than it flows into the tank at "a."

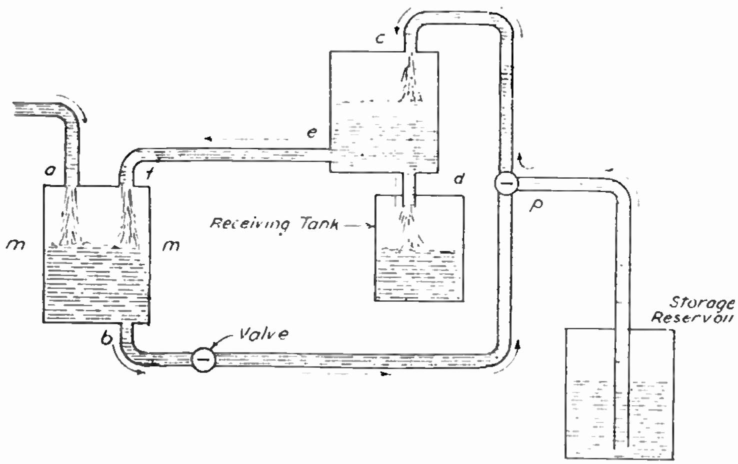


Fig. 10

In other words, we have the energy of the radio waves entering the system at the point "a," this energy is stored up in the condensers and coil (in other words, in the first tank), and is then passed on to the rest of the circuit, in this case, the electron tube (or the pump). Now you will notice that we have the water flowing out slightly faster than it flows in. This is similar to what happens in a radio circuit. Part of the energy which comes from the radio waves is used up in the resistance of the circuits.

But now the water passes on from the outlet "b" to the pump marked "p." This pump is like the electron tube. It pumps the water which has passed the valve, up to a higher and larger tank, and at the same time this same pump lifts water up out of a storage reservoir, to help fill the higher and larger tank. In the radio circuit we have the same thing; the electron tube draws energy out of the "B" batteries (that is, the storage reservoir), and by so drawing on this reserve energy, amplifies the weak signals which came in originally.

On account of this additional energy brought into the system by the pump, it is possible to fill up the larger tank, which represents the next electron tube in the circuit. The water enters this second tank at the point marked "c."

Next, we can draw off the water from this second tank and allow it to flow into a receiving tank underneath, at the point "d." This receiving tank represents a detector, or any kind of system which would make the radio-frequency signals audible (that is, capable of being heard).

So far so good; we have at least got the system working. But now suppose that some mischievous boy should come along, and connect a small hose at the bottom of the second tank at the point "e," and would connect the other end of this hose to the first tank at "f." It is clear that some of the water which we pumped around the circuit, would flow back again through this hose.

You remember that at first the water level in the first tank was dropping slowly, the water was running out faster than it ran in. But now, there is more water flowing in, for we have two streams entering the tank, one at "a" and the other at "f." As a result, the water level in the first tank drops more slowly.

Of course, the water level in the second and higher tank would drop more rapidly, but the pump makes up for this, and pumps the water up out of the storage reservoir faster, since we will suppose that it automatically makes up for the loss as the water flows out through the hose.

As a result, the water flowing through the hose is pumped around and around the system, and is continually added to by the water being pumped up out of the storage reservoir, so that the water level in the second tank is now higher, and we can draw more water out of it, to put into the receiving tank. So you see, having this automatic pump, when the boy thought he was doing a little mischief, he really was helping us out. But remember that only this automatic pump made this possible.

In other words, when we apply this to our radio-frequency amplifier, if we take a little of the energy in the plate circuit of a tube, and send this back into the grid circuit of the tube, it will combine with the energy of the incoming signals. The tube will then amplify both the incoming energy and the additional energy returned from the plate circuit, so that we shall have a much greater current flowing in the plate circuit than we would have had without this small return of energy to the grid circuit (or the input of the tube.)

Referring again to Fig. 10, in the beginning, the water level in the first tank was getting lower and lower. This corresponds to a loss of energy in the tuned-circuit. After some of the water is returned, the water level drops more slowly. In the radio circuit, the return of a little energy from the plate to the grid circuit makes up for part of the energy loss in the resistance of the tuned circuit. This effect is called *regeneration.* In radio receivers it is found that a little regeneration can amplify the strength of a weak signal enormously; without regeneration we can expect a signal to be amplified perhaps only about 3 to 5 times in each stage of the radio-frequency amplifier. But when we introduce regeneration the amplification may go as high as perhaps 15 or 20 per stage.

In Fig. 10, if we take out the hose (e f), and put in a larger hose, we shall have more *feed-back,* and the "regeneration" will be greater. That is, as we increase the amount of water "fed back," the water level in the tank drops more slowly, until we can go so far as to keep the water level from dropping at all. In other words, the *feed-back,* as it is called, has made up for all of the energy losses. This is called *critical regeneration,* and in a radio receiver is that condition which furnishes the *greatest* amount of amplification in a radio-frequency amplifier.

Now, suppose we go a little farther, and make the feed-back so great that the water level in the first tank not only does not fall, but *actually rises.* In other words, we are *more than making up* for the losses in the system. Then if the energy is fed back under sufficient pressure, and the first tank becomes entirely full of water, the water will actually *oppose* the water coming in, and, working against it, may actually *flow out* of the tank at "a" instead of flowing *into* the tank.

In the radio receiver, when the feed-back becomes great enough to *more than make up* for the losses in the resistance of the circuits, the tube is said to oscillate and it now acts as a small transmitter, because just as the water was forced *out* of the *intake* pipe at "a," the fed back energy will be forced out into the antenna circuit, and the receiving set then acts like a radio transmitter (of small power, of course) and can actually be used to transmit radio signals over short distances.

Of course, when this condition occurs, we cannot receive concerts with the receiver. We have to so adjust the receiver that we never increase the feed-back any further than the point of *critical regeneration*, in fact, we must always operate the receiver at a point slightly lower than this. This is the condition at which the receiver is most sensitive, and will tune in the most distant stations.

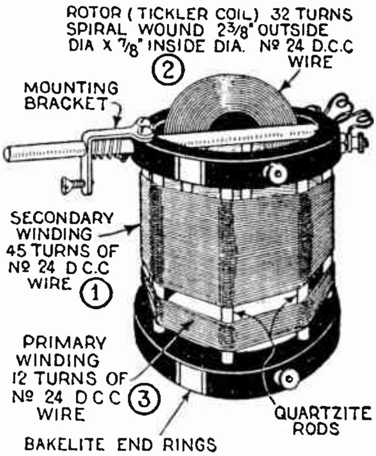


Fig. 11—Three Circuit Tuner.

Now that we have some idea of what regeneration means, let us find out how we get regeneration in radio receivers. In some cases we actually do *not want* regeneration, but we shall learn about these particular cases later on. The most popular receiver in which regeneration is purposely used in order to make the receiver very sensitive is known as the *three-circuit tuner*. In this receiver the regeneration is made to occur in the detector circuit. The circuit of the three-circuit tuner is shown in Fig. 12. In this illustration we have shown only the circuit of the *regenerative detector*, and an audio-frequency transformer connected in the output. Any of the audio-frequency amplifiers which we studied a little while ago can be added on to this circuit at its output.

This circuit differs from the ordinary detector circuit only in one respect, the plate circuit of the tube has been broken at the point "A," and at this point a coil is connected, marked T in the diagram. This coil is known as the "tickler" coil. The primary winding is P, the secondary winding is S and the ticker coil is T. The primary and secondary coils are fixed, that is, they cannot be moved, but the tickler coil is movable, so that the operator can adjust the amount of feed-back to suit his needs. A photograph of the three-circuit tuning coil is shown in Fig. 11.

To show how it works: the plate current flows through the tickler coil, and since the secondary coil S is in the magnetic field of the tickler coil, a voltage is *induced* in the secondary coil by the plate current flowing in the tickler coil. This is the old, old story again of a varying current producing a varying magnetic field, and when this varying magnetic field cuts another coil (such as the secondary), it *induces* a varying voltage in this second coil. Notice how many times you come across this same thing. You will find it many times before you are finished with this course.

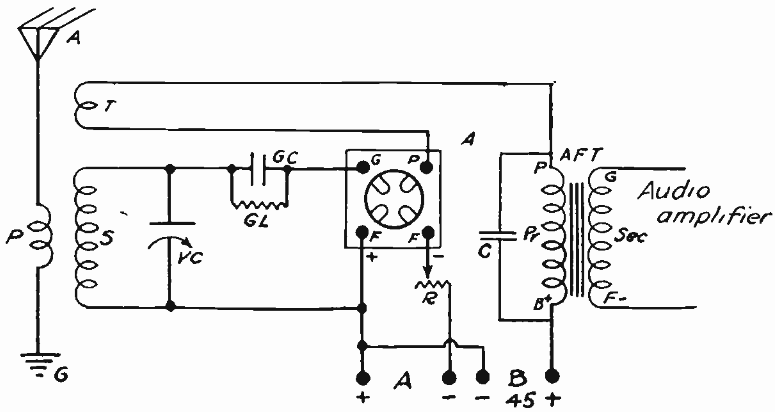


Fig. 12—Circuit Diagram of a One Tube Regenerative Set, Using a Three Circuit Tuner.

This "*feed-back*" of voltage unites with the voltage due to the signal, and the two are amplified together, thereby producing a stronger signal current in the plate circuit. There is one other thing about this circuit that we must call to your attention, and that is the by-pass condenser C connected across the primary winding of the amplifier transformer. This may or may not be necessary, depending upon the design of the transformer. The way to determine whether or not it is needed is to try the set with and without it. Connect it whichever way the set works best. The capacity of this condenser is usually .0005 to .001 mfd.

There is also regeneration in the radio-frequency amplifier, even though we have not tried to put it there purposely. Under certain conditions, which we generally have in radio-frequency amplifiers, we do not need a tickler coil to feed back the energy; the tube itself can do this. You will remember that in the tube we have three elements or electrodes—the *plate,* the *grid* and the *filament.* Any pair of these form a small condenser, since a condenser is merely composed of two metallic conductors such as these are, separated by a small space. Consequently some energy from the plate circuit can be fed back to the grid circuit through the small condensers formed by these tube electrodes. The action is really a very complicated one, but as we have stated before, we shall study it later on in another lesson.

For the present, however, this will be sufficient. But as we also said before, we must have some means of controlling this regeneration, so that the receiver will not *oscillate* and become a transmitter, instead of a receiver of radio energy. One method of doing this is to use a *potentiometer* in the grid-

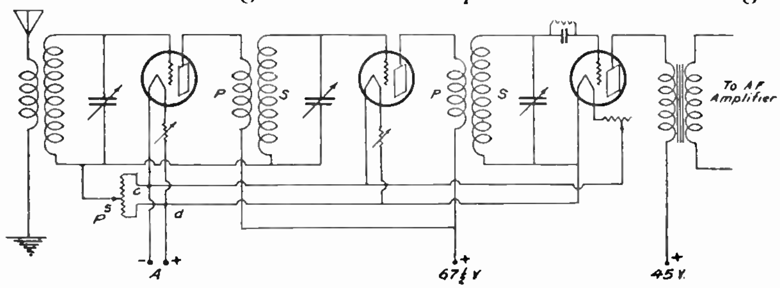


Fig. 13—Circuit Diagram of Two Stages of Tuned Radio-Frequency Amplification and Detector, Using Potentiometer to Control Oscillations.

return circuits of the electron tubes in the radio-frequency amplifiers. This is shown in Fig. 13. The potentiometer is marked "P." The only difference between this circuit and the radio-frequency amplifier of Fig. 15, Lesson 4, is that in the latter, the wires at "a" and "b" have been disconnected from the filament. Then these wires, called the grid-returns, are connected together and joined to the slider, or the movable arm, of a potentiometer. This is marked "s" in Fig. 13. The two other terminals of the potentiometer are then connected to the filament terminals, as at "c" and "d" in Fig. 13.

The idea of using the potentiometer is this: in the first place a potentiometer is nothing more than a resistance having a terminal at each end. There is also a slider or movable arm which can slide over this resistance, making contact with it at any point we wish. A photograph of one of these is shown in Fig. 14, and a diagrammatic sketch in Fig. 15. The two ends of the potentiometer are connected to a battery, as at "c" and "d" in Fig. 13 they are connected to the "A" battery.

The voltage across the points "x" and "y" of Fig. 15, is therefore the same as the voltage of the battery, and by moving the contact we can take off the potentiometer any voltage we care to up to the entire voltage of the battery. For instance, if the battery has a voltage of 6 volts, and we move the slider down half-way, the voltage between the point "x" and the slider will be one-half of 6 or 3 volts. Then, by connecting the slider to the grid-returns of the tubes, we can place on the grids of the tubes whatever voltage we need to control the regeneration. For you must remember that if we place a positive charge on the grid of a tube, it will cause the plate current to increase, and this with other effects that we shall learn later on, will control the regeneration.

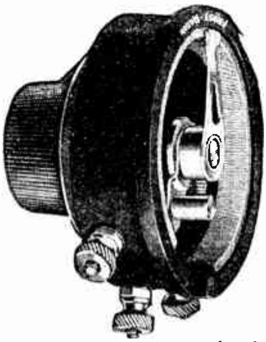


Fig. 14—A Standard Potentiometer.

As for entirely preventing the circuits from oscillating, that is, from passing the condition of critical regeneration, there are several ways in which this may be done, but for the present the simplest, and perhaps the most effective way is to use only a few turns of wire on the primaries of the radio-frequency transformers. These primary coils are connected in the plate circuits of the radio-frequency amplifiers, as at P in Fig. 13. The primary coils are marked P and the secondary coils are marked S.

LOUD-SPEAKERS

We will end this lesson with an explanation of what the loud-speaker does and how it does it. You will probably remember that several lessons back we learned that when a current flows in a coil of wire, a magnetic field is established in and about the coil. You also learned that this magnetic field can act like any other magnetic field, the main thing being, at the present time, the fact that such magnetic fields can attract pieces of iron. This principle is used in the ordinary telephone receivers, which you use every day, and in certain types of loud-speakers which use "units" as they are called, just like the telephone receiver. The word *unit* is often applied to the working part of a loud-speaker, in order to make it clear that when speaking of it we are not talking about the *horn* or *bell* of the loud-speaker. A loud-speaker is composed of two parts—the unit, and a part which acts on the air in front of the unit.

Suppose we look at Fig. 16 to see what it is all about. In this illustration we have shown a very simple form of a loud-speaker unit. First, we have a permanent magnet. In the case shown, this has a simple cylindrical shape, but in many units the permanent magnet has a horse-shoe shape. Above this permanent magnet is an iron diaphragm, which is supported on a ring, which is generally backed up with a rubber gasket or washer.

Now, since we have a magnetic field surrounding this permanent magnet, and this magnetic field passes into the iron disc which we call the diaphragm, it is clear that the iron

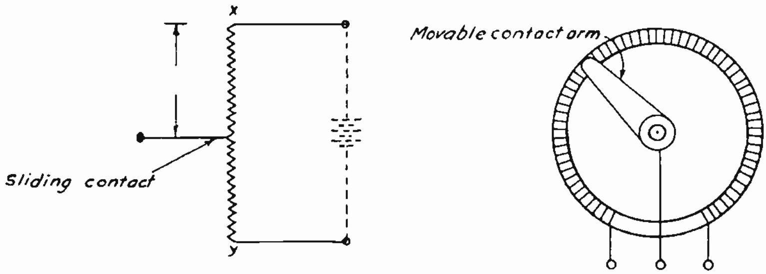


Fig. 15

diaphragm must be attracted to the magnet. Such is the case, and as shown in Fig. 17, the diaphragm is bent downward, into the position marked B. Remember, this bending is due *only* to the *permanent* magnetic field.

Now, suppose, for some reason or other, the magnetic field is made weaker. Then the diaphragm will not be bent as far, for there is a springiness in it which tends to keep it flat. Suppose that the magnetic field were made stronger by some means or other. Then the diaphragm would be bent still further, or to the position A. Of course, the amount which the diaphragm is bent, under any circumstances, is very small, perhaps only a few thousandths of an inch, but in order to illustrate it clearly, we have had to exaggerate the bending in Fig. 17.

Now, when the diaphragm is bent in this manner, every time it moves one way or the other, it either has to push the air in front of it, or suck the air after it. Consequently, if this pushing and pulling takes place fast enough, we shall have established in the air beyond the diaphragm, a series of air waves, which have spots of high pressure and spots of low pressure, one after the other, corresponding to the pushes and pulls of the diaphragm. These high and low pressure spots occur one after the other, and are at an equal distance from each other, this distance being a *quarter of a wave-length*, and the number of high pressure or the number of low pressure spots is the same as the *frequency* of the air waves. This idea is pictured in Fig. 18.

Here we have the diaphragm, and the dotted lines show the two positions when the diaphragm is pushed or pulled by the magnet. The high pressure spots are represented by the heavy shading, and the low pressure spots by the light shading in the picture.

The next thing to consider is, how do we make the diaphragm vibrate back and forth, under the influence of the

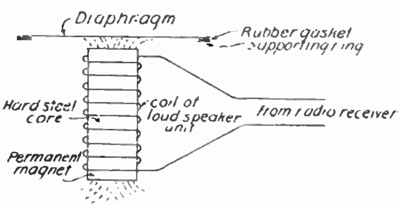


Fig. 16

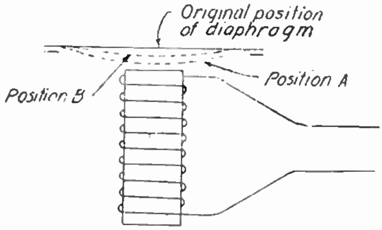


Fig. 17

magnetic field. So far we have considered only a permanent magnet, which always has a *constant* or a steady magnetic field, and therefore has always a steady attraction for the diaphragm, so that the permanent magnet by itself could not make the diaphragm vibrate.

A few moments ago we said that in order to make the diaphragm vibrate we had to make the magnetic field stronger and weaker in regular succession. There is a simple way to do this, as you may have already guessed by looking at the coil of wire in Figs. 16 and 17. The coil is wound around the permanent magnet. In manufacturing, these coils are first wound on small bobbins of fiber or of bakelite, which are then slipped onto the permanent magnet.

Now suppose we pass into this coil an alternating signal current which we may get from the output circuit of the second audio-frequency amplifier tube of our radio receiver, and is a current which varies in frequency and intensity in just the same manner as the sounds we want to hear. This alternating current reverses in direction a certain number of times a second, according to its frequency. Therefore, when we pass this current into the coil of the loud-speaker unit, it creates a magnetic field of its own, the strength of this field depending upon the intensity of the alternating signal current.

While the current in the coil is flowing in one direction, it sets up a magnetic field which is in the same direction as the field of the permanent magnet, and hence, aids it in attracting or bending the diaphragm. When the direction of the current changes, the polarity of its magnetic field changes also, and this time opposes the magnetic field of the permanent magnet. Consequently, the pull on the diaphragm is decreased and it springs back a little.

In other words, the diaphragm will spring back and forth as the current in the coil of the loud-speaker unit changes

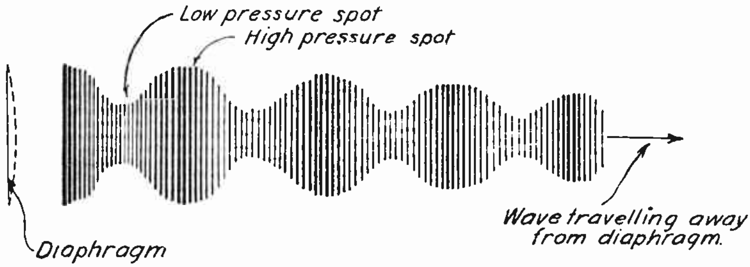


Fig. 18

its direction of flow, and these vibrations of the diaphragm will occur exactly in step with the reversals of the current. If the current reverses a thousand times a second, the diaphragm will vibrate a thousand times a second, and the pitch of the note that we hear coming from it will be exactly the same as the pitch of the note at the transmitting station which produced the alternating signal current in the receiver.

The strength of this vibration, that is, how much the diaphragm is bent during each vibration, depends on the *strength* of this alternating signal current. So, if we have an audio-frequency current coming out of the receiver which corresponds to the voice sounds or musical sounds we are receiving, the diaphragm of the loud-speaker unit will vibrate in just the same manner. And the air in front of the diaphragm will also vibrate in the same manner, both as regards *frequency* and *intensity*, and these will be air waves or sound waves, which we will hear.

Many loud-speaker units are made this way, and all headphones are made this way. There is another way in which loud-speaker units are often made, however, which we will now study. In one of your previous lessons you learned that when a coil of wire carried a current, the coil could act just like a magnet. In other words, the current flowing in the coil establishes a magnetic field, which can attract iron just like a permanent magnet. It should be possible therefore to replace the permanent magnet shown in Fig. 16, by an *electromagnet,* that is, a coil carrying an electric current.

This arrangement is shown in Fig. 19. At the bottom of this figure is shown the magnetizing coil (C), or electromagnet, which takes the place of the permanent magnet of Fig. 16. But you must know that this coil is wound on a soft iron core, (I), whereas a permanent magnet is made of hard steel.

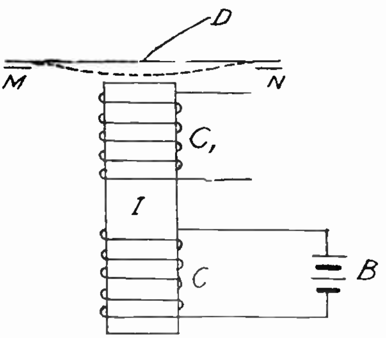


Fig. 19

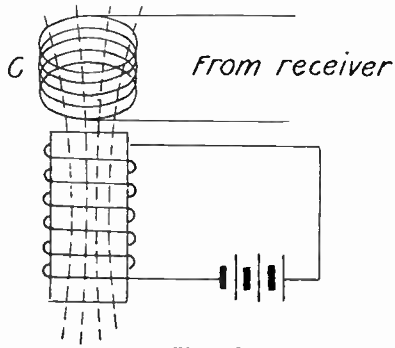


Fig. 20

The reason for this is that hard steel keeps its magnetism a long time, while soft iron does not. In the loud-speaker unit of Fig. 19 we do not want the iron core to keep its magnetism, but to have it magnetized only when the current is flowing in the coils. We shall learn the reason for this later on. There are certain advantages which this type of unit has over the other which we shall also study at the proper time.

Now we can go a step farther, and learn of still a third type of loud-speaker unit. In the units spoken of previously, we had to use an iron diaphragm. It is possible to remove this iron diaphragm by making a coil do its work. Suppose we have some kind of a magnet, such as a permanent magnet or an electromagnet. In Fig. 20, for the sake of illustration, we have shown an electromagnet, although a permanent magnet would work. Suppose also that we have a coil placed in the magnetic field of this magnet. This coil is marked C in Fig. 20. Now suppose that this coil is connected to the output of a radio receiver so that the alternating signal current will pass through it. This connection is made by means of flexible wires, so that the coil C is free to vibrate. The coil is held in position by means of a light spring, which is not shown in Fig. 20.

Now, when the signal current coming from the receiver passes through the coil C, it will establish an alternating magnetic field. It is, therefore, plain that the coil C will vibrate up and down just like the diaphragm, for at one instant the field of the coil C will aid the field of the electro-

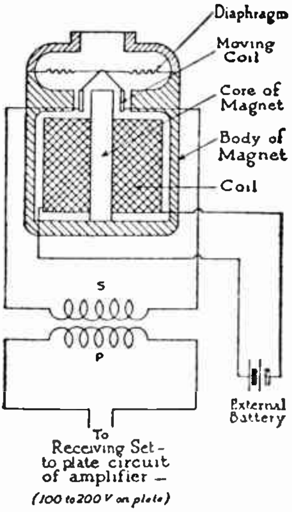


Fig. 21—Moving Coil (Electrodynamic) type of Loud-Speaker Unit.

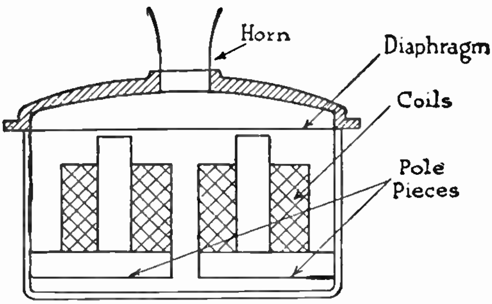
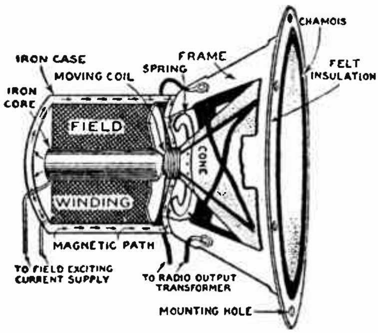


Fig. 22—Ordinary Telephone Receiver Type of Loud-Speaker Unit Showing Pole Pieces, Coils and Diaphragm.

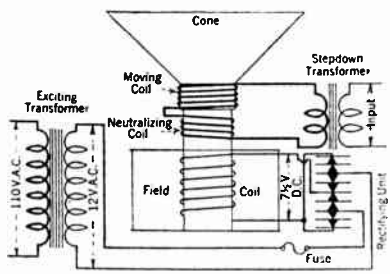
magnet, and at the other instant the combined field will be made much stronger.

To make this type of unit work, all that we have to do is to fasten a light rod to the coil C and at the other end of this rod fasten some kind of a "pusher,' which will make the air vibrate in front of it. This *pusher* may be a small diaphragm of mica, or it may be a large cone of paper. In Figure 21 we have shown a unit of this type known as the electrodynamic speaker. The illustration shows a cross-section of the unit, that is, how it would appear if it were cut right through the middle. The magnetizing coil is marked with crossed lines; it is a coil of many turns of wire, and is connected to a battery of 6 volts. This furnishes the steady or constant magnetic field for the unit. It is represented by the lower coil in Fig. 20.

Inside of the magnetizing coil is a core of iron. Above this magnetizing coil surrounding the iron core is a small coil of wire, very light in weight, which is connected to the output of the radio receiver. This is the coil that vibrates up and down in the magnetic field. It is called the "voice-coil," and is represented in Fig. 20 by the upper coil, marked C. It is supported rigidly by means of a "spider" or "tripod," and the spider and coil are attached to the diaphragm. As the coil vibrates up and down the diaphragm is thus caused to vibrate.



The Mechanical Construction of an Electrodynamic Speaker Unit For a Free-Edge Cone. The Paper Cone is Attached to the Moving Coil.



(Courtesy of Radio Broadcast).

Circuit Diagram of an A. C. Dynamic Speaker Unit Showing Connections to Transformers and Rectifier Unit.

Fig. 23

There are several variations of this type of loud-speaker unit; in one of them the diaphragm is replaced by a large paper cone. Figure 23 shows two types of electrodynamic speakers.

It will be well at this point to obtain a clear understanding of the various terms applied to different types of loud-speakers. In the first place, we must always have a steady magnetic field in the unit. This may be furnished either by a permanent magnet of steel or by an electromagnet such as shown at C, in Fig. 19.

Next, there is always required a "voice-coil," as we termed it above. It is the coil into which the alternating signal current from the radio receiver is passed. In the diaphragm type of unit this voice-coil is fixed, that is, it does not move, but operates the loud-speaker by virtue of its *magnetic attraction* on the diaphragm. Hence, this type of speaker is called the *magnetic* type. This is true regardless of whether the steady magnetic field is furnished by a permanent magnet or by an electromagnet.

In the electrodynamic speaker, the voice-coil itself moves; this is a condition somewhat analogous to the rotation of the armature of a motor in the magnetic field of the field winding.

To sum up then, the terms magnetic and electrodynamic merely means whether the voice-coil acts on a diaphragm or whether it does the moving itself. The term *electromagnetic* applies only to the method of obtaining the steady field from a coil and battery instead of a permanent magnet.

Electromagnets have many advantages over permanent magnets. They consist of coils of many turns of wire wound over cores of soft iron. With magnets of this type, it is possible to produce a field of great strength, such as is required for the reproduction of strong radio signals.

Next we come to the subject of horns; this is a very difficult problem, and there is still a great deal to be learned about them. The main object of the horn is to enable the loud-speaker unit to work on a *large* quantity of air all at once. You can easily see that if we had to be satisfied with allowing a small diaphragm about 3 inches in diameter to act on the air, we would not get much volume out of the loud-speaker. In the case of ear-phones, which are clamped very close to the ear, it is possible to obtain sufficient volume, but when we want the sounds to fill a complete room, we have to make the loud-speaker unit move quite a large quantity of air.

The simplest way in which to do this is to fasten a horn or a bell over the diaphragm. Such an arrangement is shown in Fig. 22. It is done by placing the unit in a case of some kind, and then covering the diaphragm by a cap which screws on the casing. The horn or bell is then screwed into this cap.

There are many ways of constructing loud-speakers, but we cannot go into detail concerning their construction here. In all of them, however, the aim is to obtain as great volume as possible, and also to make this reproduction as accurate as possible.

This is about as far as we can go in this bird's-eye view of radio in the matter of loud-speakers. You have at least learned how they operate, and a few other important things about them. We will study them in detail later on in another lesson of this course.

There has been a great deal of information included in this lesson, but we feel sure that you will be able to get all of it. *The better you learn this lesson, the easier it will be for you in the lessons that follow.* This is especially true of the first six lessons, which as we have said before, will give you a comprehensive or bird's-eye view of the whole matter of radio receivers and all that goes with them.

TEST QUESTIONS

Number your Answer Sheet 5—3 and add Your **Student Number**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Draw a diagram of a resistance coupled audio-frequency amplifier.
2. What is the size of the resistance in the plate circuit and the capacity of the blocking condenser recommended for a resistance coupled amplifier?
3. What is an impedance coil?
4. Draw a diagram of an impedance coupled audio-frequency amplifier.
5. What is the one common defect in transformer and impedance coupled amplifiers?
6. Name three different "B" battery voltages that may be used with the 201-A tube and the corresponding "C" battery voltages that should be used.
7. What is the advantage of using regeneration?
8. Draw a circuit diagram of a regenerative receiving set.
9. Name one way of controlling regeneration in a radio-frequency amplifier.
10. What is the advantage of using a magnetizing coil instead of a permanent magnet in a loud-speaker unit?

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(3rd Edition)

RADIO BATTERIES, CHARGERS AND POWER UNITS

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C

RADIO BATTERIES, CHARGERS AND POWER UNITS

This is the last of the lessons of this practical radio course which will be devoted to what we have called our "bird's-eye view" of radio. In these six lessons, with which we have begun our course, you will have learned quite a lot about radio; you are probably surprised yourself, at the speed and ease with which you quickly became acquainted with what is going on in a radio receiver.

But one thing we wish to warn you against; do not think that you know much about radio. So far in these first few lessons, you have merely "scratched the surface." *These lessons are intended to be only an introduction to a complete study of radio, which you will get in all the lessons that follow.* But if you have studied these lessons carefully, and have mastered all that is in them, then, with the aid of the Practical Work Sheets which the National Radio Institute supplies, you ought to be able to do valuable and practical work on ordinary radio receivers.

We shall now consider the matter of battery charging, which is quite an important item in connection with the operation of radio receivers.

BATTERY CHARGERS

As you know a storage battery is used to light the filaments of the electron tubes, and in some cases to supply current for the magnetizing coils of loud-speakers.

An average size storage battery will gradually lose its charge in a month or two, depending on how much the receiver is used, and then it will not be possible for it to sufficiently light up the tubes. Then the battery must be charged.

For this reason a number of small battery chargers have been placed on the market, which are in very wide use. You may raise the question, why does not the operator of the set simply connect his battery to the house lighting system and charge it from that source of electric power. The trouble with this is that the storage battery requires *direct* or *constant* current for charging while the house lighting system is generally operated with alternating current. There are only a few places left where lighting and power lines are supplied with direct current. Where this is the case the problem is rather simple, and it is not even necessary to buy apparatus for charging batteries, as the apparatus can be easily constructed by the operator himself.

Therefore, let us take the simpler case first. Suppose you live in a district where the house lights are connected to a *direct current* supply. This supply is generally about 110 volts. The charging voltage for a battery must be a little higher than the voltage which the battery is supposed to deliver. Thus, since our storage battery is supposed to deliver 6 volts, we use a charging voltage of about 8 volts. The problem is then, how to get 8 volts from 110 volts. As you have learned sometime ago, in any circuit which carries a current, we have a certain voltage impressed on that circuit, which is used up in the various parts of the circuit. For instance, if we have a filament of 20 ohms resistance connected in series with a resistance of 4 ohms, and these are connected to a battery of six volts, 4/24ths of the voltage will be used up in the resistance, and 20/24ths of it will be used up in the filament. That is, 4/24ths of 6 makes 1 volt lost in the resistance, and 20/24ths of 6 makes 5 volts used up in the filament.

Now we can use the same principles in connection with our charger. Having 110 volts to begin with, let us suppose we wish to charge our storage battery at a rate of 5 amperes, which is sufficiently high for most purposes. *Of course, the greater the charging current the faster the battery will charge, but in the case of ordinary home charging it is not well to go above 5 amperes.* Remember that we need about 8 volts as the charging voltage. We must now find how much resistance we must place in the circuit. Now look at Figure 1.

If we have an original voltage of 110 volts, and we want only 8 volts, it is clear that we have to lose 110 — 8 or 102 volts in the resistance. Next, if we want a charging current of 5 amperes, we can find the resistance required by dividing the voltage by the amperes.

$$\text{Ohms} = \text{Volts} \div \text{Amperes} \qquad (1)$$

Therefore we get 102÷5 or 20.4 ohms, as the resistance we require in the circuit. The next step in the problem is to find a resistance of that value which will be able to carry 5 amperes without getting too hot, for you remember we spoke some time ago about the heating effects that electric currents produce in conductors.

Fortunately, we have such resistances very close to us and easy to get. These are the ordinary incandescent lamps used in your house for lighting purposes. A 50 watt lamp has a resistance of about 242 ohms, and a 100 watt lamp has a resistance of 121 ohms. So all we have to do is to take ten 50 watt lamps and connect them in parallel, or take five 100 watt lamps and connect them in parallel. The circuit then looks like that shown in Fig. 2, where we have shown five 100 watt lamps for limiting and controlling the current.

Now, in many cases it is not necessary to use such a high charging rate as five amperes. If the battery is put on charge

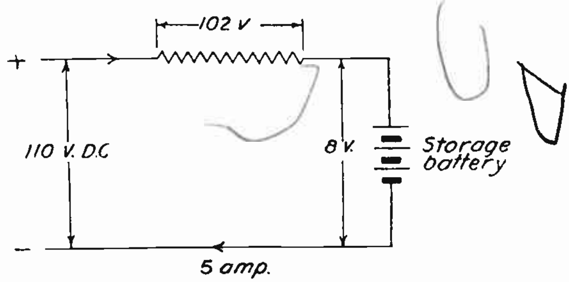


Fig. 1—Circuit Diagram for Charging a Storage Battery from a 110 Volt D. C. Line.

often enough, a two ampere charging rate may be sufficient. In that case you can work out the number of lamps required, just as we have done above. This may be done in a simpler way by remembering that every 50 watt lamp we add increases the charging rate by about ½ ampere. Therefore, if we want a charging current of 1 ampere we use two 50 watt lamps. If we want a current of 2 amperes we use four 50 watt lamps. Or, if we want to use 100 watt lamps instead of 50 watt lamps, we simply count 1 ampere to each lamp.

You must remember, in all this we are considering charging only one storage battery at a time. If we want to charge two batteries at the same time, each of these being a 6 volt storage battery, we must allow about 16 volts for the charging voltage instead of 8 volts.

When charging two batteries, they are connected in series. Requiring 16 volts for charging, the voltage drop in the lamps must be 110 — 16 or 94 volts. For a two ampere charging current the resistance must be 94 ÷ 2 or about 47 ohms. The nearest we can come to this with the lamps is to use three 100 watt lamps in parallel, which will give a resistance of 121 ÷ 3 or 40.3 ohms. The charging current will then be slightly greater than 2 amperes, but will be satisfactory. If we wish, we may use six 50 watt lamps, which will give the same charging current as three 100 watt lamps.

MECHANICAL, BULB AND ELECTROLYTIC RECTIFIERS

All this is a very simple matter, but when it comes to charging batteries in places where we have alternating current instead of direct current, the problem is much more difficult. We cannot then use a simple method like the one

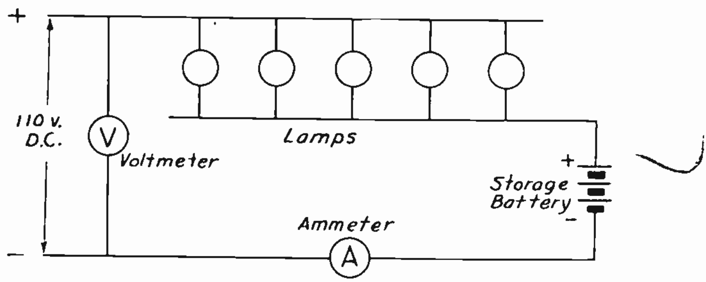


Fig. 2—Charging Storage Battery, Using Lamps as Charging Resistance.

described above, but must use a special instrument called a *rectifier*, which will take the alternating current and break it up, so that instead of flowing into the battery at one instant and out of it at the next, the current is *always* flowing into it.

Suppose we think of what an alternating current is. It is a current which reverses its direction of flow regularly so many times a second; in the case of house lighting systems it generally reverses 60 times a second. Hence it is called a 60 *cycle current*, or its *frequency* is 60 *cycles per second*. Suppose now we have a battery connected to the line, and that at a certain instant the current from the house line is flowing *into the positive* terminal of the battery. Now, suppose again that when the current reverses and tries to flow *out* of the positive terminal of the battery, that we open a switch. Then the current cannot flow out of the positive terminal. In other words, if we open the circuit every time the current begins to flow out of the positive terminal of the battery, we shall never have any current flowing in that particular direction. On the other hand, since we always allow the circuit to remain closed when the current is flowing *into* the positive terminal, it is plain that this is the only way in which the current can flow through the battery.

Of course it will then flow in *"jerks"* or *"impulses,"* but as far as concerns the charging of the battery, this will be satisfactory, and the battery will charge up. This is the way in which the *"mechanical"* rectifiers work. There is just such a switch as we have mentioned here, which, however, operates automatically. Every time the current begins to flow in the wrong direction this switch opens, and every time the current is in the right direction the switch is closed.

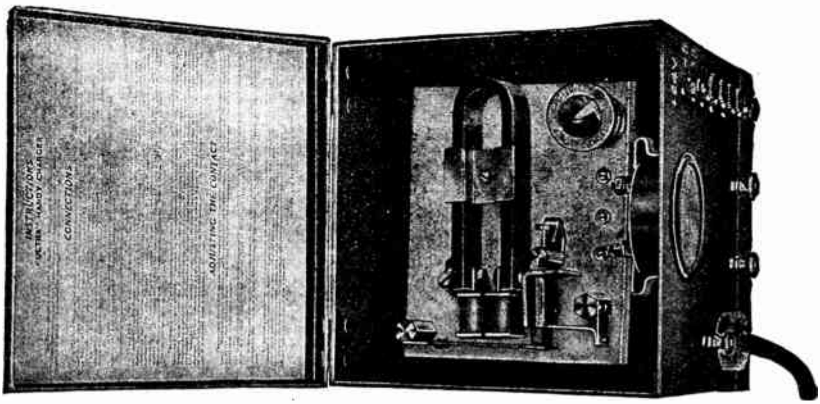


Fig. 3—Picture of a Mechanical Rectifier Charger With Cover Removed.

MECHANICAL RECTIFIER

The simple diagram of such a *"mechanical rectifier"* is shown in Fig. 1. This illustration is not a complete diagram, but is merely a *skeleton diagram*, which will be sufficient at the present time for explaining how the rectifier works. The alternating current (60 cycle) enters the transformer, at the top of the diagram. In the transformer the voltage is "stepped down" to whatever voltage is necessary to work the charger and charge the battery; as we have seen before, we require about 8 volts for charging, so that we may require a few more volts to operate the charger. The total voltage in the secondary winding of the transformer (marked S) may therefore be about 10 volts. The primary winding of the transformer (marked P) is connected to the house lighting circuit.

The alternating current flowing in the secondary winding of the transformer also flows through the magnetizing coil and the strength of this current is regulated by the resistance R_1. When the current from the transformer to the battery is of the correct polarity to charge the battery, the contacts close and the current flows to the battery. But when the supply line reverses its polarity, the contacts open so that the battery cannot be discharged.

The name *armature* is given to the part of the charger that vibrates. A spring supports the armature and when there is no current flowing, prevents it from coming in contact with a piece of carbon, which is held in an adjustable clamp. The screw is for the purpose of adjusting this piece of carbon so that when the charger is not in operation it is at the right distance from the armature.

A fuse is generally used in the circuit, which is a small piece of material which melts easily and breaks the circuit when an excessive current flows, which might damage the charger or the battery. The ammeter is an instrument which tells us how much current is flowing at any time.

You will also note that in the diagram of Fig. 4 there is included a permanent magnet M. You may suspect therefore that the operation of the charger is very similar to that of a diaphragm type of loud-speaker unit. Such is the case, as we shall see.

Since the magnetizing coil is connected directly to the secondary of the transformer, when the primary is connected to the house lighting circuit there is always an alternating current flowing in this coil. The coil, therefore, has a *magnetic field* which alternates as the current alternates, first in one direction, then in another.

Now, the permanent magnet always attracts the armature with the same force. The screw is adjusted so that the armature is not quite touching the piece of carbon. Therefore, when the magnetic field of the coil is in such a direction that it aids the field of the permanent magnet, the attraction on the armature is greater than it was, and the armature is pulled over and makes contact with the carbon. While the current is in this direction, therefore, and the contact is closed, the current can flow into the battery.

But when the alternating current through the coil is in such a direction that the field of this coil *opposes* the field of the permanent magnet, it is clear that the attracting force on the armature will be less than is required to pull it over, and the spring will keep it from making contact with the carbon. When this happens no current can flow into it, since there is no complete circuit to the battery. As a result the charger automatically breaks the circuit when the current is in the wrong direction, and closes the circuit when it is in the right direction.

You will notice there are three terminals to the charger at the bottom of the diagram of Fig. 4. When there is one battery to be charged, it has its negative terminal connected to the — terminal of the charger, and the other is connected to the terminal marked 6V. When there are two 6 volt batteries to be charged they are connected in series. Then the negative terminal of the battery is connected to the — terminal of the charger and the other terminal of the battery is connected to the 12V+ terminal of the charger.

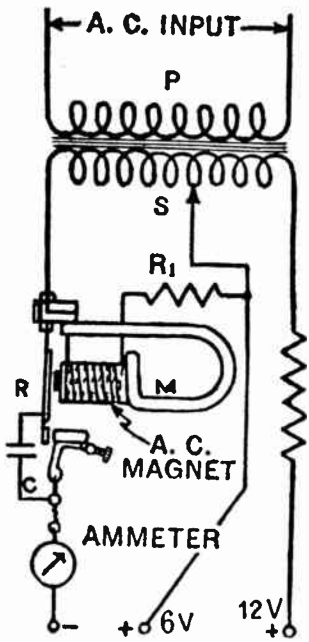


Fig. 4—Wiring Diagram of a Simple Mechanical Rectifier.

The chargers are so designed that it is not necessary to adjust anything on them excepting the screw, which regulates the position of the carbon contact. Very little difficulty is experienced with good mechanical chargers, the only servicing that they ever require being an occasional replacement of the piece of carbon, which gradually wears out, due to rubbing of the armature, and an occasional spark. A good charger should not spark at the contacts and when it does spark, it is an indication that the charger is not working properly.

BULB RECTIFIER

There are two other types of chargers which we will review rather quickly at the present time, for we shall study them in more detail in a later lesson. We must introduce them here in order to make our bird's-eye view more complete. You must remember that all rectifiers work in the same manner; they all break the circuit when the current to the battery is in the wrong direction, and complete the circuit when the current is in the right direction. If you keep this in mind you will not have much trouble in understanding how chargers work.

The first of these two types, which we shall consider, is the *"bulb"* type of rectifier. There are several of these on the market, all of which use the same kind of bulb or tube, called the *"tungar"* bulb. A tungar bulb is an electron tube which has a filament and a plate, but no grid. It also has inside the glass envelope argon gas. This differs from the electron tubes used in amplifiers for all the gas or air has been removed from these as is possible to remove.

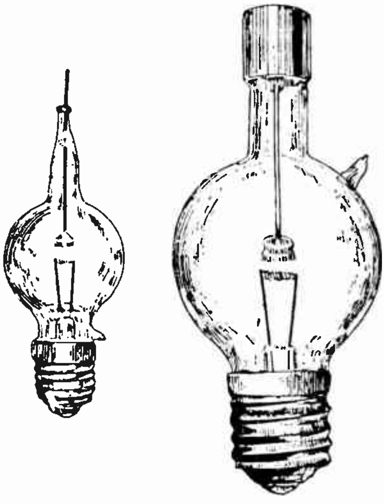


Fig. 5—Small and Large Size Tungar Rectifying Bulbs.

The diagram of one of the rectifiers which uses the tungar bulb is shown in Fig. 7. The 110 volt A.C. line of the house lighting system is connected as before, to the primary winding of the transformer, marked P. The lower alternating voltage is delivered by the secondary winding, marked S. Connections are made to a small part of this secondary winding, as at "a" and "b," where a voltage is taken off to furnish current for lighting the filament of the tungar tube.

The plate (or anode, as it is also called) of the bulb, is connected to the — terminal of the charger, and the other side of the transformer secondary is connected to the + terminal of the charger. The + terminal of the battery to be charged is connected to the + terminal of the charger, and the — terminal of the battery is connected to the — terminal of the charger. A fuse is included in the + side of the charger.

The operation of the tungar charger depends on the fact that the tube will only allow current to pass in one direction.

This is because the heated filament gives off electrons, while the cold plate does not.

When the filament is heated and a difference of potential exists between the plate and filament an electric current will flow between the plate and the filament.

If an alternating current is impressed across the plate and filament, a current will only flow when the plate is positive. When the voltage reverses its polarity, no current flows and thus the negative half-waves are suppressed.

ELECTROLYTIC RECTIFIER

The last type of rectifier or charger which we shall study is known as the *"electrolytic"* rectifier. This type of rectifier is widely used, especially for *"trickle"* charging. The word *trickle* indicates exactly what it means; the charging rate is made very small, so that the current merely trickles into the battery, and hence the battery charges very slowly. When a trickle charger is used, it is necessary to have the battery on charge at all times when the radio receiver is not in use. This is easily done by throwing a switch when you have finished using the set.

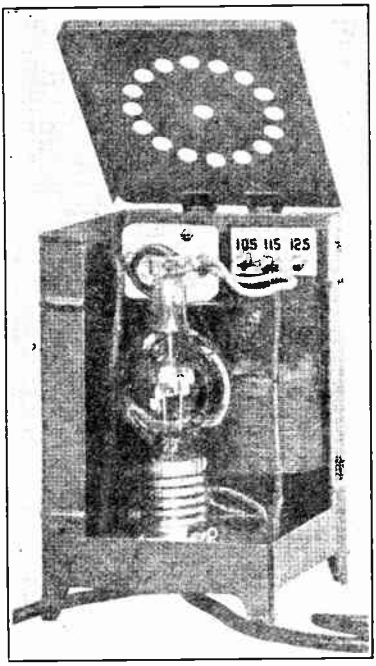


Fig. 6—General Appearance of a Commercial One Tube Rectifier with Two Sides and Top Removed.

There is not a great deal known about the way in which electrolytic rectifiers operate. The circuit diagram of this type of charger is shown in Fig. 8. Note that the diagram is about the same as that of the bulb rectifier. The house line is connected to the primary of the transformer P. In the secondary circuit of the transformer there is connected the electrolytic rectifier. This consists of some kind of a container, such as glass, which cannot leak or be attacked by acids, and in it are placed two pieces of metal. The container is then filled with a certain liquid called an *"electrolyte."*

There are various combinations of metals and electrolytes which may be used, but the best of these, and the most widely used are:

Aluminum rectifier: plates of aluminum and lead, with a solution of borax in water.

Tantalum rectifier: plates of tantalum and lead, with a solution of sulphuric acid in water.

The latter type of electrolytic rectifier is also known as the Balkite rectifier. The lead plate is in both cases the negative (—) terminal of the charger and the other plate is the positive terminal.

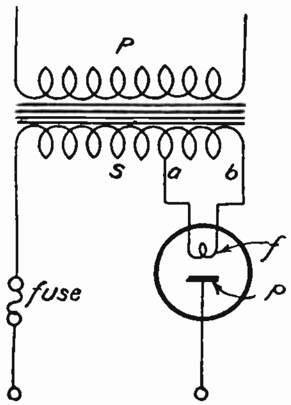


Fig. 7—Diagram of a Charger Using Tungar Bulb.

The electrolytic rectifier, if well constructed, should not require much attention. It is necessary to replace the water which evaporates out of the electrolyte, just as it does in a storage battery, but in the average electrolytic rectifier used for trickle charging, this need be done hardly more than every two or three weeks, and in many cases less frequently than this. It is well not to place the electrolytic rectifier very near to heaters or radiators, as the water will evaporate more quickly.

When used for charging batteries at other than trickle rates (which are generally about ½ ampere or less)—say at one or two amperes, the electrolytic rectifier, especially the aluminum type, is apt to give trouble, due to the chemical formation of salts on the jars, which may creep over the sides of the jar as they accumulate, and may then do damage to furniture and carpets, etc. It is well to place electrolytic rectifiers (and storage batteries too), in glass or porcelain pans, which will prevent acid and salts from doing damage to the home.

If you should accidentally spill acid on the floor, rug, or furniture, the best thing to do is to run for the ammonia bottle as quickly as you can, and douse the acid with it. Sulphuric acid is very destructive, and is also dangerous;

pure sulphuric acid may give you very serious burns if you are not careful. Pure acids are not used in batteries or rectifiers, but they are mixed with water. In this state they are not quite as dangerous, but it is best to be very careful. If you should get some acid on your hands, apply ammoninum hydroxide, or bicarbonate of soda immediately. This will take care of dilute acid all right, but you are in for a lot of trouble if you get pure acid on your skin. Fortunately, it is never necessary for you to use pure acid, unless you should some day go into the battery charging business. As we said before, the acids you will use are generally diluted in water.

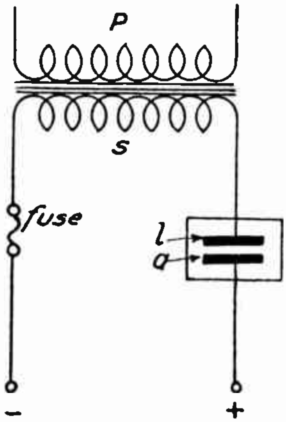


Fig. 8 — Diagram of a Charger Using Electrolytic Rectifier.

Now, before we go into the subject of battery eliminators, you should learn something about batteries.

CHEMICAL CELLS

Look at Figure 10. Here we have shown a very simple form of cell. It consists of a copper plate and zinc plate. These two are placed in a solution called an *electrolyte*. The copper plate and the zinc plate are called electrodes. In this simple cell the electrolyte is salt dissolved in water. Ordinary table salt will do the trick very well, but it has been found that a salt known as *sal ammoniac* is better. When such an arrangement is set up, it is found that the copper plate becomes positively charged and the zinc plate becomes negatively charged. We could connect to this cell then, as we see in Fig. 11, any kind of a circuit through which a current can

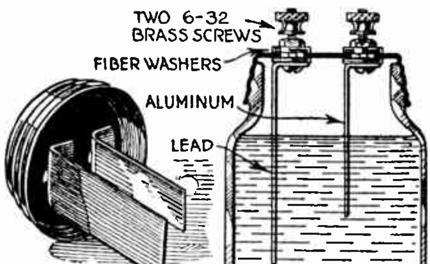


Fig. 9—Electrolytic Rectifier.

flow. The circuit shown, consists of a resistance R and the filament of an electron tube F.

The instant we connect a circuit to the cell, a chemical action starts in the cell, and it is this chemical action which furnishes the electric power which the circuit takes from the cell.

Now, since we have the chemical energy of the cell continually being changed into electrical energy while the circuit is connected, there must be an end to it sometime, when the chemical energy of the cell is all used up. This actually happens. The chemical energy is furnished by the salt and the metals. So when these are used up, we cannot obtain any more energy from the cell. The zinc electrode and the salt in the electrolyte combine chemically; the zinc is gradually eaten up by the salt solution. After a while, in order to make the cell continue working, it will be necessary to replace the zinc electrode and the electrolyte. This is what we have to do with "wet cells," which are merely glass jars in which we place the carbon and zinc electrodes and the sal ammoniac electrolyte.

RADIO BATTERIES

"Dry cells," such as we use to opérate radio receivers, work in the same way. There is a carbon and a zinc electrode in each cell. As a matter of fact, a zinc container takes the place of the glass jar. This is shown in Fig. 12. The electrolyte is not now a solution, but rather a paste. It is made in the form of a paste so that it holds the liquid and does not leak. After the cell is put together, the whole thing is sealed at the top with pitch or sealing wax, so that the liquid will not evaporate and allow the paste to dry out.

This is the way in which ordinary dry-cells are made: "B" batteries are made the same way, a number of these small dry-cells being connected together and the whole outfit being enclosed in the same cardboard box. See Fig. 13. With care, "B" batteries should last quite a long time, especially if the receiver which they are to operate is well designed. But we must be careful to not make them furnish currents of more than perhaps 40 milliamperes, for if we do, the batteries will not last very long. This fact must be carefully remembered, especially when power tubes are used in the radio receiver. When these are used, be sure that the proper "C" battery voltage is applied, for it will be remembered that the "C" battery keeps down the current in the plate circuits of the tubes.

There are other things used in the construction of dry batteries which we have not mentioned, and we will not study now; we will learn about these things when we come to study batteries in detail, in a later lesson. The things we have spoken of above are the main things to be remembered in connection with all batteries.

In the *construction of a cell of a storage battery, we have two electrodes and an electrolyte.* The storage battery which is mostly used today is the *"lead"* battery, because the plates (or electrodes) are made of lead. One of these plates is coated with a chemical called *lead peroxide*, while the other plate is a spongy lead. The electrolyte is a solution of *sulphuric acid* in water. The chemical action going on in the cells changes the coating of lead peroxide into lead sulphate, just as the chemical action in the dry cells changes the chemicals in that type of battery. The action is very much the same. In the dry cells, however, the electrodes and electrolyte are so cheap and easily obtained that we rarely ever try to *recharge* the cells, or renew the electrodes and the electrolyte. We simply throw away the worn out dry cells and buy new ones.

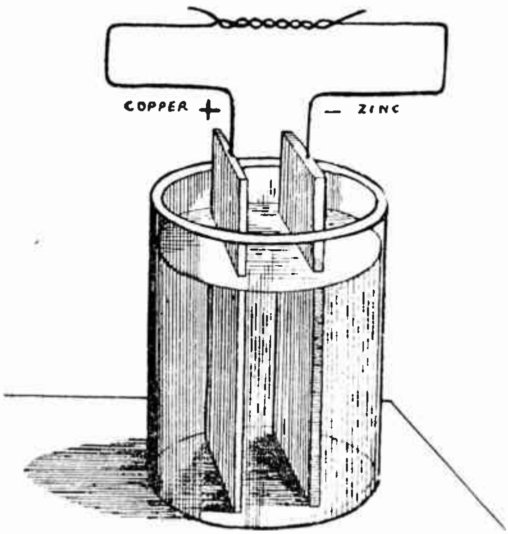


Fig. 10—Simple Chemical Cell. Two or more of these cells joined together would be a battery.

The lead plate storage batteries are expensive, however, so instead of throwing them away when they are worn out, we put them into good condition again by reversing the action, that is by charging them, either at a charging station or by using the house current and a rectifier. When the battery was being used, you will remember, the chemical action caused the lead peroxide to change into lead sulphate. Now, when the battery is being *charged,* this lead sulphate changes back into lead peroxide again.

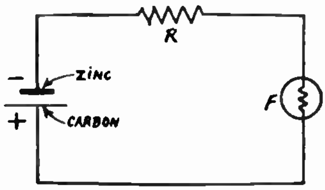


Fig. 11

The electrolyte does not have to be removed very often, however. If the battery is in good shape, all that the electrolyte loses is water, and this is certainly cheap enough. It loses the water by evaporation. But it does not lose the acid. So in using a storage battery, we must be careful to look at it about once every two weeks, to see if it needs any water. If we can see the plates (or electrodes) sticking up out of the electrolyte, it is time to add water. The electrolyte should

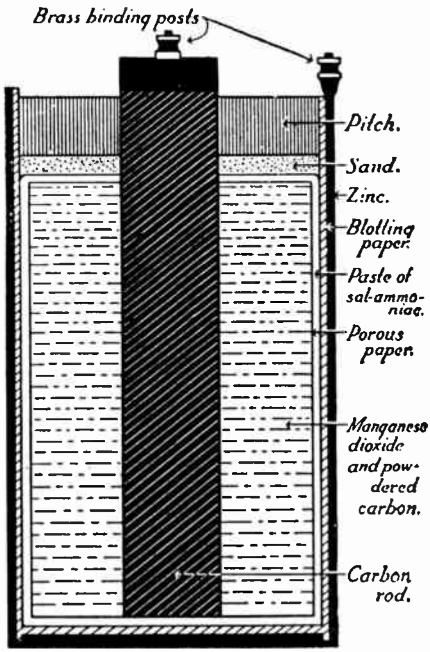
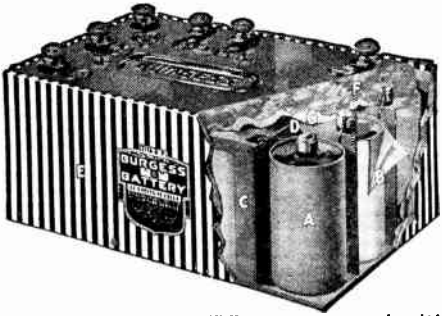


Fig. 12—Cross-Section View Showing Inside of a Dry Cell.

always cover the plates completely by about a quarter of an inch. And be sure to remember, never use any kind of water but *distilled water.* Never mind what your friends tell you; they may use water out of the hydrant, but sooner or later they are going to spoil the battery by having a lot of *sediment* or dirt collect at the bottom of the battery.

Next we must learn how to connect batteries to the radio receiver. As you have already learned, it is necessary to have several different voltages for the different parts of the radio receiver. For instance, the voltage often used on the



"A" One-piece seamless zinc can.
"B" Moisture-proof wrapper.
"C" Sealing material between cells.
"D" Waterproof partition between cells.
"E" Heavy waterproof non-metallic insulating material.
"F" Heavy triple seal over the top.
"G" Webbing between seals.

Fig. 13—22.5 Volt "B" Battery, used with Vacuum Tube Receiving Sets. The Battery Consists of a Number of Small Dry Cells Connected in Series.

radio-frequency amplifier is 67½ volts, on the detector 45 volts, on the first audio-frequency amplifier 90 volts, and often on the second audio-frequency amplifier 135 volts. And finally, as you already know, we usually have to have a voltage of 6 volts to light the filaments of the tubes.

You have also learned something about the amount of current that must be furnished by these batteries. If we have a six tube receiver, each filament taking a current of ¼ ampere, and all these filaments are connected in parallel, as is usually the case, it is clear that the total current taken from the 6 volt battery is 6 x ¼ or 1½ amperes. Therefore the battery which lights the filaments must be capable of furnishing a current of that amount. As we have said before, we cannot expect the small cells to furnish this current as they would not last long. So as a rule we use a storage battery to light the filaments of the tubes.

Fig. 14—45-Volt "B" Battery.

Now, as to the "B" batteries. These are generally made in "blocks" of 45 volts each, and the middle of each block has a separate connection to the batteries, so that we can use either half of the cells in the block, thereby obtaining 22½ volts, or we can use all of them, obtaining 45 volts. This is illustrated in Fig. 14. The negative (—) terminal is at the one end of the block; then there are 11 cells connected in series, giving a total of 16.5 volts for the first tap. (Each cell gives 1.5 volts and 11x1.5 = 16.5 volts). Then we have another cell connected in series with the 11 others. This gives us the 18 volt tap. Another cell added in series gives 19.5 volts, another cell in series gives us 21 volts and still another cell in series gives us 22.5 volts. In other words, we use 15 small cells in the "B" battery block to give us the 22.5 volts. After the 22.5 volts tap there are 15 more cells added in series,

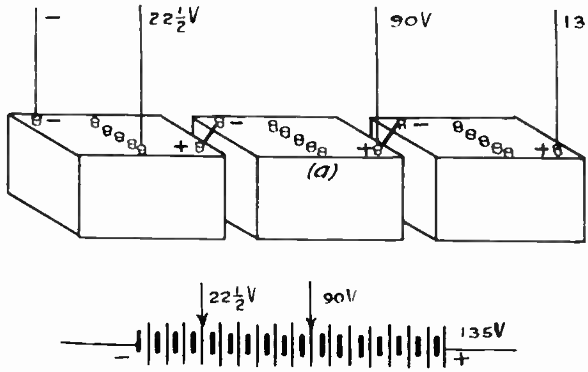


Fig. 15—Three 45-Volt "B" Batteries, Showing Taps Taken Off for 22½, 90 and 135 Volts.

making a total of 30 cells, which gives 45 volts as the total voltage of the block. The reason why the 16.5, 18, 19.5, 21, and 22.5 volt taps are furnished is that many detectors are operated on voltages of about those amounts. These taps are furnished so that we can pick out the exact voltage which makes the detector work best.

But this only gives us 45 volts; we really need 90 volts and 135 volts. How are we going to get all this? The answer is simple; merely connect together several of these 45 volt block, in series. Two of them in series will give 45 + 45 or 90 volts, and three in series will give 45 + 45 + 45 or 135 volts. The diagram of connections is given in Fig. 15, with the schematic way of representing it. It must be clear to you that there are other combinations of voltages that you can use. For instance, if we wanted to operate our radio-frequency amplifier tubes on 67.5 volts, we would connect them to the tap marked (a) in Fig. 15.

The connections of the "A" battery, that is, the storage battery, are very simple. An ordinary 6 volt storage battery is shown in Fig. 16. It consists of 3 cells, each cell furnishing 2 volts, so that 3x2 gives us six volts for the complete battery. One terminal of the battery is marked + (positive) and the other terminal is marked — (negative). We simply connect the binding post on the set marked + to the plus terminal of the "A" battery, and the – binding post on the set to the — terminal of the battery.

This will be sufficient about batteries for the present. As we have stated before, we shall study batteries quite in detail in a later lesson. But before we leave the subject, it may be well to mention that "C" batteries are exactly the same as "B" batteries in construction, excepting that they are smaller.


Fig. 16—Cross-section of Lead plate Storage Battery.

Next we go on to the subject of "B" battery eliminators.

BATTERY ELIMINATORS

The simplest kind of "B" battery eliminator is that which can be used in districts where the house lighting circuit carries *direct current*. This is the same kind of current that the "B" batteries furnish, so the problem is mainly to obtain the proper voltages from the house lighting system. The voltage of the system is 110 volts or thereabouts. This voltage can be used for operating the audio-frequency amplifiers without change.

Besides this voltage for the audio-frequency amplifiers, we need a much lower voltage for the detector, 22.5 or 45 volts, and a voltage of about 67.5 volts for the radio-frequency amplifiers. The problem then is to get these other voltages. This can be solved in a manner similar to the way in which we solved the problem of the direct current charging circuit for charging storage batteries. We can place resistances in series with the line and the receiver, and so adjust these resistances as to furnish the voltages which we require to operate the set.

Suppose you look at Fig. 17 for a moment. This will explain the method very easily. First we have to find out how much resistance is required in the connection which goes to the R. F. amplifier (R. F. is an abbreviation for radio-frequency). Next we have to know how much current the radio-frequency amplifier tubes take. As a rule this should not be high; we may assume that about 5 milliamperes is the most they will take in a well designed receiver. Suppose also that the receiver is designed to have the R. F. tubes operate with

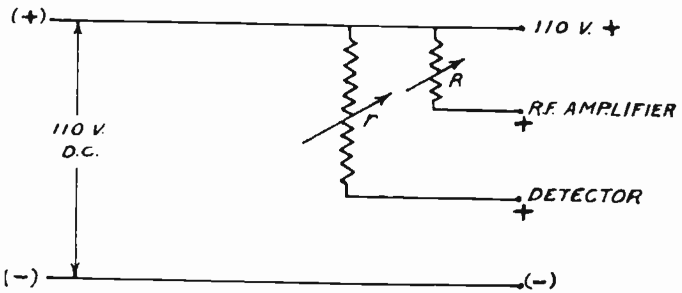


Fig. 17—Illustration Showing How Various Voltages are Obtained From 110 Volt D. C. Line.

67.5 volts on the plates. This is all the information we need in order to find out how much resistance we need at R in Fig. 17.

Now to begin. Since we have an impressed voltage of 110 volts and we need only 67.5 volts, the resistance must be of such a value that it makes up for the difference. This difference is

$$110 - 67.5 = 42.5 \text{ volts} \qquad (2)$$

In other words the resistance must use up that amount of the voltage. Now, if this is so, then knowing what current it must carry, we can find the value of the resistance by the old rule:

$$\text{Ohms} = \text{Volts} \div \text{Amperes} \qquad (3)$$

The resistance must carry 5 milliamperes. A milliampere is 1/1000th of an ampere, so that 5 milliamperes is

5/1000ths or .005 of an ampere. Therefore, the resistance required is

$$R = \frac{42.5}{.005} = 8500 \text{ ohms} \qquad (4)$$

Next we must find the resistance to be placed in series with the detector tube. This tube will rarely take more than about 2 milliamperes, or 2/1000ths or .002 of an ampere. Let us suppose that this tube is to be operated with 45 volts on its plate. Then the voltage drop required in the resistance is given by

$$110 - 45 \text{ or } 65 \text{ volts} \qquad (5)$$

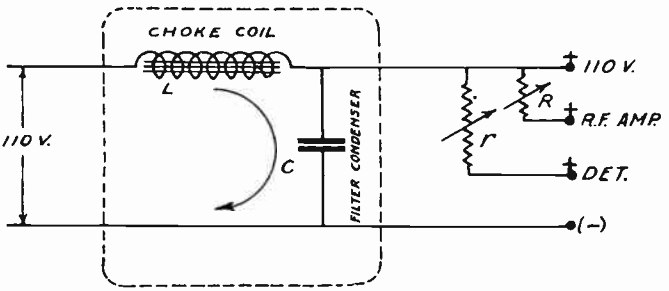


Fig. 18—One Section Filter Arrangement for 110 Volt D. C. Line.

This much voltage must be used up in the resistance *r* in Fig. 17. The value of the required resistance can be obtained the same as above, that is

$$R = \frac{65}{.002} = 32{,}500 \text{ ohms} \qquad (6)$$

It is practically impossible to buy resistances which have these exact values, so the way we do it is to buy *variable* resistances. These resistances come in *ranges* anywhere from zero to 150,000 ohms and upwards; that is, it is possible for us to adjust them to any value we want, or to any value which may work best. Therefore the problem is greatly simplified for us when we use variable resistances, and simply adjust them by *trial* until we find the adjustments that make the set operate best.

So what was thought a big problem at first turns out to be a simple problem after all; our great problem will be tackled next. As you probably know, the power which the electric company sends into your home or your shop, which furnished your power for lighting purposes, is generated in a dynamo at the company's power station. In this dynamo there are various things going on which make the current slightly irregular. Why and how this happens we shall learn in a later lesson. At one instant, there is a sudden but slight jump or increase of current. Next there is a sudden but slight decrease. And these jumps or irregularities do not follow each other in any regular order. They are very small jumps, so small that you can not notice the effect in the way your incandescent lamps light up. But they are there, nevertheless, for when we try to operate such an extremely sensitive thing as a radio receiver on such a power supply, we can constantly hear an annoying noise in the loud-speaker. So, as far as our "B" battery eliminator is concerned, it will not work in the

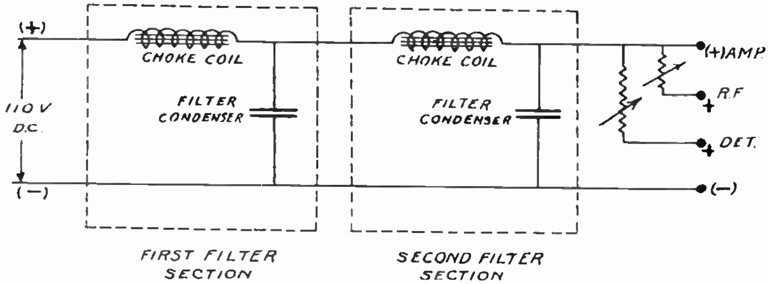


Fig. 19—Two Section Filter for 110 Volt D. C. Line.

simple form shown in Fig. 17. We must modify or change this arrangement in some way, so as to get rid of this noise, which is due to the variations in the generator.

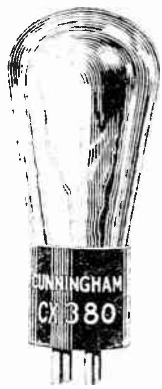
As you recall, sometime ago, when we were learning about condensers and coils, we explained how the coil tries to keep up the current when it is decreasing, and how it tries to hold it down when it is increasing. We also explained how the condenser acts in just the reverse manner. It tries to increase the current further when it is increasing, and to decrease it more rapidly when it is decreasing. It seems, therefore, that some good might come if we should connect a condenser and coil in the circuit of Fig. 17, as this might cut out the noise or the hum. This is exactly what we have done, as is shown in Fig. 18.

In this figure we have connected a very large coil in series with the 110 volt line, and have connected a very large condenser across the line. The large coil tries to slow down the slight changes in the current, and the small changes that do get through the coil are hurried up by the condenser. The condenser, therefore, acts partly as a *short circuit* for these *ripples,* as the variations of current are called. It enables what little ripple is left after the greatest part has been ironed out by the coil, to return to the generator in the direction of the arrow, so that hardly any of the ripple can go as far as the radio receiver.

The large coil marked L is called a *choke* coil because it "chokes" out these ripples. The condenser marked C is called a *filter condenser.* The whole arrangement enclosed by the broken line in Fig. 18 is called a *filter,* because it "filters" out the ripples. Figure 18, therefore, represents a complete "B"

Half-Wave Rectifier Filament Type

Full-Wave Rectifier Gaseous Type



Full-Wave Rectifier Filament Type

Fig. 20—These Three Pictures Illustrate the Appearance of Rectifier Tubes Used in Power Units.

battery eliminator, which can be used when the house lighting system is operated on *direct current. It cannot* be used with *alternating current.*

Sometimes, when the ripple is very bad, that is, when the variations of the current are rather large, the filter of Fig. 18 may not be sufficient. When this is the case, it is necessary either to use a larger choke coil and condenser, or to use *two filter sections.* Such a circuit is shown in Fig. 19, where the separate filter sections are enclosed by broken lines.

After all, the problem of the eliminator to be used on direct current systems is a small one. The next problem is to devise an eliminator which will supply direct current without a ripple, when it is operated on alternating current. Let us suppose that we have a source of direct current which has quite a large ripple in it. It makes no difference where we get it, we can always apply to it the filter system of Fig. 19, and finally get the ripple out of it. Of course we may have to use very large choke coils and condensers, but at least we can do it. The problem that remains is to find a means of changing the alternating current into at least some form of direct current.

Fig. 21—Picture of a Typical "B" Eliminator.

You remember that not long ago we learned about rectifiers? Remember how in one of these rectifiers, which are used for charging batteries, we used a tungar bulb which allowed the current to pass through it in only one direction? When the current tried to pass in the other direction it was blocked. So what we actually got out of the bulb was not a constant current, but a *pulsating* current. It would flow for an instant, say 1/120th of a second; then the next 1/120th of a second it would not flow. The next 1/120th of a second it would flow again, and in the same direction as before. So we have a current which flows in "jerks" or "spurts."

The tungar bulb will not operate well on the higher voltages needed for the plates of the electron tubes. It works only on low voltages such as are used for charging storage batteries. However, there are other tubes available, such as the Raytheon and filament types, which act in a different manner, but produce the same effects. They can furnish a pulsating current always in the same direction, when supplied with alternating current.

The Raytheon tube consists of three electrodes in its simplest form, one of these electrodes being rather large, and the other two, small. There is helium gas inside the tube. The current can flow only from the small electrodes to the large one, just as in the tungar bulb the current can flow only from the anode to the filament or cathode.

Figure 22 shows a typical circuit of a "B" eliminator. The transformer has impressed on one winding (the primary) the voltage of the house lines. It is so designed as to deliver from its secondary winding a voltage of somewhere about 450 volts. This is the voltage at which one type of Raytheon tube operates satisfactorily.

The particular Raytheon rectifier tube which is used has *one* large electrode and two small ones. In order to explain how it operates, suppose that at a certain instant the current is flowing in the transformer secondary in the direction of the arrow F. Now remember that the current can flow only from the small electrodes to the large one. Therefore the current can flow from A to B, and will then pass around the circuit in the direction of the arrow D and the arrow E, back to the center tap of the transformer.

Now suppose the next instant the current in the transformer secondary reverses, or flows in the direction of the

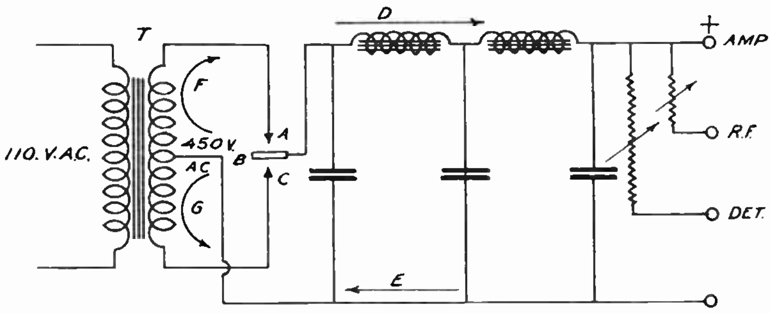


Fig. 22—Complete Circuit Diagram of "B" Eliminator.

arrow G. Then the current can flow through the tube only from C to B, and will travel around the circuit in the direction indicated by the arrows D and E.

At one time we are using the voltage in the upper half of the transformer secondary and the electrodes A and B of the rectifier tube. At the other time, we are using the lower half of the transformer secondary winding and the electrodes C and B of the tube. In each case, however, it will be noted that the current always flows through the filter sections in the same direction, and consequently, after the ripple is filtered out, we shall have more or less pure direct current on which to operate the receiver.

The rectifier tube, which we have been discussing in the previous paragraphs, is the Raytheon type of tube, also known as the *cold cathode* rectifier, because the cathode, or large electrode is not heated. This is the electrode marked "B" in

Fig. 22. On account of this fact, it is necessary to introduce into the tube a gas which can be made capable of conducting electrons from one electrode to the other when the voltages applied to the tube are quite small. Let us first refresh our memory on the nature of an alternating current. Look at Fig. 23. This represents a wave of alternating current.

An alternating current or voltage is one which at a certain instant has a value of zero. Then, as time goes on, current begins to flow in a certain direction in the circuit, which we will call for convenience, the *positive direction,* and continually increases until it assumes a maximum value. Then it begins to decrease in value until it becomes zero again, after which it begins to flow in the opposite (or negative) direction, increasing in this direction until it again attains a maximum, and once again decreases to zero. In commercial alternating

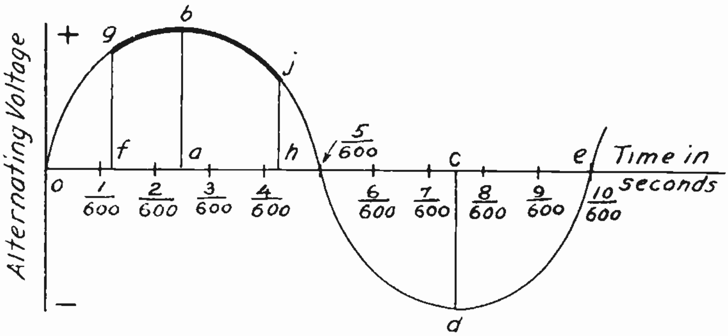


Fig. 23—An Alternating-Current Curve.

current circuits, this cycle of events is accomplished in 1/60th of a second, whence we call this a 60 cycle current or 60 cycle voltage.

In Fig. 23 we have shown this whole cycle in the form of a curve or graph. The divisions marked off horizontally represent 1/600th of a second of time, so that 10 of these divisions represent 10/600ths of a second, or 1/60th of a second. The height of this curve at any point above or below the horizontal axis represents the voltage at any instant. For example, between 2/600ths and 3/600ths of a second after the start of the cycle, the voltage has its maximum, say 110 volts, indicated by the length of the line ab. Being above the horizontal line, we say the voltage at this instant is in the positive direction. Between 7/600ths and 8/600ths of a second after the start of the cycle, the voltage is again maximum, but this time it is in the negative direction, indicated by the line ed, Fig. 23. At the instant 5/600ths after the start of the cycle the voltage is zero; likewise at the end of the cycle, as at e.

Now, in the *cold cathode* type of rectifier, or the Raytheon tube, a certain voltage is required in order to *ionize* the gas within the tube, or to make it capable of conducting electrons. Therefore, at any time when the voltage is less than this, no

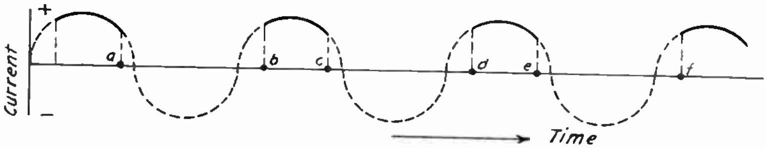


Fig. 24—A Rectified Alternating Current.

current can flow through the tube. So, starting at the beginning of the cycle, as at O, Fig. 23, the voltage is zero, and the gas is not ionized. As time goes on the voltage increases, but still the gas does not become ionized until a certain critical voltage has been reached, which has the value, let us say, indicated by the line fg in Fig. 23. During the part of the

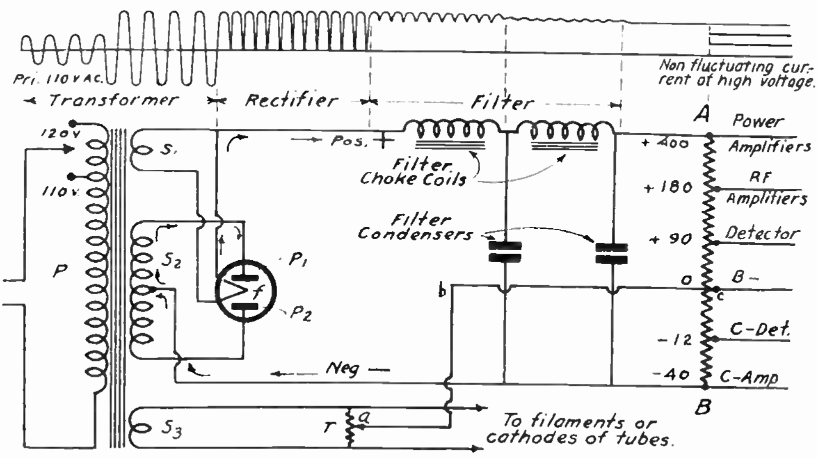


Fig. 25—Schematic Diagram of a Full-Wave Rectifier Power System.

cycle when the voltage is greater than this critical value, current will flow through the tube for the gas remains ionized, but when the voltage has decreased to a certain value again, the gas ceases to be ionized, and current ceases flowing. The voltage at which it ceases flowing is slightly less than the voltage at which it starts flowing, for it is easier to maintain the ionized condition than it is to start it. Hence the *cut-off* *voltage,* as we call it, is less than the ionizing voltage, which is indicated in Fig. 23 by the fact that the point j is lower than the point g.

Of course, when the voltage is reversed no ionization can occur at all, regardless of the value of the voltage, so that current flows through the tube only during the short interval of time occurring between f and h in the figure. So you see, we have a pulsating current, which flows only for a short time during each cycle, always in the *positive direction,* and which is repeated from one cycle to another. The heavy part of the curve in Fig. 23 has this current varying with time during a single cycle. In Fig. 24 we have indicated the nature of the current over a number of cycles. It is clear that this is a pulsating current, since no current flows during the intervals of time ab, cd, ef, and so on.

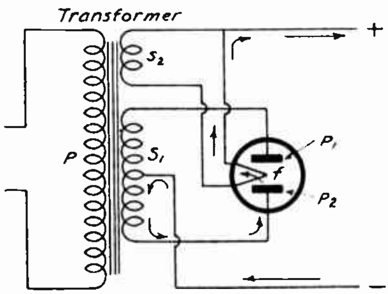


Fig. 26.

On account of this, for reasons which we shall learn later, it is a little difficult to properly filter out the noise or hum in circuits which use the cold cathode, gas filled rectifier. For this reason, the *hot cathode* type of rectifier is now used. This type of rectifier does not rely on the ionization of a gas and does not have critical voltages. Furthermore, current will flow through the tube during the complete half-cycle, the value of the current being simply dependent upon the value of the voltage impressed on the tube.

The *hot cathode* type of rectifier, just like the Raytheon, consists of a cathode and two other electrodes, but this time the cathode is a filament which can be heated by an alternating current passing through it. Figure 20 shows one of these tubes, known as CX-380. The tube has no gas in it, and it operates just like the other electron tubes we have studied previously. When the cathode is heated it emits electrons, and when one or the other of the additional electrodes is charged positively, it attracts the electrons to it and a current flows through the tube. Figure 25 shows the circuit arrangement. The primary "P" of the transformer is connected as usual to the house lighting circuit. The two windings going to the rectifier tube from the secondary side of the transformer, winding S_1 supplies the high voltage, which is to be rectified, and the winding S_2 supplies the alternating current for heating the filament (or cathode) f of the rectifier. The ends of the winding S_1 are connected to the two plates of the tube. The filament, being heated, emits electrons; during one-half the cycle the plate P_1 is positive, so that the current flows through the circuit in the direction indicated by the various arrows. During the other half of the cycle the plate

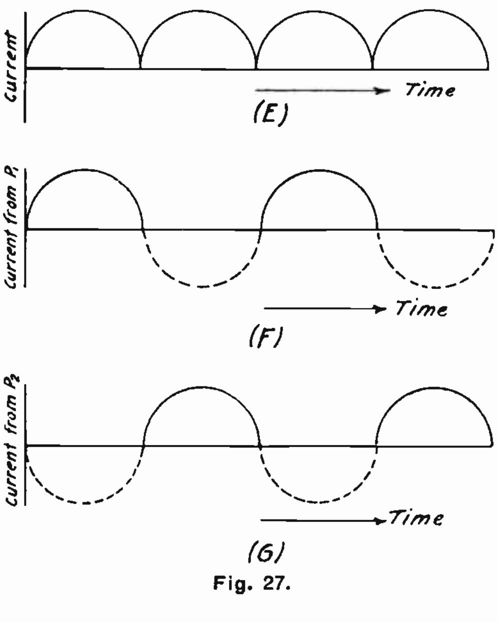


Fig. 27.

P_2 is positive, so that the current now flows in the direction indicated by the arrows in Fig. 26. In each case, you will notice, the current flows out of the rectifier and into the radio receiver at the + (plus) terminal, showing that our current is now unidirectional; that is, it always flows in the same direction. It, however, is not a constant current, but has the wave form indicated by the curve in Fig. 27-(E). Since current flows from each plate to the filament during only one-half the cycle, it is clear that Fig. 27-(E) is obtained by adding together the current waves of the two plates, shown in Figs. 27-(F) and 27-(G).

We have now found a means of obtaining a fairly constant direct voltage by means of which we can operate our radio receiver. It remains now for us to find a means of supplying current to the filaments of the electron tubes, so that we can dispense with the storage battery. This has been accomplished by designing tubes just for this purpose, and by adding other windings to the transformer for supplying the filament current.

There are several ways of obtaining the "C" voltages for the receiver, but for the present we will consider the rather simple method shown in Fig. 25. The output of the rectifier, after passing through the filter, sends current through a high resistance AB, which is variously known as the *output resistor* or *bleeder resistor*. Note that this is a different arrangement from that shown in Fig. 17. Many arrangements and combinations are possible.

There is a voltage of, let us say, 440 volts across the terminals of this resistor. If we require a "C" voltage of —40 volts on the grid of the power amplifier tube, we can call the lower terminal —40 volts. Then, 40 volts above this on the resistor wil be the B— connection, which goes to the cathodes of filaments of the tubes. If we are using a "C" bias detector, perhaps we need a bias of —12 volts on its grid. Then this connection is 12 volts down from B— on the resistor. For simplicity we have marked the B— connection as being at zero potential. Then the plate voltages are plus and the "C" voltages are minus. Various other connections can be made to the resistor, depending upon the voltages we require in the radio receiver. Several voltage taps are shown in Fig. 25. Bear in mind that many combinations of voltages may be used, depending upon the types of tubes used and the particular design of the set.

Before concluding this lesson there remains one thing to be pointed out. That is, when current flows from the output resistor to the plate of any tube and then to the cathode or filament of that tube, it must get back to the B— connection of the output resistor. In Fig. 25 we have shown the cathodes or filament connected to the transformer winding S_3, which supplies the alternating current for heating the cathode. We must therefore show a connection between this winding and the B— tap on the output resistor. This connection is generally made by placing a resistance r across the heater winding, as it is called, and connecting the midpoint of this resistance to the B— tap. This is the connection abc in Fig. 25.

We have now arrived at the end of our "bird's-eye view." By this time you have become acquainted with the fundamental ideas of radio. It is no longer a mystery to you, as you have learned that it is the result of a long period of development. They are the same as the fundamentals of electricity, which were learned years ago. Radiotelegraphy and radiotelephony are highly specialized branches of electrical engineering.

TEST QUESTIONS

Number your Answer Sheet 6—3 and add Your **Student Number**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What amperage should be used for charging a 6 volt storage battery at home?
2. Draw a diagram showing how to charge a storage battery from 110 volts D. C., using lamps in parallel for resistance.
3. What is the purpose of the ammeter shown in Fig. 4?
4. Name the three types of rectifiers or chargers mentioned in this lesson.
5. Draw a wiring diagram of a Tungar charger, naming the three principle parts of the charger.
6. Name the parts used in the two electrolytic chargers described in this lesson.
7. Of what is a dry cell made?
8. Describe the construction of a lead storage cell.
9. What is the purpose of the filter used in a battery eliminator?
10. Draw a complete circuit diagram of a Raytheon tube B-eliminator, showing all choke coils and condensers.

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HAVE A NEAT DESK

A Personal Message from J. E. Smith

A neat desk and a neat set of lessons indicate a neat and orderly mind. A neat personal appearance is a well-known business asset. Neatness counts in study. If your work is neat and orderly, the instructor is prejudiced in your favor. The work may be of poor quality but if it is neat, you will receive a higher grade. On the other hand, work of high quality but put up in a "sloppy" manner will not receive the mark it would otherwise deserve. This factor of neatness in mental work is a business asset as well. Nobody wants a set of blotched lessons.

What are the factors in neat work? In writing up your lessons, there are several that contribute to neatness: (1) Use only clean pens. Pens that are dirty or rusty are sure to leave a blotched page. (2) Use only smooth ink of good quality. Poor ink is sometimes responsible for a bad looking page. (3) Keep plenty of blotters on hand and use them freely. Do not try to make one blotter last you a life time. When it gets full of ink, throw it away and get a new one. (4) Do not erase unless you have to. (5) Do not "ride your pen." The pressure exerted on a pen makes a great deal of difference in the looks of the page. The neatest page is obtained by a moderate and constant pressure. (6) Dirty fingers are often the cause of dirty papers and "messy" work.

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FUNDAMENTAL D. C. THEORY

We have now finished our "bird's-eye-view" of radio. The first six lessons of this course were written as a "bird's-eye-view" so that you would be able to grasp the whole meaning of radio in a very short time. These first six lessons gave you a clear idea of what it is all about; of course, you may not be able to design radio receivers as yet, but at least you are in a position to understand what you hear and read about in radio. Radio is no longer a mystery to you. You have learned that it is a genuine product of hard work, in research and design, and more of the development of radio can be ascribed to this than to so-called "inventions."

The foundations of radio were laid down, not by "radio engineers" but by teachers and students of electricity and physics. As we look back into the history of science during the past hundred years or so, and at the same time keep our eyes on radio as it is today, we will find that radio was made possible by such men as Maxwell, Hertz, Michael Faraday, Prof. Henry, Prof. Ohm, and a host of others. But strange to say, most of these men knew nothing of radio or at least of radio used as a means of communication. Faraday and Maxwell, for instance, developed, mathematically, the theory of radio waves, but, of course, they did not call them "waves." They gave them other names. Furthermore, they did not produce these waves in the laboratory.

Maxwell, as another instance, showed that it ought to be possible to create a certain kind of wave motion from the discharge of a condenser, and he showed mathematically that these waves ought to be very similar to, if not the same as, light waves. And to go farther, he gave to us many of the laws of these waves.

But Maxwell, as we have said before, did not demonstrate the existence of these waves practically. He may have been sure that when he discharged a condenser that there were such waves being generated, but he had no means of showing that they were there. It remained for Prof. Heinrich Hertz of Germany to give the practical demonstration. Hertz transmitted and received electric energy over distances of a few feet or a few yards; he generated the waves from a discharge of a condenser, and showed that they were present when he held a small broken ring of copper where the waves could pass through it. When the waves were being generated, a small spark took place at the break in the ring.

We shall not go into Hertz's researches, for they are mainly of historical interest. Nevertheless, it is surprising how much of radio, as we know it today, is the result of work done a long time ago, and it is equally surprising how much of radio which seems new to us is really fairly old.

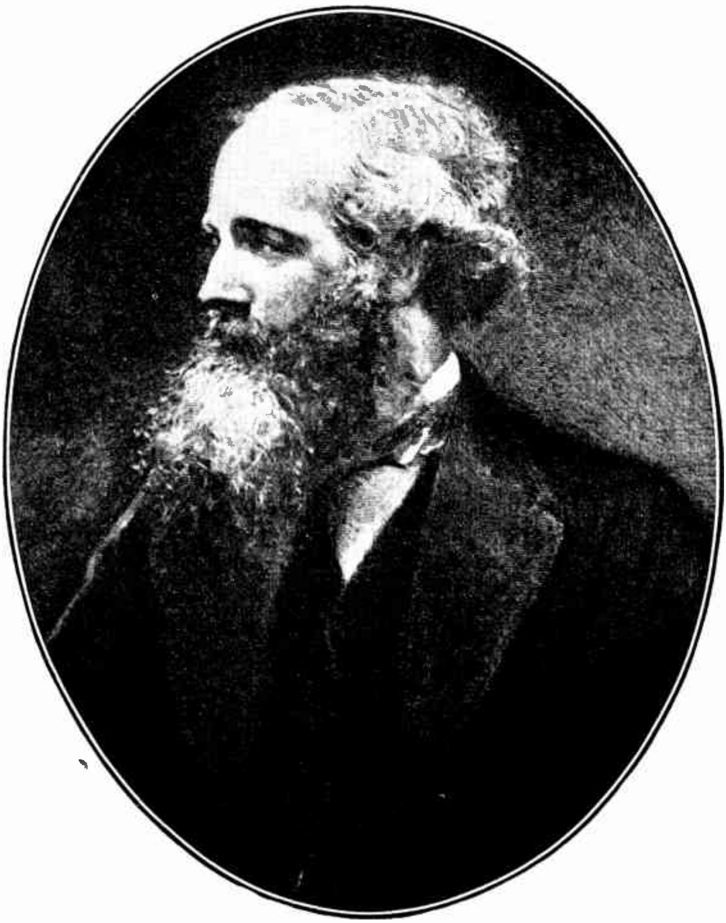
But the point we wish to bring out here is that radio, as we know it, owes its existence to men who worked on problems which may seem to have no connection with radio. But think a minute, and remember that radio works by **electricity** and that in order to know radio **we must also know the laws of electricity. It is the laws of electricity which we shall begin to study in this lesson.** In this lesson, and in the next, we will not deal with radio proper; we will deal with "Electricity," and we will learn the laws of electric charges, and of electric currents. Then, after we have gone through this period of our study, we will be in a position to study radio waves themselves, and will learn in great detail all the things which we could not put into our "bird's-eye-view."

Many of the laws governing electricity are as simple as A, B, C. You can learn them without much difficulty, and, once learned, they will stay with you because the subject is so intensely absorbing.

STATIC AND DYNAMIC ELECTRICITY

There are two kinds of electricity, **static** and **dynamic.** The electricity that flows through the electric light wires in your home is called **dynamic or current electricity.** Current electricity is the electricity of the workaday world. It is generated in batteries and dynamos. When you see Vacuum Tubes in a radio receiver, an electric light, an electric motor, a door-bell, or other electrical devices that we use today, always remember they are operated by current electricity.

Now, there is another kind of electricity that is known as **static electricity.** If you will refer to the dictionary, you will find that static means "to remain at rest." It is only in very rare cases that static electricity is used in the workaday world. Static electricity is that which sparkles in your hair on a cold winter morning when you comb it with a rubber comb. When you come too close to a rapidly moving leather belt, a spark is apt to jump off and give you an unpleasant shock. This is static



James Clerk Maxwell, in 1863, formulated the theory that the discharge of a condenser across a spark gap sets up disturbances in space which traveled at the same speed as light.

electricity. We might say that static electricity is "tramp" electricity, because it refuses to work.

Tremendous charges of static electricity accumulate in the clouds as they burst to earth with a terrific roar. That is lightning, which is made up of billions of little charges of electricity.

Let us keep these facts in mind:

1. Current or dynamic electricity is electricity in motion.
2. Static electricity is electricity at rest.

STATIC ELECTRICITY

Electrostatic charges, or electric charges, as they are frequently called, may be produced by rubbing a glass rod with silk, or by rubbing a rod of sealing wax with flannel. The rubbing operation causes the rod in either case to be electrified.

The development of radio waves greatly increased the need for a more intense study of static charges. Small charges which accumulate on a short length of small wire such as the filament of a vacuum tube, the connecting wires between different parts of apparatus and also the charges which may accumulate or be induced on metal surfaces, such as the grid and plate of a vacuum tube, become of vast importance in the design and operation of both transmitting and receiving sets in connection with short wavelengths which are fast becoming standard practice.

There are **two kinds of electric charges**, to which the names **positive** and **negative** have been applied. The charge developed on glass when it is rubbed with silk is arbitrarily called positive, and that developed on wax, being just the opposite, is called negative. Although only one kind of charge was present on either charged rod, neither charge could be developed without the development of the other. In this case, the opposite charges reside on the cloth with which the rod was rubbed. The piece of silk has a negative charge and the piece of flannel a positive charge. Likewise, if equal and opposite charges are combined, the effect of each is neutralized.

ELECTROSTATIC LAWS

The following laws apply to electrostatic charges:

1. When two dissimilar unelectrified substances are rubbed together, one assumes a positive and the other a negative charge.
2. An unelectrified body on coming in contact with an electrified body becomes electrified with a charge similar to that on the electrified body.
3. Similarly charged bodies repel each other. Dissimilarly charged bodies attract each other.

Figures 1 and 2 illustrate the action of unlike and like charges.

DYNAMIC ELECTRICITY

Electric Current. There is no subject in the world of greater interest than current electricity. We are going to learn something about this great force now.

Heinrich Hertz, who is recognized by all as the real founder of present-day Radio communication. These Radio waves are sometimes called Hertzian waves.

An electric current is a flow of electricity, and manifests its presence by the magnetic or heating effect it produces. Just as water can be forced through a pipe and made to do work, so can electricity be forced along a wire and made to do work. The exact nature of an electric current is rather speculative, but according to the electron theory, it is considered that electrons in motion constitute an electric current.

To make matters easy we are going to compare the flow of electric current through a wire with the flow of water through a pipe. That is about the easiest way to get at it. Let us assume that we have water flowing through an iron pipe with an internal diameter of one-half inch. Do not get confused. We are not trying to tell you that electricity is like water; we are merely trying to tell you how easy it is to understand the flow of electricity by comparing it with water.

A long pipe, as shown in Figure 3, is filled with water. The pipe represents a conductor, and the water illustrates the electricity in the conductor. Both ends of the pipe are held upwards on a level with one another, so that normally there is no difference in pressure acting at each end of the tube, and therefore the water will not flow through the tube.

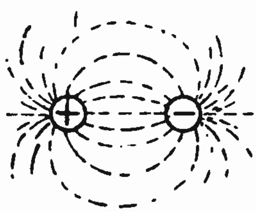


Fig. 1—Attraction of unlike charges.

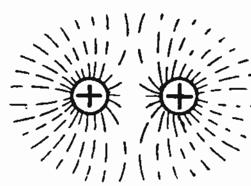


Fig. 2—Repulsion of like charges

If, however, we exert a pressure at one end of the pipe by blowing down it, or by increasing the height of one end above the other, or, better still, by connecting a tank of water to it which is situated at a higher level than that on which the experiment is being carried out, as shown in Figure 4, then the water will immediately flow through the pipe.

By connecting the tank to one end only of the pipe, we exert a difference of pressure on the two ends of the pipe, but if we connect the tank simultaneously to both ends of the pipe, then there is no difference of pressure on the two ends of the pipe, and, consequently, no water will flow through it.

As the water represents electricity, the flow of water represents an electric current.

What will the number of gallons of water per minute passing through this half-inch iron pipe depend upon? You know the answer to this. If you do not, put on your thinking cap. One thing it will depend upon is the pressure, is it not? The higher the pressure of the water, the more gallons we will receive per minute through the pipe. Now, there is another thing that the delivery of the water depends on. What is that? The size of the pipe. The smaller the pipe, the greater the resistance offered to the flow of the water. If we had a larger pipe, the resistance would be less.

Now, for these words that we have heard so often, **VOLTS, AMPERES** and **RESISTANCE.** First, let us say that the pressure of the water in our half-inch pipe represents voltage. We will call the rate of flow gallons per minute, amperage or amperes. Then the resistance will depend upon the size of the pipe.

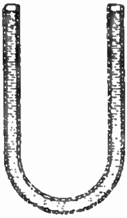


Fig. 3—Water pipe.

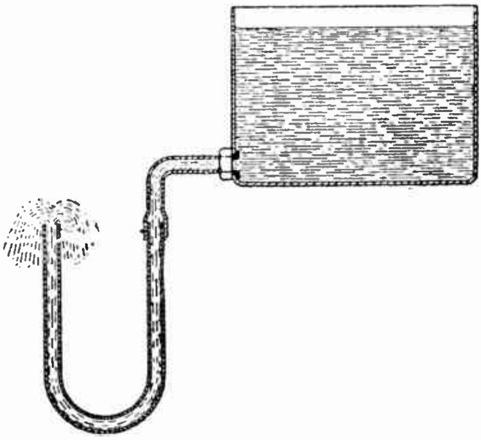


Fig. 4—Water pipe attached to a tank of water

Now, let us assume that we have a wire with a current of electricity flowing through it. The resistance that this wire offers to the flow of the current will depend upon its **size** (length and diameter) and the **metal** from which the wire is made. If we had a very small wire, the resistance would be great and very few amperes would flow through it. If we increased the voltage (pressure) we could cause more current to flow. If we doubled the size (area of cross section) of the wire carrying the current, the resistance would be cut in half, and the current flowing would be doubled.

We must look upon electrical voltage as pressure, the pushing force that causes the amperes to flow through a wire. Remember that the amperage of an electric current is really the current itself, the working force. Resistance is merely that portion of an electrical conductor that tends to hold the current back. Keep in mind the fact that any moving substance, like a block sliding across the floor or a baseball rolling down a hill, meets with resistance. In fact, we meet with resistance in our daily lives. We must keep plugging along. Some of us do not have enough pressure, others have too much pressure and not enough amperage.

The next time you hear some one mention a high voltage current, say, for instance, 10,000 volts, do not jump at conclusions and think this is a powerful source of electricity. Voltage is no measure of electric power, it is only the pressure. We could have a very small pipe carrying water under a terrific pressure, but would that pipe deliver as many gallons of water per minute as a large pipe of water under the same pressure? No, it would not. In the same way, we can have a small electric current with an extremely high voltage. In the ignition system of automobiles, we have an electric current with a voltage of as high as 10,000 volts, but the amperage is small.

What if we had a very small copper wire running from Washington to Baltimore and we wanted to send a current of electricity over this wire? We would have to use a high voltage in the same way that we would have to use a high pressure if we had a very small pipe. As we increased the voltage, we would increase the flow of the current and we would receive more amperage at the opposite end.

Voltage alone cannot do the work. An electric current must have considerable amperage before it is able to turn motors, etc.

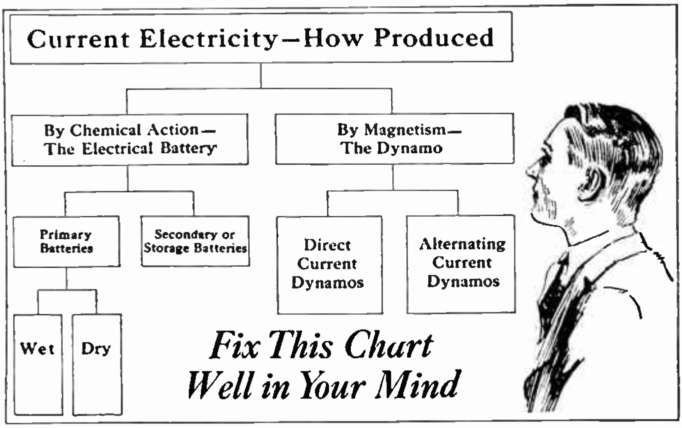
So far, this has been very easy, hasn't it? There is nothing difficult about this subject of electricity. Let us go on. It gets more interesting.

GENERATION OF CURRENT ELECTRICITY

Now that we have learned what current electricity is, we will be interested to know how it is produced. There is no use of us stopping half-way, we have to make a good job of this proposition. In general, **current electricity is produced in two ways, by chemical means and by mechanical means.**

Where any great amount of power is desired, the dynamo is used because it is the most convenient and efficient method of procuring current in large quantities. The word "dynamo," which is the name applied to a machine for generating electricity, comes from the word dynamic and in recent years the Radio Engineer has developed a new type of loud-speaker operating on the principle of the dynamo and is called the dynamic type of Radio speaker.

The chemical method of producing electricity is employed where a small amount of current is all that is required, such as for door-bells, radio sets and laboratory work, etc., or where a large amount is required for only a short time. The Dry Cell and Storage Battery is a familiar example of the chemical production of current on a small scale.



UNITS OF ELECTRICITY

In order to measure and define the different electrical factors of a circuit, certain practical standards or units have been adopted.

The following table has been arranged in a manner convenient for memorizing, clearly showing the particular quality or property which each represents and the relation which one bears to another.

The unit of current is one ampere.
The unit of quantity is one coulomb.
The unit of electromotive force or pressure is one volt.
The unit of resistance is one ohm.
The unit of inductance is one henry.
The unit of capacity is one farad.
The unit of energy is one joule.
The unit of power is one watt.

The **Ampere** is the electrical **unit of flow of electric current.** When a current of water flows through a pipe, the amount of flow can be defined by stating how many gallons per second are flowing; similarly in an electrical circuit, when a current of electricity flows through a conductor, the rate of flow can be defined by stating how many **coulombs** per second are flowing.

The standard method of checking the unit flow of current, the ampere, is measured very accurately by its chemical effect. Thus, a definite amount of a given metal will be deposited by a current when it is passed through a solution containing this metal. Equal quantities of electricity will deposit different amounts depending upon the different metals, but the amount of any given metal is always the same for the same quantity of electricity. Hence, the ampere (international unit) is that unvarying current which, when passed through a neutral solution of silver nitrate, will deposit silver at the rate of 0.001118 gram per second.

The **Coulomb** is the **unit of quantity** and can be compared with the unit of quantity for water, namely, a gallon. If a current of one ampere is allowed to flow past a given point for one second, then a charge of one coulomb has passed that point.

The **Volt** is the **unit of electrical pressure** often described as difference of potential, or electromotive force. It can be compared with the practical unit of mechanical force, namely, the pound. The flow of water, that is, the number of gallons per hour that will flow through a pipe of given length, size and shape, will depend upon the number of pounds of pressure applied at one end of the pipe, or, to put it more correctly, upon the difference in the number of pounds acting on the two ends of the pipe. Similarly, the flow of electricity, or the number of amperes that will flow through a conductor of given length, size and shape will depend upon the difference in the number of volts acting at each end of the conductor.

The **Ohm** is the **unit of resistance.** Resistance can be compared with mechanical property of friction, for example, with the friction between the water and the inside of a pipe when the water is flowing through the pipe, or the friction between a shaft and its bearings.

Just as friction occurs in a flow of water through a pipe or the rotation of a revolving shaft, so does resistance oppose the flow of electricity through a conductor. A conductor having a resistance of one ohm will require an electromotive force of one volt to force a current of one ampere through it.

The **Henry** is the **unit of inductance.** Inductance is that quality of a circuit which tends to oppose any change in the flow of electricity. It should not be confused with resistance which offers friction to the flow of electricity. It can be described by comparison with the mechanical property of mass, as its effect in an electrical circuit is very much like the effect of the inertia and momentum of a heavy body in motion. It is well known that it takes a considerable time for an engine with a heavy fly-wheel to get up full speed. This is due to the inertia of the fly-wheel. Also an engine running at full speed takes a considerable time to be brought to a stand still. This is due to the momentum of the fly-wheel.

In the same way there is a tendency in a circuit to oppose any increase or decrease in the current flowing through it. This quality is called inductance. If an electrical pressure be applied to a circuit possessing inductance, current flowing as a result of the E.M.F. (voltage) will only gradually increase and the greater the inductance, the slower the rate of increase. Again, if, when the current is flowing through a circuit possessing inductance, the E.M.F. which is making it flow is suddenly removed, the current will gradually stop flowing unless, of course, the circuit is broken.

Thus, it will be seen that the effect of inductance in a circuit or on any current flowing through it is exactly similar to the effect of inertia in a body or any movement of that body.

One great difference between the effect of resistance and that of inductance in a circuit is that resistance absorbs energy and dissipates it in the form of heat, just as friction absorbs mechanical energy and dissipates it in the form of heat, whereas inductance only stores up energy when the current is increased, and gives its energy back when the current is decreased.

A circuit has one henry inductance when it requires one volt of pressure to make a change of one ampere in one second.

The **Micro-henry** is sometimes used as a **more convenient unit** when the circuits under consideration have very small inductances. **One micro-henry is one-millionth part of a henry.**

The **Farad** is the **unit of capacity.** Capacity is the property which a condenser has of holding a certain quantity of electricity; it can be compared to the property of mechanical flexibility of a spring. Similarly, the electrical unit of capacity is a measure of the quantity of electricity which will flow into a condenser when a pressure of one volt is applied to it. Thus, a condenser which requires one coulomb of electricity to bring its plates to a potential difference of one volt, has a capacity of one farad. Such a condenser would require immense plates very close together; the unit is altogether too large to represent the capacity of ordinary condensers. In ordinary engineering practice, such as telephone circuits, "B" eliminators, etc., the microfarad is used as the unit of capacity.

A condenser of one microfarad requires a charge of one-millionth of a coulomb to charge it to one volt. Taking it in another way, a current of one ampere will have to flow only one-millionth of a second to charge the condenser to one volt potential difference, or one microampere flowing for one second would charge it to the same extent.

In some radio circuits, the microfarad is too large a unit to be conveniently used; a more suitable unit is the **millimicrofarad**, which is the thousandth part of a microfarad. Another unit is the **micro-microfarad** which is one-millionth of a microfarad.

An important point to grasp is that although energy is expended in charging up a condenser, this energy is in reality only stored up by the condenser, and is available for use by discharging that condenser through a useful channel, just as in the case of a spring, although energy is expended in expanding or compressing a spring, that energy is only stored up by the spring, and is available for use by discharging the spring in a useful way; for example, a spring used in a toy air gun for driving a shot when the spring is released.

The **Joule** is the practical **unit of electrical energy or work.** In order to cause a current of electricity to flow in a circuit, energy or work must be expended. The electrical unit of work is, as we have already stated, the joule and can be defined as follows. If a force of one volt is used to cause an electric current to flow through a circuit, one joule of work has been expended when one coulomb of electricity has flowed. From this definition of a joule in forms of quantity and pressure, it follows from the fact that one ampere of current is one coulomb per second, that a joule is also the amount of energy expended during one second of time in causing one ampere to flow through a resistance of one ohm.

The **Watt** is the electrical **unit of power.** Power is the work done per unit time, or the rate of doing work. One watt is the power required to do one joule of work per second.

Now, since a flow of one coulomb per second is one ampere, it follows from the definition of a joule that one watt of power is expended when one volt is used to cause a current of one ampere to flow. This can be expressed as an equation.

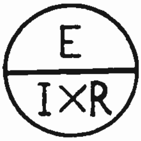
Watts equals Volts multiplied by Amperes.

For convenience, the kilowatt is often used as a unit of electrical power instead of the watt; one kilowatt equals one thousand watts. For example, if a certain Broadcasting Station required 50 amperes at 110 volts to operate it, then the electrical power used is 110x50 which equals 5,500 watts or 5½ K.W.

OHM'S LAW

We have now reached a point where we can consider the work of a very great German scientist whose name was Dr. Ohm. Dr. Ohm originated a very simple law. Do not let the word "law" scare you, since nothing could be easier to learn than Ohm's Law.

A very simple method for using Ohm's Law in three forms is to insert the three letters, E, I, R, in a circle, as shown below.



(1)

Fig. 5—Ohm's Law in a nut shell.

If the student wishes to find the value of any one of the quantities, he puts his finger over one letter in the circle and reads the value in terms of the other two.

The letter E is used to represent the electrical pressure since E is the first letter of the expression "E.M.F." (electromotive force).

I is used to represent the intensity of the current measured in amperes.

R is used to represent the resistance measured in ohms.

These letters are standard abbreviations adopted by both the American Institute of Electrical Engineers and the Institute of Radio Engineers, and are also considered standards in all text books.

A student should become familiar with the abbreviations and use them whenever referring to these terms.

VARIATIONS OF THE POWER EQUATION

Just as Ohm's Law has the three forms—I equals E divided by R, E equals I x R, R equals E divided by I, so this power equation P equals IE may have three forms, found as follows:

It is well to learn the equation in its three forms. P equals IE, P equals I^2R, P equals E^2 divided by R. This will save a considerable amount of mathematical work. When the volts and amperes are given, multiply the volts by amperes to get the watts (P equals IE), when the amperes and ohms are known, multiply ohms by the square of amperes (P equals I^2R), when volts and ohms are known, divide the square of volts by ohms (P equals E^2 divided by R). The result is the same as though we used Ohm's Law first to find the amperes and volts and then multiplied.

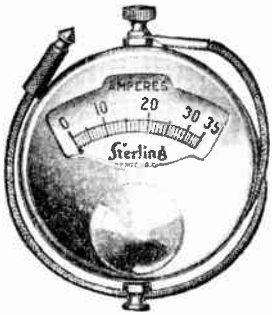


Fig. 6—D. C. Ammeter.

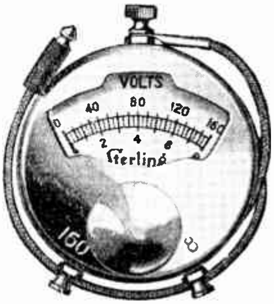


Fig. 7—D. C. Voltmeter.

MEASUREMENT OF CURRENT AND VOLTAGE

Meters. Any instrument which measures electrical values is called a meter. An **ammeter measures the current in amperes, a voltmeter measures the electromotive force in volts, a wattmeter measures electrical power in watts. A milliammeter measures current in milliamperes** or thousandths of an ampere.

Meters—Ampere and Volt.

An ampere-meter or ammeter measures electrical current flowing in amperes, its scale being graduated in amperes and parts of amperes. A voltmeter measures electrical pressure, potential, or electromotive force in volts with a scale divided in divisions representing volts and parts of volts.

The principles upon which ammeters and voltmeters operate are the same. The ammeter allows a current to flow practically unhindered and indicates the effect of the current passing in a circuit. The voltmeter offers such high resistance to the flow of current that this flow is practically stopped. The voltmeter then measures the effect of the voltage or pressure acting upon its terminals.

Ammeters are connected in series with the circuit in which the current is to be measured. That is, the circuit is opened and the ammeter inserted between the open end as shown in Figure

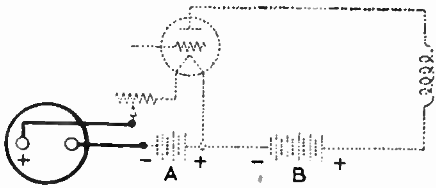


Fig. 8—Connections for measurement of filament or "A" Battery current using a D. C. ammeter.

8. Voltmeters are connected in parallel across the two sides of a circuit without opening the circuit when the voltage difference between the two sides is to be measured. Voltmeters are also connected across any two points in a circuit where the voltage drop between these points is to be measured. A voltmeter may be connected between any two points whose voltage difference is to be measured, either in an open circuit or a closed circuit. Such connections are shown in Figure 9.

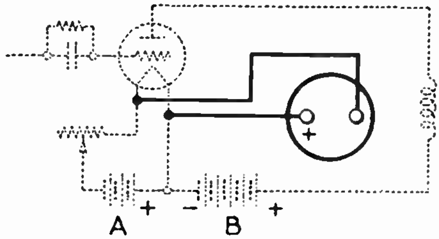


Fig. 9—Connections for measurement of filament voltage using D. C. voltmeter.

Ammeters may be used in a receiving circuit to measure the flow of current through the filament of vacuum tubes. Milli-ammeters are often used to measure the flow of the direct current in the plate circuit of the vacuum tube, this being an indication of considerable value in the proper operation of a Radio receiving set.

Voltmeters are often used to measure the voltage across the tube's filament terminals and other voltmeters or a double range meter may be used to measure the voltage applied to the plate circuit.

The voltage or potential difference in a circuit is always measured between two points. For example, if we wish to cause a current of electricity to flow from one point to another, we

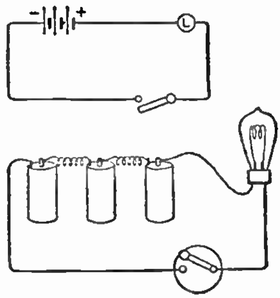


Fig. 10—Three dry cells, lamp, and switch connected in series.

have merely to raise the potential (pressure) of the first point above that of the second. Then a pressure (voltage) is set up proportional to their difference in potential; in other words, one point will have potential only with respect to the other.

Ranges of Meters. The range of a meter is the greatest value it will measure in amperes or volts. For example: A volt-

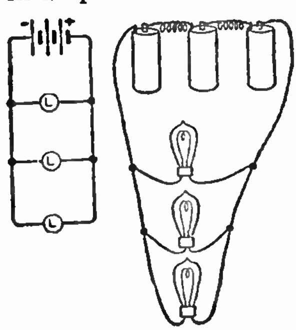


Fig. 11—Three dry cells connected in series and three lamps connected in parallel.

meter which reads from 0 to 8 volts is said to have a range of 8 volts. For measuring filament voltages, when using storage batteries, the voltmeter should have a range of at least 0 to 8 volts. For measuring plate voltages when using batteries, a voltmeter of 0 to 150 volts range is generally employed, since voltages greater than 150 volts are seldom secured from batteries. Voltmeters having two or more ranges combined in one instrument are often used with a switch or other connection so that either range may be employed. These double range meters generally have the first range of from 0 to 8, 0 to 10, or 0 to 15 volts, and the other of 0 to 200 volts.

It is very important to learn the correct use of ammeters

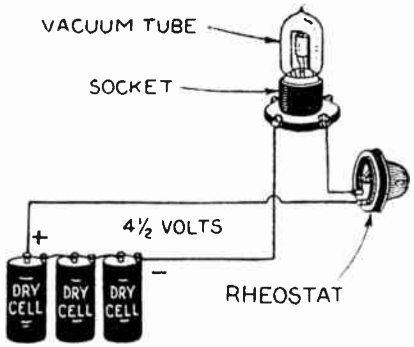


Fig. 12—Three dry cells connected in series give 4½ volts, serving as the "A" battery for a vacuum tube such as the UX-199 or CX-299.

and voltmeters. An ammeter is inserted in series in a circuit, while the voltmeter is merely tapped across (in parallel) the circuit.

SERIES AND PARALLEL CIRCUITS

Electrical apparatus may be connected either in series or in parallel. In a series circuit all the current is made to pass

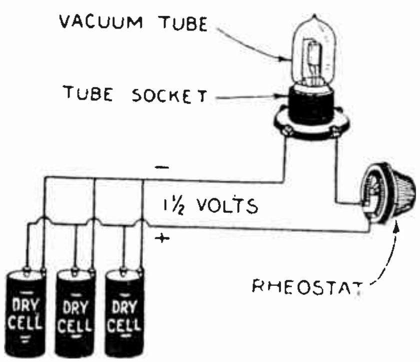


Fig. 13—Three dry cells connected in parallel give 1½ volts, serving as an "A" battery for a vacuum tube such as the WD-11 or WX-12.

through every unit in succession, as Figure 10, where the battery, the lamp and the switch are so related.

In a parallel connection, the current is divided so as to pass through several units at the same time, such as the three lamps in Figure 11.

When battery cells (or for that matter any number of electrical sources) are connected in series, the total voltage supplied by them will be equal to the sum of the voltage of each unit, while the amperage will be equivalent to that of a single cell. When they are connected in parallel, the opposite holds true. The voltage is now that of one unit but the currents are added together.

So, for instance, if it were necessary to obtain a voltage of 4½ volts from a set of three dry cells capable of delivering 1½ volts each, it would be necessary to connect them in series, such as shown in Figures 11 and 12, in which case the amperage in the closed circuit would be regulated by the resistance in the circuit. If the same batteries are connected in parallel, however, current will flow at a pressure of 1½ volts. See Figure 13.

Now let us try to apply in a practical way what we have digested in the previous paragraphs. We must come to understand that knowledge for knowledge's sake is absolutely useless. We must be able to use what we put into our heads—otherwise, the knowledge is useless. In this course, we have included only those things that are going to be of value to you in your Radio career.

Look at Figure 14 and you will see that secured to the upper end of the carbon is a binding post and that to the upper edge of the zinc cup is fastened another binding post. Binding posts are used to make it easy to connect the ends of wires to the carbon and to the zinc.

Five dry cells when connected together will give enough current to run a toy motor. These cells are connected with each other as shown in Figures 14 and 14-A. That is, the zinc of one cell is connected with the carbon of the next cell by a piece of copper wire about 3 or 4 inches long.

Any kind of copper wire will do for the connection, but the kind known as bell wire—that is, copper wire No. 18 Brown and Sharpe gauge covered with cotton thread and soaked in paraffin is mostly used.

Let us solve this problem: Suppose that we desire to obtain 6 volts of electric pressure to be used in lighting the filament of a vacuum tube. This we desire to do by the use of dry cells. A single dry cell is able to produce a voltage of 1½. Let us digress for a moment at this point. On one hand, we will assume that we have a cell the size of a thimble and, on the other hand, a dry cell the size of a barrel. Will the voltage increase in proportion to the size of the cell? You will be probably surprised to learn that it will not. The voltage of the tiny cell and that of the big cell will be exactly the same, 1½ volts. But what about the amperes or the current of the cells? Will that increase? The answer is "yes." **The amperage of a dry cell increases with its size, due to the fact that its capacity is greater than a small cell.**

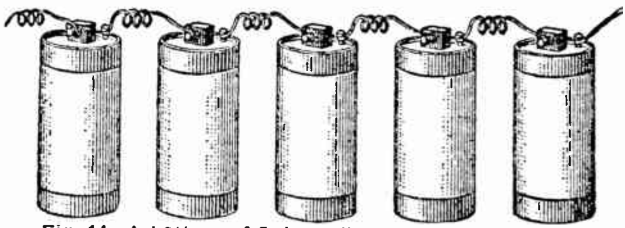


Fig. 14—A battery of 5 dry cells connected in series.

Well, let's go back to our original problem. If we wish to obtain 6 volts, we must use 4 dry cells, since 4 times 1½ equals 6.

Do not make the mistake of calling a single dry cell a battery. A battery refers to a number of cells used in combination.

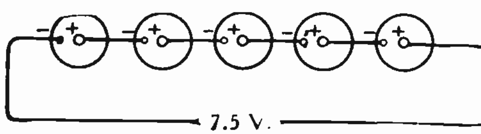


Fig. 14-A—Dry cells in series.

We will now consider the method of connecting up dry cells. The method of connecting them usually depends upon the duty they are to perform and upon the amount of current or voltage

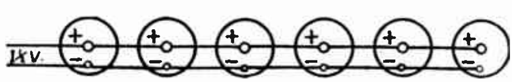


Fig. 15—Dry cells in parallel.

we require for our use. Figures 14 and 14-A show how dry cells are connected in series. They are simply connected in a single line, but do not be too hasty here. Notice how the poles are connected together. We could not connect two positive poles together and expect the battery to function properly. If we look close, we will notice that the positive pole of one cell is connected to the negative pole of the next, and so on. We notice that the potential of the cells as they are connected in Figure

14-A is 7½ volts. In other words, it is 5x1½, because we have five cells and each cell produces 1½ volts. Dry cells of standard size produce a current of about 30 amperes. What will the current of this battery amount to? In this series connection, the current will be the amperage of one cell.

It should be understood that the initial current of a dry cell is measured by short circuiting a cell through an ammeter. The required drain in any kind of work is less than the lowest initial current.

A dry cell of a size used for A battery work in a radio receiver will deliver approximately ½ ampere for 50 or 60 hours of intermittent use, or it will deliver approximately ¼ ampere for about 150 hours of intermittent use. As far as the voltage is concerned, only a single dry cell is required for the operation of vacuum tubes requiring 1.1 volt for their filament. These

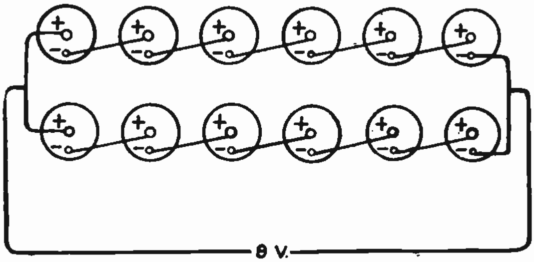


Fig. 16—Dry cells in series-parallel.

tubes draw ¼ ampere of current and this is the maximum current that may be taken from a single dry cell if any reasonable length of service is to be obtained. It is much better practice to connect two or three dry cells in parallel with each other to form the A battery supply in a receiving set using 1.1 volt tubes. There should be at least 1 dry cell in the parallel connection for each vacuum tube used in the radio receiver. In order to furnish current for vacuum tubes requiring 3 volts on their filament, such as the 199 tubes, three dry cells are connected in series, giving 4½ volts pressure to the filament; therefore a variable resistance is used in the filament circuit to regulate the voltage and amperage so as to apply 3 volts to filament terminals of the tubes. The current consumption of these tubes is only .06 ampere, so four tubes may be operated in parallel and draw only 0.24 ampere which is within the current ability of a single dry cell. However, much longer life will be secured if six or more cells are connected in series parallel, using 3 cells in each series bank.

Figure 16 shows what is known as a **series parallel connection** of dry cells.. You will notice that this is a combination of the first two methods. The two sets of cells are called banks, and when cells are connected in this way, we must have an equal number of cells in each bank. The voltage of a series parallel connection is equal to the voltage of one cell multiplied by the number of cells in one bank, and the amperage is equal to the amperes of one cell multiplied by the number of banks. For example: 1½ volts multiplied by 6 equals 9 volts and 30 multiplied by 2 equals 60 amperes.

Let us now turn our attention to a few practical applications

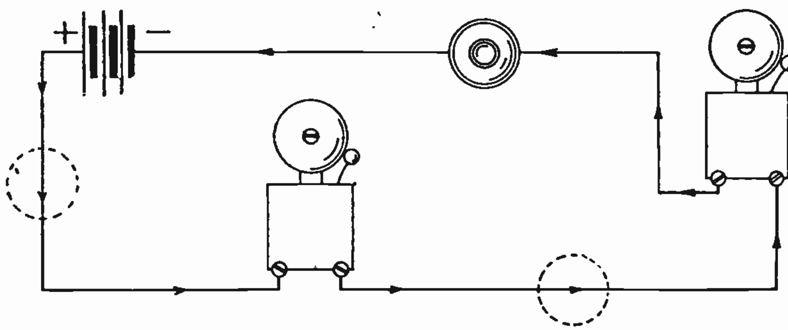


Fig. 17—Two bells, push button and battery connected in series. Push button may be placed in either of dotted-in positions instead of in location shown.

of these various types of circuits as apply to the wiring of push-buttons and bells in our homes.

The definition of a series connection is the same for other apparatus as for cells. Several lamps or bells may have to be connected to the same circuit. They may be arranged in series, applying the same principle. Figure 17 shows a circuit in which two bells are operated from one push-button. The bells are connected in series with each other and also with the button. The current must flow through the one before it can flow through the other. There is no other path for the current from positive pole to negative pole. It is immaterial on which side of the bells the push-button is located. An interruption of the circuit at any point means a stopping of the current. But the bells require the current in order to ring. It is likewise just as good to have the current flow through the bell in one direction as in the other. With the exception of special apparatus the direction of current through an instrument is of no importance. As long as the bell is in working order and a current of sufficient strength is passing through it, it will ring. This arrangement of bells is very seldom used due to the fact that you have two interrupters in series and unless one is kept closed at all times the bells will not ring when the push-button is pressed, in other words it is an impractical arrangement.

Whenever the necessity arises for connecting any piece of electrical apparatus, no matter how simple the connection may be or appear, it is a good scheme to work out the connection on paper first.

Parallel Connection.

The proper way to connect vibrating bells is in parallel with each other. This means a connection where each device may be traced out separately from pole to pole of the battery. There is more than one path for the current to reach the negative pole

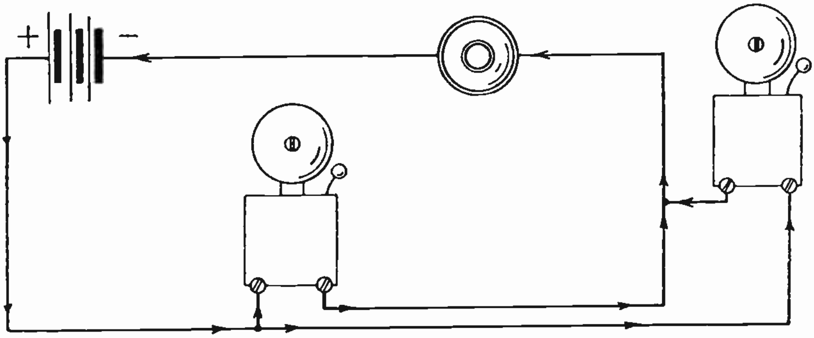


Fig. 18—Two bells connected in parallel, battery and push button in series.

after flowing from the positive. Divisions of current take place. The connection may be best understood by a specific example, Figure 18. Two bells are to be operated by one push-button. The button, in order to make or break the circuit for each bell as desired, must be in series with each. But, as can easily be traced from the drawing, it is possible to start out from positive, go through either bell and from there through the push-button in completing the circuit to the negative pole. Right at the point where a wire branches off toward the right-hand bell, the current divides. Later, after flowing through the bells, the currents again join and flow together back to the negative pole of the battery. Each one of the bells is connected to the battery and push-button independently of the other.

Should we desire to cut the wire of either bell somewhere between the branch-off and where it rejoins the system, we could do so without any interference with the other bell circuit. Having two buttons in series means that the circuit is open normally at two points. Pressing one button does not close the other open circuit. But you could not very well press the vestibule button and the one on the top floor at the same time. That is exactly

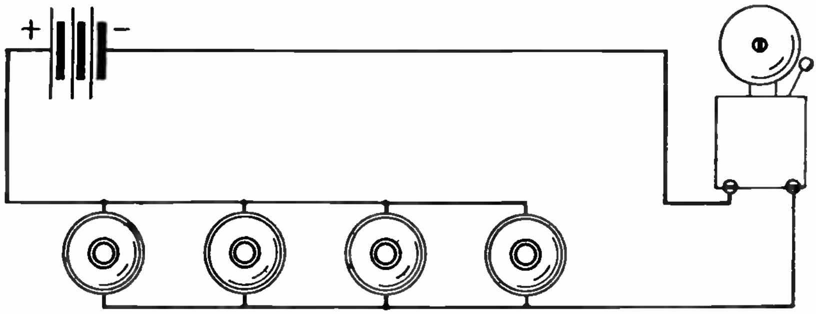


Fig. 19—A number of push buttons connected in parallel to operate one bell.

what would be required to close the circuit if the buttons were in series with each other. That leaves only a parallel connection to use—Figure 19 will show you how. Tracing from positive to negative, you will find each button to be in series with the bell—one after the other. But you can also trace out a separate, independent circuit for bell and each individual button without having any use for the others at that time.

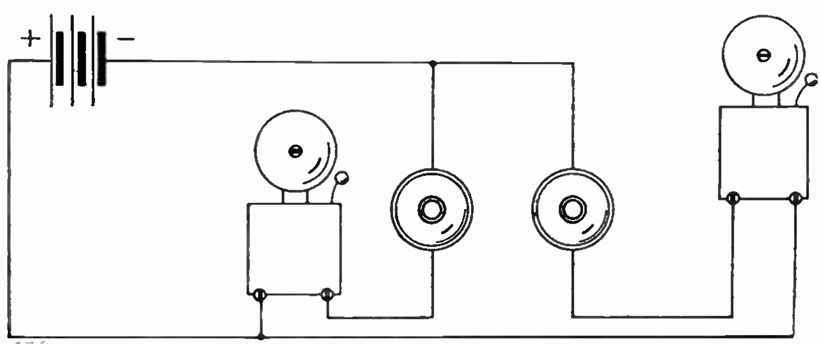


Fig. 20—Two independent bell circuits connected to the same battery.

In Figure 20, we see two bells and two push-buttons connected to the same battery in series, each button in series with its bell. Each button operates only one of the bells. They have nothing in common except the battery. The two independent bell hook-ups, each being fundamentally the same, are, therefore, connected in parallel with each other.

We may conclude that devices which we wish to work independent of others connected to the same circuit, should be in parallel with the others; while devices which should always and without fail operate simultaneously with others in the same circuit should all be in series with each other. There are modifications at times but not as a rule.

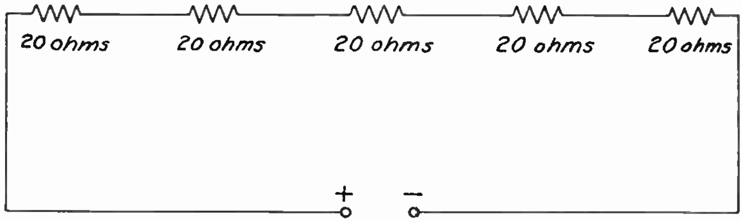


Fig. 21—Five resistances of 20 ohms each connected in series.

Resistances in Series and Parallel.

When we have resistances in series, we simply add them up to get the total resistance, or, if they are all the same values of resistance, we simply multiply the number of resistances by the resistance of one of them. For instance, if we have five resistances connected in series as shown in Figures 21 and 21-A, each of them having a resistance of 20 ohms, the total resistance is

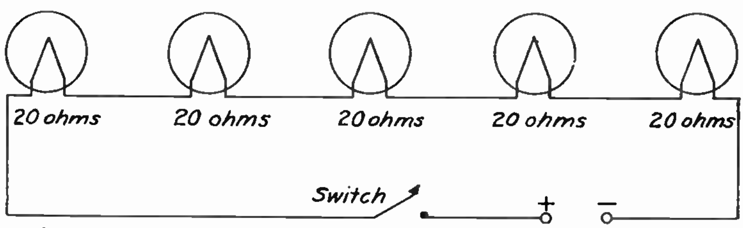


Fig. 21-A—Drawing showing five filament circuits connected in series.

20 multiplied by 5 or 100 ohms. But if we have different resistances, as, for instance, one of 5 ohms, one of 10 ohms and one of 4 ohms, all connected in series as shown in Figure 22, the total resistance of them all will be 5 plus 10 plus 4 or 19 ohms.

When we have several resistances, each having the same value, connected in parallel, such as a number of vacuum tubes about which we have already learned in the first six text books, we simply divide the resistance of one of them by the number of resistances. For instance, if we have five resistances connected in parallel as shown in Figures 23 and 23-A, each of them having a resistance of 20 ohms, the net resistance of this arrangement will be 20 divided by 5 or 4 ohms.

But if the resistances in parallel are not all the same, the situation becomes more complicated. It does not occur very often in practical Radio that we have more than two different resistances connected in parallel, so we will only consider one case, at least for the present. If we have one resistance R1 connected in parallel with another resistance R2 as shown in

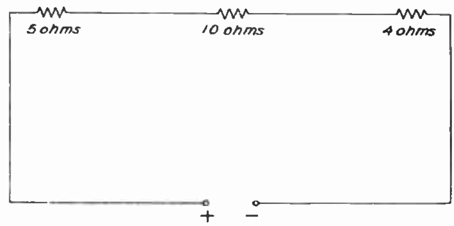


Fig. 22—Three unequal resistances connected in series.

Figure 24, then the total resistance of the two in parallel is expressed by the formula R equals R1 multiplied by R2 divided by R1 plus R2.

$$R = \frac{R1 \times R2}{R1 + R2} \text{ or } R = \frac{3 \times 6}{3+6} = \frac{18}{9} = 2 \text{ ohms.} \qquad (2)$$

That is, the product of the two divided by their sum. To explain

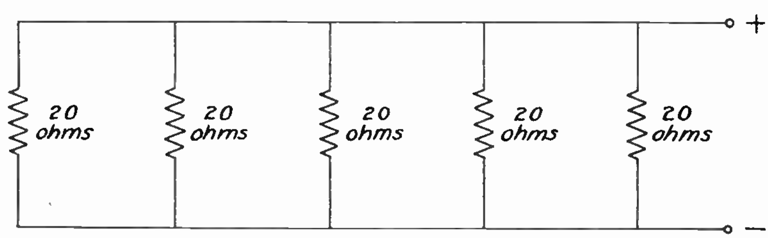


Fig. 23—Five resistances of 20 ohms each connected in parallel.

the use of this formula, suppose we have a resistance of 3 ohms connected in parallel with one of 6 ohms. The total resistance between the points A and B, Figure 24, is, therefore, R equals 3 multiplied by 6 divided by 3 plus 6 or 2 ohms.

In connection with resistances in parallel, it will be well to remember one thing particularly, and that is the joint resistance of the whole arrangement must always be less than the smallest resistance in the parallel arrangement. For example, in Figure 24, the joint resistance is less than 3 ohms. If we had a number of resistances in parallel, the joint resistance of all of them must be less than the smallest in the lot.

Resistance of Wires.

Now we must learn something about the resistance of wires, for you must know that wires are used everywhere in radio receivers, and as a matter of fact throughout all kinds of electrical work. And, **in connection with wires, we must clearly understand that there are three things about them that are of great importance.** One of these is the **length of the wire,** another is the **diameter** and the third is the **material of which the wire is made.**

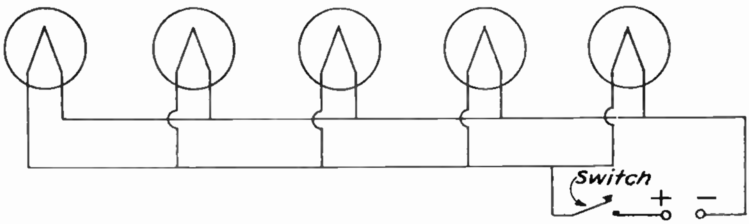


Fig. 23-A—Drawing showing five filaments connected in parallel.

If we double the length of the wire, we double the resistance, or if we triple the length, we triple the resistance. So it is clear that the resistance of the wire is directly proportional to its length. We also learned in the previous paragraphs that if we had several wires and connected them in parallel, the total or joint resistance would be lowered. So we may consider a large

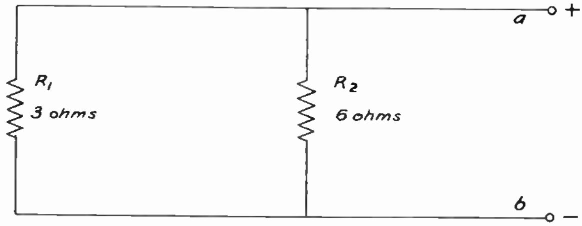


Fig. 24—Two unequal resistances connected in parallel.

wire as being equal to a number of smaller wires in parallel, and we learn then that larger wires have less resistance than smaller wires.

If we have two wires of the same length, but one made of copper and the other made of iron or some other material, the latter wire will have a resistance of so many times that of the copper wire. In other words, we can express the resistance of a wire made of a certain material as being so many times the resistance of another wire similar in all respects except the material of which it is made.

There has been given on these pages two tables which tell you the resistance, diameter, etc., of various sizes of wire. In order to illustrate how these tables are used, let us solve an imaginary problem. Suppose that this problem is as follows:

WIRE TABLE NO. 1
BROWN & SHARPE COPPER WIRE GAUGE
WIRE TABLE

Size B & S Gauge	Diam. Bare Wire in Inches	Ohms Per 1000 ft.
16	.0508	4.009
17	.0453	5.055
18	.0403	6.374
19	.0359	8.038
20	.0320	10.14
21	.0285	12.78
22	.0253	16.12
23	.0226	20.32
24	.0201	25.63
25	.0179	32.31
26	.0159	40.75
27	.0142	51.38
28	.0126	64.79
29	.0113	81.70
30	.0100	103.0

We have a certain Radio receiver, or we are going to build one, in which there are 4 vacuum tubes of the 201-A type. The filaments of these tubes are to be lighted by a 6-volt storage battery, and we must have a voltage of exactly 5 volts impressed on the filament terminals. The problem is then to design a rheostat or resistance which will do this.

TABLE NO. 2
TABLE OF RELATIVE RESISTANCE OF WIRES OF VARIOUS MATERIAL

Material	Relative Resistance
Silver	.0925
Copper	1.000
Aluminum	1.587
Iron	9.
German-Silver	17.3
Manganin	29.3
Constantan	32.
Nichrome	100.

This problem has two parts; the first part you have already learned how to solve—that is, to fix what resistance is required. In order to familiarize you with this important step, we will go through it again.

Having 4 vacuum tubes connected in parallel, and each tube taking a current of ¼ ampere, the total current which the resistance must pass is 4 multiplied by ¼ or 1 ampere. Then, having a 6-volt storage battery, and requiring only 5 volts at the filament terminals of the tubes, we must have a 1-volt drop in the resistance. The resistance, therefore, must be:

$$R = \frac{V}{I} = \frac{1}{1} = 1 \text{ ohm.} \qquad (3)$$

That is, the resistance of the rheostat must be one ohm.

Now, the next part of the problem is to find what kind of wire to use in the resistance, and how long this wire should be. Let us suppose we are going to use German silver wire in the rheostat, and that the size of wire is to be No. 20 B & S gauge. Now, the table of copper wire tells us that copper wire No. 20 gauge has a resistance of approximately 10 ohms per thousand feet. Since we desire a resistance of 1 ohm, then 1/10 of 1000 feet equals 100 feet or the length required for 1 ohm of No. 20 B & S gauge copper wire in the rheostat. This is quite a lot of wire of that size to put in a small piece of apparatus like a rheostat, so now you see why we use such a wire as German silver.

Now, German silver wire has 17.3 times the resistance of copper, as you can see by looking at the table of relative resistances. So, when we use German silver in the rheostat, we only have to use:

$$\frac{100}{17.3} = 5.8 \text{ or approximately 6 ft.} \qquad (4)$$

of wire. So now the electrical design of your rheostat is completed, you must have in it 6 ft. of No. 20 German silver wire, and then your tubes will have a voltage of 5 volts on the filament terminals when your storage battery has a voltage of 6 volts.

Of course, it would have been possible to use other sizes of wire, or we may have used some other kind of material. The solution of the problem would have been the same in any case. But there are other things to consider besides obtaining the right amount of resistance. First, the rheostat must be fairly strong, so that it will not break easily. This means that we must not use very fine wire, and, for this reason, we have chosen No. 20.

So now we come to the end of our 7th lesson. In this lesson, we have learned quite a bit of the way and manner in which an electric current acts in the circuits of Radio receivers. In this lesson we have considered only direct current, or currents which always flow in the same direction. It is necessary to learn more about these currents before we are able to study the other kinds of currents properly. We shall study these in our next lesson. Principally, among the other kinds of currents, we have alternating or oscillating current, which we mentioned quite a few times in the first six lessons of this Practical Radio Course. Your knowledge of Radio receivers is increasing quite rapidly, and with each lesson we open further into the great store of interesting information and knowledge that there is to be found in the study of Radio.

TEST QUESTIONS

Number your answers 7—2 and add your **student number**.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

No. 1. Into what two general divisions may electricity be divided?

No. 2. Explain the action of like and unlike charges.

No. 3. How is current electricity produced?

No. 4. What is the difference between the effect of resistance and that of inductance in a circuit?

No. 5. What is a kilowatt?

No. 6. Name the instruments used for measuring different electrical values.

No. 7. Draw a diagram showing how you would place the voltmeter and ammeter in a simple radio circuit.

No. 8. What is the important thing to consider when connecting dry cells in various ways?

No. 9. Draw a diagram of a series-parallel connection of dry cells.

No. 10. What three things determine the resistance of a wire?

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FUNDAMENTAL A C THEORY

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Washington, D. C.

"The only road, the sure road—to unquestioned credit and a sound financial condition is the exact and punctual fulfilment of every pecuniary obligation, public and private, according to its letter and spirit."—Rutherford Birchard Hayes.

SOME GOOD STUDY HABITS

A Personal Message from J. E. Smith

Speed. Attention is called to the fact that habit increases the speed of work. The question here is how to get up speed in doing mental work and at the same time avoid errors. Most persons have a certain gait at which they can do the best work. Try to add a column of figures very, very slowly. See how slowly you can do it. Note the number of mistakes you make. Now do it as fast as you can and count the mistakes. Both times you make more mistakes than you would by working at your natural speed. This natural speed is a matter of habit; it is not fixed by nature.

Speed of thinking is not altogether a gift; it is an achievement as well. There are some minds that work faster than others, true enough. But these individual differences in speed can be traced to habit. All our minds will work faster than we think they will; they only need speeding up. How can this be accomplished? By working right up to the speed limit all the while. The main reason why you work slowly is that you have never consistently tried to work faster. Or perhaps, you have not tried in the right way. To accomplish speed in mental work, two things must be observed. First, do not increase the speed too much at once. Go at it gradually. Second, learn short cuts and new tricks. The lightning calculator performs his "stunts" by applying certain established mental habits. The chances are that he is no more "gifted" than you are. The difference is that he has worked at it and you have not. You, too, with the right amount of practice in the right direction, could become a lightning calculator. It's all a matter of habit.

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FUNDAMENTAL A. C. THEORY

We have now come to the point where we shall have to begin studying the difference between **direct current** and **alternating current** and the action of each in radio circuits.

DIRECT CURRENT

There are two kinds of electric current used in Radio, first, **direct current** (D. C.) such as furnished by storage batteries, dry cells, or dynamos, and the second kind is **alternating current** (A. C.). Direct current is one which always flows in the same direction through its path, as, for example, the flow of water from a spring, through the brook, the river, and into the ocean. Another example is shown in the top of Figure 1, where we show a centrifugal pump C, which keeps a steady flow of continuous or direct current in the pipe B. This water flows in the same direction at all times. So it is with the flow of direct current electricity. It always leaves one part of the source of power and flows along the wire in a fixed and definite direction at all times.

This particular type of electricity is most efficient for certain classes of work as, for example, the driving of small electric motors, operation of electromagnets, applying high voltage direct current to the plates of vacuum tubes, for charging storage batteries, and electrical chemical processes, etc.

ALTERNATING CURRENT

As the word signifies, it is a flow of current which changes its direction, alternating first in one direction, and then reversing to the opposite direction, going through these changes a certain number of times during each second. One might get a clear understanding of this reversing motion by referring to a water pumping system such as illustrated in the center of Figure 1. Here we have a cylinder with a pipe line connecting at either end which supplies the water by the action of a piston, this piston moving back and forth within the wall. One can readily see that the flow of water in the main pipe "A" would be continuously reversing in its flow. The curved line at the bottom of this figure shows the change in value and direction for the alternating current flow for one complete change of current. This is called a cycle, which is one complete operation.

Let us now look at this action from another point of view; if you were in a room 18 feet wide and you started to run from one side of the room, and then after you passed the center of the room, you began to slow down and stopped at the other wall, and turned around and ran back in the other direction, you might repeat this operation many times, this would represent an alternating motion of travel and this would correspond very nearly to the flow of an alternating current.

Let us think of alternating current in comparison with the flow of water through a pipe line which is connected to a plunger type of pump, where the piston goes back and forth in a cylinder as illustrated in the middle Figure 1.

Now you can readily see by looking at that diagram that the piston passes from one end to the other, therefore, the water will begin to flow through the pipe in one direction, and when the piston reaches the end of the pump and stops for a moment, the water will stop flowing and, therefore, the flow will reach a zero value. And when the piston comes back on the return stroke, the water will be forced in the opposite direction in the pipe line. This is the correct way to look at it instead of looking at it as falling below the zero value. In other words, alternating current flows in one direction, then stops and flows in the other direction.

Alternating currents of from 25 to 60 cycles per second are used for industrial purposes, while the frequencies of current used in Radio communication range all the way from around 15,000 to 150 million cycles per second. To simplify the figures used, the word "kilo" is used to represent 1 thousand, for instance, 100,000 cycles is referred to as 100 kilocycles.

We will now review some of the things we learned in our "bird's-eye view" of the first six lessons to refresh our memory before we take up the subject of **Electromagnetic Induction**, etc.

MAGNETS AND MAGNETISM

Kinds of Magnets.

A natural magnet is, as you have learned, a piece of ore (a natural substance containing a mineral) that has the property of attracting pieces of iron, steel and a few other metals. This ore was first discovered in the Province of Magnesia, Asia Minor. The peculiar property was, therefore, called magnetism and the name magnet was applied to a piece of ore possessing this property.

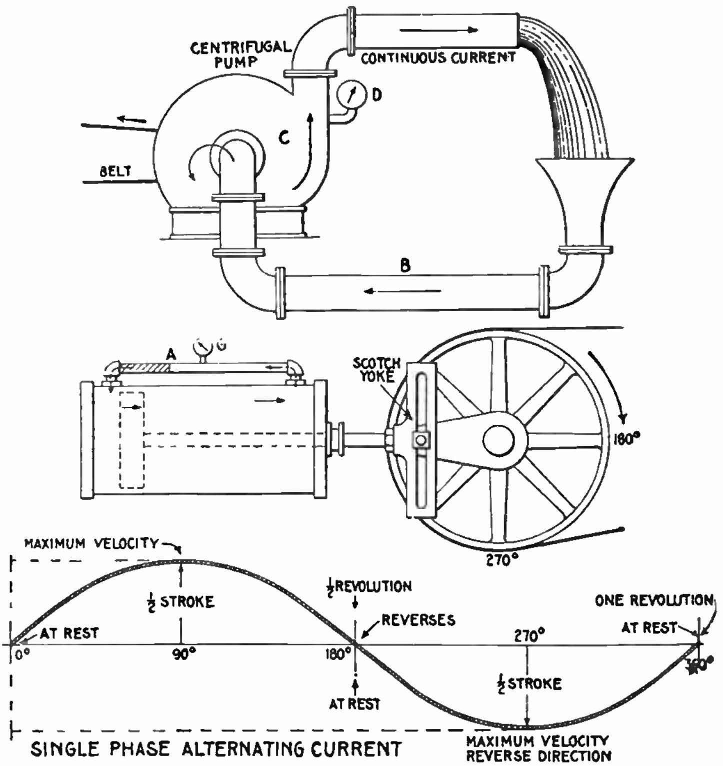


Fig. 1—This diagram illustrates the difference between direct and alternating current. In the above diagram a centrifugal pump C forces water to the upper pipe, from which it falls by gravity to the lower pipe B and re-enters the pump. The water is continuous, always flowing in one direction, that is, it does not reverse its direction. Similarly a direct electric current is constant in direction, though not necessarily constant in value. The center diagram illustrates a double acting cylinder with the ends connected by a pipe A and the piston driven by a crank and a Scotch yoke. If the cylinder and pipe is full of water, a current will flow through the pipe in the direction of arrow as the piston begins its stroke increasing to maximum velocity at one-quarter revolution of the crank, decreasing at one-half revolution, then reversing and reaching maximum velocity in the reverse direction at three-quarters revolutions, and coming to rest again at end of return stroke. If a pressure gauge is inserted as shown in the diagram marked G it will measure a pressure which varies with the current of water. Since alternating electric current undergoes similar changes this simple illustration will explain the single phase alternating current as shown in bottom diagram, which will apply equally as well to the pump cycle as to alternating current cycle.

Later the discovery was made that if such magnets were suspended so they could turn freely, all would come to rest in a position pointing North and South. Small bars of the ore were thus used to guide ships over the sea. They were, therefore, called lodestones (leading stones), a name that is also applied to the ore. These lodestones were thus the forerunners of the modern compass.

Bar Magnets.

A small rod of iron or steel which is brought near to a piece of lodestone, or which is rubbed on it in a certain way, shows the same properties and is said to be magnetized. If the rod or bar is made of rather hard steel, the effect persists after the lodestone has been taken away, and the magnetized rod is then called a permanent magnet, or simply a bar magnet. These permanent magnets may be made in the form of straight bars of round or square sections, usually with the length rather large as compared with the diameter. They are also often bent in various shapes, a common form being the horse-shoe or U shaped magnet.

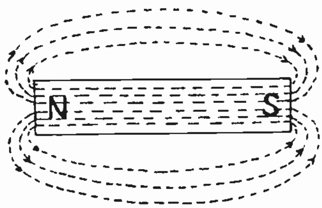


Fig. 2—Distribution of magnetic field around a bar magnet.

Magnets may also be made by passing an electric current through a coil of insulated wire which surrounds the rod. **If the rod is made of soft iron, it is only magnetized as long as the current flows.** It is then called a temporary magnet, or an electromagnet. Examples of electromagnets are seen in induction coils and buzzer cores, in telegraph sounders and in telephone receivers. Electromagnets are very useful because the magnetism is so easily controlled by variations in the current strength. **If the bars are of hardened steel, the magnetism due to the current remains after the current ceases and a permanent magnet is the result.**

The Magnetic Field About a Current.

It has already been pointed out in our "bird's-eye view" that there is a magnetic field about a wire in which a current is flowing. Experiments with a compass show that this magnetic field has lines of force in the form of concentric circles about the wire. These circles lie in planes at right angles to the axis of the wire. If the wire is grasped by the right hand with the thumb pointing in the direction of the current, the fingers will show the direction of the magnetic field as shown in Fig. 3.

The Solenoid and the Electromagnet.

If the wire which carries a current is bent into a circle, the magnetic field is of the form shown in Figure 4. If many turns are wound close together in, what may be called, a bunched winding, the intensity of the magnetic field is increased in direct proportion to the number of turns. When the wire is wound

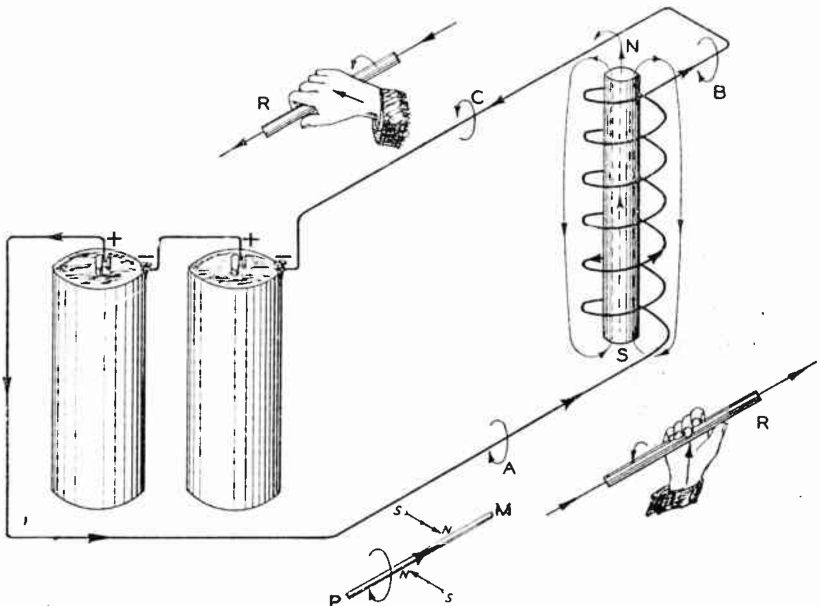


Fig. 3—Illustrating the direction of current and magnetic field using the right-hand rule.

closely with many turns, side by side along the surface of a cylinder in a single layer, the coil is called a solenoid. In this case, the magnetic field is nearly uniform for a considerable distance near the center of the coil, and the solenoid has the property of a bar magnet. This can be clearly seen by observing the magnetic fields of Figure 2 and Figure 5. The intensity of the field and the density of the magnetic lines within the solenoid depend entirely upon the strength of the current and the number of turns of wire. The same magnetizing effect can be secured with many turns and a weak current, or with a few turns and a strong current, provided only that the product of wire turns times amperes of current is the same in each case. **This product is called the ampere-turns.**

If the space within the solenoid is filled with iron, the magnetic lines are very greatly increased. This is due to the property of iron called magnetic permeability. To say that iron is more permeable than air means that the magnetism is stronger when iron is present than it would be if the space were filled with air alone.

It can be clearly seen that when a direct current flows through a coil, it acts exactly like a magnet and will attract iron in the same manner, but as soon as the current is cut off, the

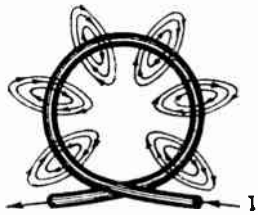


Fig. 4—Magnetic field about a single loop carrying current.

attraction ceases. While the current flows, a magnetic field is produced—that is, the space inside and around the coil is full of lines of force, which are as shown in Figure 5. These lines of force are strong inside the coil and spread out in all directions around it. When the current flows in one direction, the North Pole is at one end of the coil and the South Pole at the other.

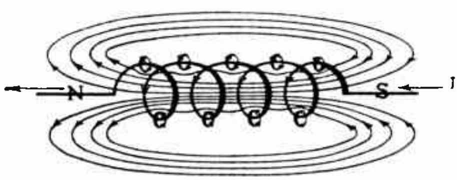


Fig. 5—The total magnetic field of a solenoid (inductance coil) carrying current.

The polarity of a coil of wire carrying a direct current can be found by the **end rule (sometimes called the corkscrew rule)**, that is, looking at the end of the coil, if the current is flowing into or out of the end turn in a counter-clockwise direction, that end is the North Pole of the coil (see right-hand side Fig. 6); if in a clockwise direction, it is the South Pole (as shown at left, Fig. 6).

Therefore, when the current flows in the opposite direction, the poles are reversed so that when alternating current is applied to the coil, the direction of the field is constantly changing at the frequency of the alternating current.

Now that we hav elearned a great deal about **solenoids** and **electromagnets**, let us turn our attention to **Electromagnetic Induction.**

HANS CHRISTIAN OERSTED—1777-1851
Professor of Natural Philosophy in the University of Copenhagen, 1820, accidentally discovered that a wire through which a current was flowing had the power of deflecting a near-by compass needle. In other words, when an electric current flows through a wire or coil "magnetism" will be made.

ELECTROMAGNETIC INDUCTION

In the following pages, we will learn how a current can be generated in a coil of wire if that coil of wire is moved in a magnetic field. In the year 1831, Michael Faraday discovered the principle of electromagnetic induction. In one of his experiments, he wrapped a coil of wire about a block of wood and connected the terminals to a galvanometer (an extremely sensitive instrument used for detecting and measuring electric current and also for indicating the direction of the current in a circuit). Another coil was wrapped around the first one and connected to a battery. He found that upon closing the circuit of the coil in series with the battery, that the needle of the galvanometer was momentarily deflected, and upon opening the circuit, that the needle again deflected, but in the opposite direction.

This experiment opened up a new field of investigation in electrical science and the principle deducted from it is of great importance, due to it being the basic principle of the production of electricity by mechanical motion. There is an interesting experiment in this connection which is pictured in Figure 7. A small sensitive voltmeter is connected to a solenoid (coil of wire)

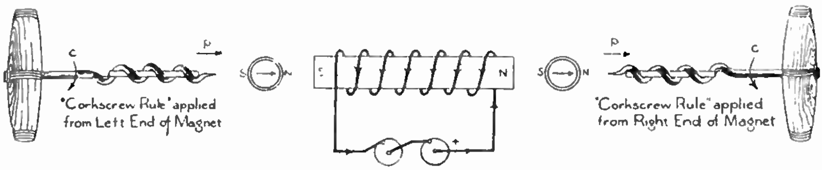


Fig. 6—Showing the application of the "corkscrew rule for solenoids" to a magnet.

which is formed by winding a piece of wire around a cardboard cylinder. If we were to take a permanent magnet in our hand and move it up and down in the solenoid, we would find that the voltmeter would register, proving that an E. M. F. (voltage) has been produced in the coil. What if we were to hold the magnet still? Would a current be produced? Not at all, we cannot fool nature. There is an inflexible law that states work must be done to create energy. This is the law of conservation of energy. We could hold the magnet still in the center of the solenoid, but we would find that no voltage would be generated. If we move the magnet up and down, however, the voltmeter will register faithfully, and we will see that the needle of the voltmeter would jog back and forth following the movement of the magnet. When we move the magnet in one direction, and then move it back in the opposite direction, the current will reverse.

Here we have in a nut-shell the principle of the generation of the electrical power that is used today. This same principle applies to the generation of radio currents in your receiving antenna. Will the generated current in the solenoid depend upon the power in the magnet? Yes, it will. It will depend upon the power of the magnet and the speed with which we move the magnet. If we move the magnet rapidly, we cause more work to be performed and the current generated will be greater. We might put it this way. The strength of the current flowing in the solenoid will depend upon the number of lines of force cut by the solenoid per minute. We use the word "cut" here in rather a peculiar way. Of course, we could not cut the lines of force with a knife or even with a good safety razor blade in the generally accepted sense of the term.

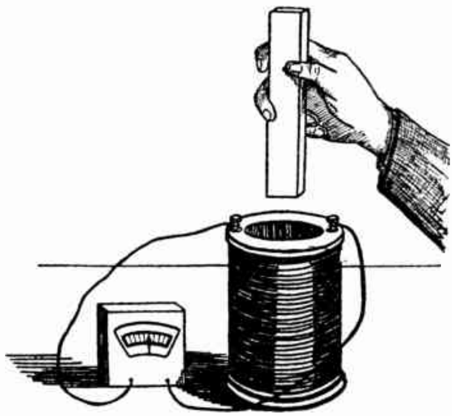


Fig. 7—Electromagnetic induction, using a coil of wire, magnet and voltmeter.

There is another interesting experiment illustrated in Figure 8. Here we have two independent electrical circuits. If you trace out the two circuits, you will notice that one circuit contains a small key or switch, a solenoid and a dry cell. The other circuit contains another solenoid larger than the first and a small voltmeter. This small solenoid fits within the large one. If we close the circuit with the switch and place the small solenoid within the large one, we will notice that the voltmeter needle will move, proving that there is an electromotive force (voltage) produced in the second circuit. This should be easy to understand. It is simply another case of electromagnetic induction. The small solenoid will generate a concentrated magnetic field when a current is flowing through it, and these magnetic lines of force will cut the second solenoid and a current will be produced in the second circuit. If the small coil is allowed to run slowly in the center of the large one, current will be generated only at the moment the key is pressed and the magnetic lines of force spread outward. If the circuit is kept closed, a current will be produced in the larger coil if we keep the smaller coil moving. Therefore, the three ways a current can be induced in a coil of wire are:

(1). **By moving a magnet inside a coil of wire and connecting the two ends of the coil together, a current of electricity will flow through the coil.**

(2). **By replacing the magnet by a coil of wire through which a current is kept flowing and making this coil move inside another coil of wire; the effects then produced are known as those of mutual induction.**

(3). **By leaving one coil inside of the other and making and breaking the battery circuit by means of a switch.**

In the last two cases, the battery circuit is called the primary and the coil in which the current is induced is called the secondary.

The point to remember here is this: The magnetic lines of force have to be constantly moving about or around the wire or coil. Note that in the first case mentioned, the moving magnetic lines cause the lines to cut the wire.

We readily recognize the second case is using the same principle as that of the first case, only here we use an electromagnet in place of a permanent magnet of steel.

What would happen if we had the magnet stationary and moved the coil? Again, we would have a current induced in the coil showing that the magnetic lines were being cut.

So far, so good. But what about the third case? Here the coils are not moving. Why should we get an induced current in the coil now? Of course, you have the answer. In testing electromagnets, you would observe that when a current stopped flowing, then the magnetic lines would cease to exist. Thus, when the current was made in the electromagnetic coil, magnetic lines moved and extended outward which cut the secondary coil. Again, as the current was broken in the magnet, the lines collapsed, causing the lines to cut the coil in the opposite direction. This caused the induced current to flow in one direction as the primary current was made, and then the induced current flowed in the opposite direction when the primary current was broken. Thus, the induced current was found to be an alternating current. **It is called an "alternating current" because it alternates**

in its flow of direction. This third method is the underlying principle for the operation of all radio and audio frequency transformers in radio receivers.

In the little experiment shown in Figure 8, we use **direct current.** What if we had taken the battery out of the circuit and

MICHAEL FARADAY—1791-1867
Who discovered the principle of electromagnetic induction.

replaced it with an **alternating current** generator? Now put on your thinking cap. What would happen? Think hard. We know that an alternating current falls to zero a number of times each second, and if the current falls to zero, then the magnetic field must collapse with it and rise with it when the current builds up again. We picture, then, an alternating magnetic field as having a sort of a breathing effect. It rises and falls like the waves of the ocean. In other words, it is constantly in motion, where the magnetic lines of force produced by a direct current are at rest after they are once produced. If there is an alternating magnetic field about the little solenoid, the larger solenoid will constantly cut through these magnetic lines of force, or we might say, the magnetic lines of force will cut through the big solenoid and current will be generated in it. **This is the principle of electric transformation upon which all electrical transformers operate.**

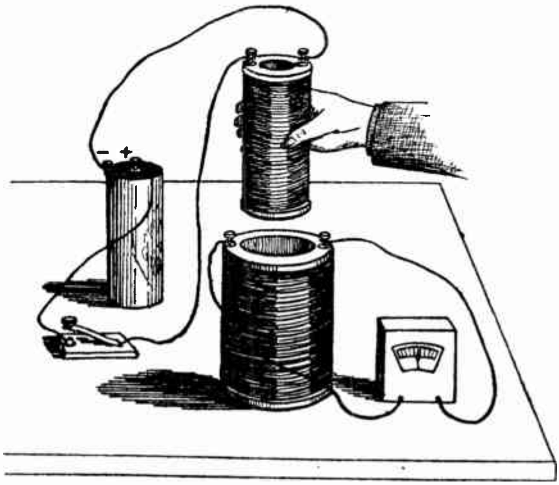


Fig. 8—Electromagnetic Induction.

Could there be such a thing as a direct current transformer? Surely you would not make the sad mistake of saying that there could be. If we wish to use this principle of transformation with a direct current, it would be necessary to interrupt the direct current many times per second so that the lines of force would be constantly expanding and contracting, building up and collapsing.

Let us refer again to Figure 8. The first circuit which contains a small coil would be called the primary circuit. The second circuit would be called the secondary; the primary circuit then always contains the original current and the secondary circuit contains the induced or transformed current. Nothing confusing about that, is there?

It was noted in the Experiment, Figure 7, that when the magnet was thrust into the solenoid, the current generated in the solenoid flowed in one direction, and when the magnet was removed from the solenoid, the current flowed in the opposite direction. Now, if instead of thrusting a magnet or electro-magnet in and out of a solenoid, we rotate a coil of wire within a magnetic field as in Figure 9 so that the lines of force of the magnetic field pass through the coil of the rotor first in increasing numbers as when the magnet was thrust into the coil, and then in decreasing numbers, as when the magnet was removed from the coil, we will have generated in the rotor a voltage which causes a current to first flow in one direction and then in the other.

Figure 10 will greatly aid one in understanding the simple principles involved in the production of direct current. The current is taken off from the coil of wire (which rotates between the North and South poles of the magnet) by the use of a device

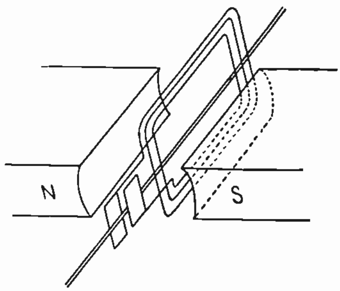


Fig. 9—If we rotate a coil of wire within a magnetic field an alternating potential will be set up in the coil. This is the basic principle of the alternating current generator.

known as a **commutator.** This is really a rotating conductor making contact with the stationary parts called **brushes.** These brushes are the real terminals of the generator and are connected to the outer circuit. The revolving coil in a generator of this type is referred to as an armature. The magnet is called the field magnet since it is depended upon to produce the magnetic field through which the armature rotates.

Upon what will the voltage and current of this small generator depend? A little thought and you can readily see that the voltage and current will depend upon (1) **the strength or density of the magnetic field between the N and S poles,** (2) **size and number of turns of wire on the armature,** and (3) **speed with which the armature revolves.**

The generator shown in Figure 10 is of the simplest type. Larger and more efficient current generators are always provided with what is known as a field winding. Generators with field windings do not have permanent magnets. In place of permanent magnets, soft iron is used and the field windings are placed over this iron mass.

Do not make the mistake of thinking the above description covers all types of direct current generators used. There are several different types and designs used for various purposes. For instance, the commutators of all but the simplest types, are made up of a number of copper segments in place of the two shown in Figure 10 and instead of one independent coil, there are a number of coils connected to the segments.

This simple explanation of a small direct current generator that is capable of producing direct current should be clearly understood by the student and at the same time it must be remembered that this simple device does not produce direct current in the sense of a battery. That is, the current produced, although it is in the same general direction, is not of uniform value. It will be seen that every time the brushes come to a break between the segments, there will be an interruption. In other words, the current does not change its polarity, but it falls back to zero in every revolution. By increasing the number of coils on the armature and the number of segments, and by providing the field with a pole to match each coil, we can produce a voltage or a series of voltages that have a tendency to build up a fairly uniform value. The little variations are known as ripples and for all ordinary purposes the voltage may be looked upon as uniform.

Now, if we wish to change our simple direct current generator into an alternating current generator, it is only necessary to alter one part—that is the commutator. In place of the two segment commutator, we use two independent metal rings each attached to one terminal of the armature coil, as illustrated in Figure 11. The brushes would make contact with these rings. Under certain conditions, there would be two complete reversals of the current at each revolution of the armature. It can be clearly seen then that the frequency of such a generator would depend not only upon the speed of the armature, but upon the number of coils in the armature and the number of poles in the field of the generator. By providing the generator with two field coils and four poles, the frequency would be doubled at the same speed. Alternating current generators operate on the same principle as direct current generators—that is, currents are produced with armature coils that cut through magnetic fields. Broadcasting stations use several types of generators, low voltage A. C. or D. C. for tube filaments and a high voltage D. C. for grid and plate supplies or an A. C. generator.

MUTUAL INDUCTION

The subject of **mutual induction** will now be considered. By this time, we must have come to understand that this subject of induction has many ramifications or divisions into branches,

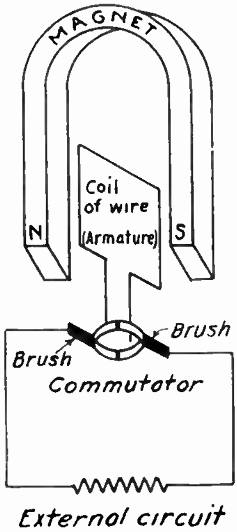


Fig. 10—D. C. dynamo principle. The D. C. dynamo is nothing more or less than a coil of wire moving in a magnetic field provided with a commutator and brushes for leading the current away from the coil.

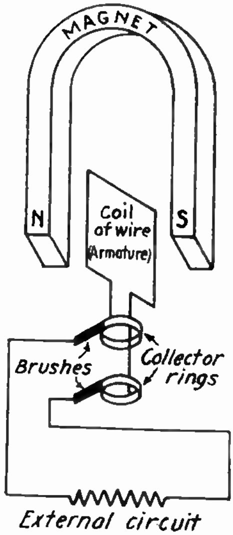


Fig. 11—A. C. generator principle. The above is the same as the dynamo except the commutator arrangement is different. This machine employs two collector rings and brushes.

and that the thing taken as a whole is simple enough. The laws are by no means difficult to learn. **When two electrical circuits are close to one another, the current flowing in one will be induced into the other. This is called mutual induction.** Mutual induction is easy enough to understand if you have followed the foregoing subjects closely and progressively. A study of the definition of the word "mutual" is apt to fix this clearly in your mind. "Mutual" means "reciprocal" or, in other words, it is a term which describes the act of giving and taking interchangeably. All of us have at some time or other made a mutual agreement. Likewise, then, when we speak of mutual induction, we refer to the making of electric pressure from one circuit into another circuit interchangeably. Of course, we know now that this is done through the medium of magnetism.

THE ALTERNATING CURRENT TRANSFORMER

A very important application of the principle of mutual inductance is the alternating current transformer. The transformer is a device for securing mutual induction between two circuits; in some cases, the purpose of using a transformer is to change or transform alternating current of low voltage and large current to alternating current of high voltage and smaller current or vice versa. **A transformer used to deliver an output of higher voltage than the input is called a step-up transformer. A transformer used to deliver an output of lower voltage than the input is called a step-down transformer.** For example: To increase the voltage of a 60-cycle current from 110 volts to 220—

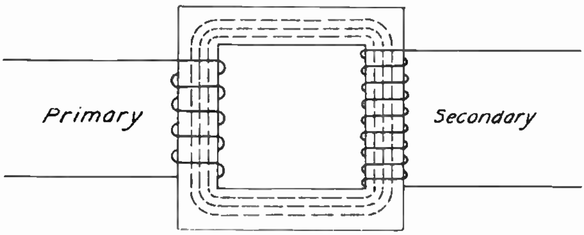


Fig. 12—Step-up iron core transformer.

in other words, we wish to multiply our voltage by 2, therefore, we must have twice as many turns in the secondary winding as in the primary winding or a ratio of 2 to 1. If we desire to triple the voltage, the ratio would have to be 3 to 1, etc.

It can be seen from the foregoing paragraph that the change between the voltage and amperage in the primary circuit and the voltage and amperage in the secondary circuit depends on the turn ratio of the windings, that is, on the ratio of the number of turns in the secondary winding to the number of turns in the primary winding.

The ratio of the secondary turns to primary turns is the same as the ratio of secondary volts to primary volts. In other words, if we have ten times as many turns in the secondary winding as in the primary, we will have ten times as many volts in the secondary as in the primary. If we have one-half the number of turns in the secondary as in the primary, then the secondary voltage will be half that of the primary voltage.

Since the power must be the same in both of the windings, an increase of secondary voltage means a decrease in secondary amperage, while a decrease of secondary voltage will mean an increase of secondary amperage. For example, suppose we start with 100 watts of power and assuming the primary circuit to carry this 100 watts at 20 volts and 5 amperes, let us see what will appear in the secondary with different turn ratios. Suppose the transformer has twice as many turns on its secondary as on its primary, and the primary voltage is 20. The secondary voltage at a ratio of 2 to 1 will be 40. The secondary power must be the same as the primary power, therefore, the number of amperes in the secondary will be 100 watts divided by 40 volts or 2½ amperes. If we were using a step-down transformer and there were 6 primary turns and 3 secondary turns so that the ratio of the primary to the secondary would be 1/2, since the primary voltage is 20 and the ratio is 1/2, the secondary voltage

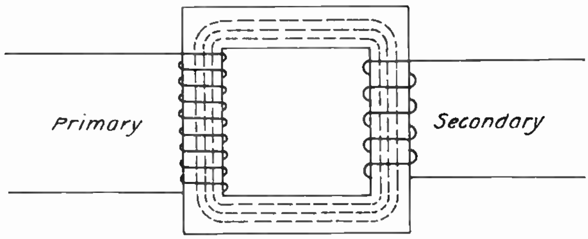


Fig. 13—Step-down iron core transformer.

must be 10. The number of watts in the secondary will be the same as in the primary 100, therefore, the secondary current will be 10 amperes since 100 watts divided by 10 equals 10.

It is evident that we cannot increase both the current and the voltage for here again we would be interfering with the law of conservation of energy. We must not forget that as we increase the voltage and the curent, we increase the power, for voltage times amperes equals watts. If we increase the voltage, we must decrease the amperage; and if we increase the amperage we must decrease the voltage. In other words, we cannot get something for nothing.

Transformers are used for many purposes in both electricity and radio in general. Perhaps one of the most important functions in the workaday world of electricity is that of boosting voltage over long distance transmission lines. By using a high pressure, the line losses are reduced and it is possible to use smaller conductors.

The use of power lines for transmission of radio signals is sometimes found throughout the country, known as wired wireless.

For commercial use, this system has certain advantages, such as lack of interference which makes its use valuable, but it is unlikely that the system will ever replace broadcasting. The number of different stations that can be tuned in by using this system is naturally limited, and this is a definite disadvantage.

The system actually differs very little from that of ordinary broadcasting, the major difference being that the power of the transmitter, instead of being radiated into the air by means of an antenna is coupled directly to the power lines. The coupling between the transmitter and the power line is generally made through high voltage coupling condensers and special filter and protective circuits. At the receiving end, an ordinary radio

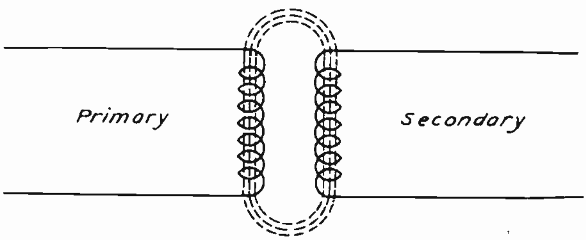


Fig. 14—Air core transformer.

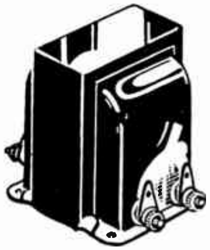
receiver can be used to detect the signals. It also must, of course, be coupled in some way to the transmission line.

The electric light companies all use power transformers for home lighting. The current is distributed over transmission lines at a very high pressure. It is then tapped off through the secondary of the step-down transformer and delivered to the customers at 110 to 220 volts as a rule. Small sizes of power transformers such as are used in battery chargers, A and B eliminators, A. C. receiving sets, and other power supply devices are attached to the 110 or 220 volt line to step up or step down the voltage according to what apparatus is to be operated from it.

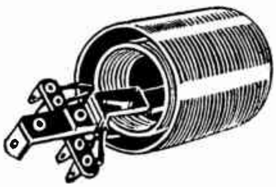
In nearly all power transformers in use for electrical transmission of power, the wire for both coils of the transformer is insulated, and there is additional insulation between the two coils. In most cases, the coils are wound so they have a common iron core which greatly increases their mutual inductance. The iron core is not a solid piece of iron, but is composed of thin sheets of metal. In some transformers there may be no iron core. These are called air core transformers. Air core transformers are often used when dealing with very high frequencies. The mutual inductance of the windings of an air core transformer is necessarily comparatively small. At low frequencies, only small amounts of power can be conveyed from one circuit to another by air core transformers.

RADIO AMPLIFYING TRANSFORMERS

The amplifying transformer used in radio receiving sets, whether of the audio frequency or radio frequency type is a coupling or a link between one stage and another in the building up of signal strength or volume strength. The action of the



Audio frequency transformer.



Radio frequency transformer.

Fig. 14A

amplifying transformer, as it is sometimes called, is based on changes in its magnetic field brought about by fluctuations in current flowing through the primary winding. These magnetic fluctuations, in turn, cause current with similar fluctuations to be induced in the secondary winding.

The purpose of using an iron core is to serve as an ideal path for the magnetic flux or field between the two windings. The iron core is constantly being magnetized and demagnetized and its magnetic polarity is reversed many times per second in audio frequency work. Audio frequency variations range between 30 and 10,000 cycles in the usual broadcast reception. But when it comes to handling of radio frequency currents, calling for frequencies or changes from 300,000 to millions of cycles per second, it is practically impossible to have an iron core, therefore, the iron core is dispensed with and an air core is substituted in radio frequency work.

SELF-INDUCTANCE

The property which is called "self-inductance" causes the generation of a second electromotive force or voltage in any circuit whose current is changing its rate of flow. The flow of current in the circuit may be starting and then increasing, or it may be decreasing and coming to a stop, or it may be changing its direction of flow. Of course, there is a voltage being applied to the circuit in order to cause the flow of current, but the current itself causes a second and different voltage to appear. The ability of the circuit to generate this second induced voltage in itself is called the circuit's self-inductance or simply its inductance, in most cases. The self-induced voltage is called counter-electromotive force.

The induced voltage tries to prevent the current from doing whatever it may be doing at the time. If the current is on the increase, the induced voltage tries to hold it back, tries to prevent its increase; if the current is already decreasing, then the induced voltage tries to keep it going, tries to keep it from decreasing. Such application of self-induction is made use of to act in place of resistance coils in alternating current circuits. Again, in Radio, this principle is made use of to choke a high frequency current from places where it is not wanted. You, no doubt, have noticed such a radio frequency choke coil in many diagrams. Just remember that it works because of the first observation in studying self-induction.

As the effect of self-inductance is that of holding back the current flowing through the circuit, it can be measured just as resistance, and its magnitude expressed in ohms; when so expressed, it is called reactance.

REACTANCE

When only direct current flows through a circuit, it is opposed only by the resistance of the conductors, but when alternating current flows it is opposed by both the resistance and the reactance. We can say that inductive reactance is the effect that a coil of wire has on an alternating current. Every coil of wire has inductance, that is, any change of current in a coil causes a voltage which opposes the change of current. The effect of a coil of wire on alternating current is to hold back the current, or to temporarily choke it. This reactance effect which appears in a coil is called "inductive reactance" because it is caused by inductance. The inductive reactance turns part of the energy of the alternating current into a magnetic field around the coil, or causes such a field to be built up. As this magnetic field collapses it returns energy to the circuit and that is why we say that reactance differs from resistance in that it does not lose energy, but stores the energy.

Later on in this text book, we will take up the difference between "inductive reactance" and "capacitive reactance."

OHM'S LAW FOR A. C.

Now, having learned what we mean by reactance in a circuit, we will represent reactance by the letter X, then just like we did with Ohm's Law in the last lesson for direct current, we simply divide the voltage V by the reactance X in order to obtain the value of the current I, or

$$I = \frac{V}{X} \text{ or amperes (effective)} = \frac{\text{volts}}{\text{ohms}} \text{ (effective)} \quad (1)$$

You see, reactance is spoken of as so many ohms, just as the resistance is, therefore, the relation can be expressed in three ways, so that if we know any two of the three things, reactance, voltage, or current, we can always find the third, viz:

$$I = \frac{V}{X} \quad \text{or } V = I \times X \quad \text{or } X = \frac{V}{I} \quad (2)$$

Now it remains for us to find out how to determine what the reactance X is in a circuit. When we have only a coil in the circuit, or rather, no condenser in the circuit, we call the reactance "inductive reactance," since it is due to the inductance. On the other hand, if we have only a condenser in the circuit, we would have "capacitive reactance," since it would be due to the capacity in the circuit. Then again, we have a combination of these, which will be explained later.

CONDENSERS

A condenser is formed by any two surfaces of metals separated by some insulation; each metallic surface or plate may be in one piece or composed of several plates connected together. The capacity, that is, the amount of electricity which will be stored in the condenser at a given voltage increases as the area of the plates used is made larger, as the number of plates is increased, or as the dielectric between the plates is made thinner.

A simple explanation of the action of a condenser may be explained by water analogy. If a rotary pump is connected to a tank of water and in the center of this tank is stretched a piece of rubber as shown in Figure 15, when the pump rotates, the water from A will be pumped up and compressed in B, in which case the rubber will be forced out of shape until the back pressure is sufficient to prevent any more water from filling B. This is equivalent to a condenser connected to a battery supplying direct current to the circuit. In which case the condenser gets charged until full, when no more current can flow. In the tank, the amount of water which B can hold depends upon its size. In the condenser, the quantity of electricity stored up (at a given voltage) depends upon its capacitance (surface area and number of plates). In the water tank, the thinner the rubber sheet, the more water B will hold because the thinner it is, the further it will stretch, as shown in Figure 15. In the condenser, the thinner the dielectric or insulation between the plates, the more electricity the condenser can store at a given voltage. It can be clearly seen from the foregoing explanation that direct current will charge a condenser but cannot flow through the circuit once it is full.

Now, taking the same analogy to show the effect of an alternating current in the same kind of circuit, suppose the rotary pump is replaced by one having a reciprocating motion representing an alternating current generator. See Figure 16. One may easily see that the water may flow back and forth through the pipe when the piston is operating, the pressure in A and B moving the rubber sheet up and down in accordance to the motion of the water. In an electrical circuit, as shown in Figure 16, the alternating current can flow in a similar manner because the condenser is charged and discharged at each reversal of the alternating current.

$$C = \frac{\text{capacity of one condenser}}{\text{number of condensers}} = \frac{.001}{2} = .0005 \text{ mfd.} \qquad (3)$$

To increase the capacity in a circuit, several condensers may be connected together in parallel. In this case, the total capacity is equal to that of all the condensers added together. For example, if three condensers of .001, .002 and .0005 mfd. capacity were connected in parallel, the total capacity is .0035 mfd. **When condensers are connected in series, the total capacity is lower than that of the smallest one in the group.** For example, if two .001 mfd. condensers are connected in series, the total capacity is .0005 mfd.—that is, half the capacity of one of the condensers.

The formula (3) on page 22 can only be used when all condensers have the same capacitance.

Condensers when connected in a circuit through which alternating current flows, oppose the flow of current to a certain extent, depending upon the frequency. For a given capacity, the lower the frequency, the less current will pass through the condenser until zero frequency is reached, when no current at all can flow through it. It is as though the resistance in the

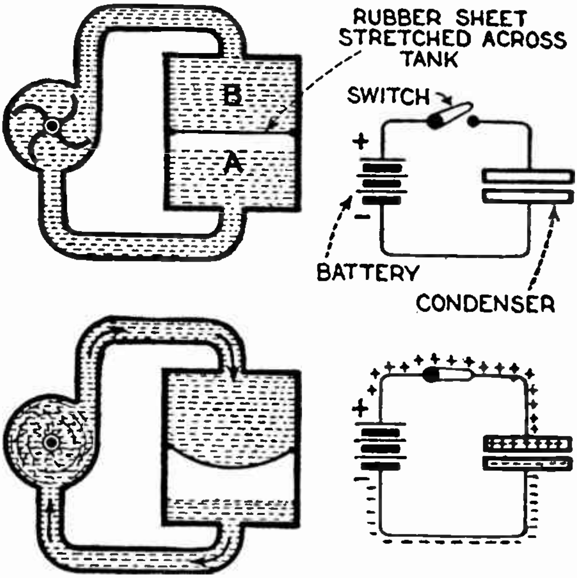


Fig. 15—Hydraulic analogy showing how a condenser is charged with direct current.

circuit were automatically increased as the frequency decreases. This effect is called "reactance" and explains why it is necessary to use large capacities when low frequencies must pass through a condenser, as for instance, in a resistance coupled audio amplifier where the low frequencies (low notes) cannot be satisfactorily amplified by the tubes if the coupling condensers are too small.

CAPACITIVE REACTANCE

Reactance, as stated before, is the name given to the opposition of flow of alternating current when this opposition is caused by the inductance of a coil, or by the capacity of a condenser. Reactance is measured in ohms. The total opposition to the passage of an alternating current through a circuit is grouped under the head of **impedance.** Reactance is called the reactive component of the circuit impedance. Reactance caused by a condenser capacity is called capacitive reactance. Either kind of reactance may act to hinder the flow of alternating current. **Inductive reactance, the reactance of a coil, increases with the increase of frequency and is often called positive reactance. Capacitive reactance, the reactance of a condenser, grows less with increase of frequency, and is often called negative reactance.** The values of inductive reactance may be preceded by the positive sign plus, while the value of capacitive reactance may be preceded by the negative sign minus. When the frequency is measured in kilocycles and the inductance in millihenries, the inductive reactance in ohms is as follows:

Inductive reactance = 6.2832 x frequency x inductance.

The same formula holds true when the frequency is measured in cycles, and the inductance in henries. If the frequency is measured in kilocycles and the inductance in microhenries, the formula becomes:

Inductive reactance = .0062832 x frequency x inductance.

The number 6.2832 is the approximate value of 2π the Greek letter which stands for the ratio of a circle circumference to its diameter. When the frequency is measured in cycles and the capacity in microfarads, the capacitive reactance in ohms is as follows:

Capacitive reactance = 159,154.6 ÷ frequency x capacity.

If the frequency is measured in cycles and the capacity in micro-microfarads, the formula becomes:

Capacitive reactance = 159,154,600 ÷ frequency x capacity.

159,154.6 and 159,154,600 are constants which are necessary to use in these formulas.

If the inductive reactance which is considered as a positive quality just equals the capacitive reactance which is considered a negative quality, the two will balance each other so that there is no effective reactance remaining in the circuit. The only opposition then remaining to the flow of alternating current at the particular frequency being considered is the resistance, and the circuit is resonant at that frequency.

To a direct current, a condenser has extremely high resistance. In fact, to direct current whose voltage is not great enough to break through the dielectric, the condenser forms an open circuit or an infinitely high resistance. A condenser does not offer this infinitely high resistance to alternating current, but offers only reactance. Here again, the reactance does not cause a loss of energy but stores it on the plates of the condenser in the form of electric charges which will return the energy to the circuit.

To an alternating current of given voltage and amperage, a large condenser has less reactance than a small one and the larger the capacity of the condenser, the less is its reactance to a given current and voltage.

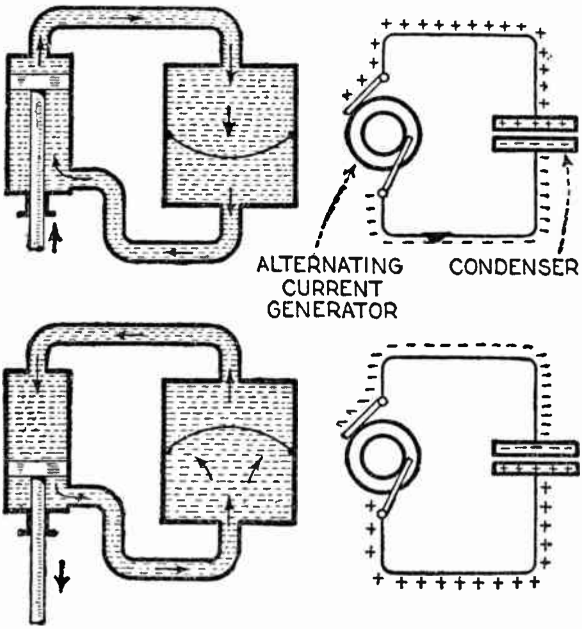


Fig. 16—Hydraulic analogy illustrating the flow of alternating current through a condenser.
(Courtesy of Radio Electric Laboratories.)

IMPEDANCE

Impedance is the effective resistance or opposition to flow of current in an alternating current circuit when this circuit contains in addition to ohmic resistance, inductance, capacity, or both. Impedance is measured in ohms. The impedance of a circuit is the combination of the circuit reactance and its resistance, but the impedance is not equal to the sum of the reactance and the resistance, but is equal to the square root of the sums of the squares of the resistance and the effective reactance. This is shown by the following formula (4):

If a circuit contains only resistance and inductance, the impedance is found by using a number of ohms resistance and a number of ohms inductive reactance, using the formula given below. If a circuit contains only resistance and capacity, the impedance is found from the ohms of resistance and the ohms of capacity reactance, but when a circuit contains both inductance and capacity in addition to resistance, it is necessary to first compute the effective reactance of the inductance and capacity together. This net value of the total reactance is then used in the following formula.

$$\text{Impedance} = \sqrt{(\text{ohmic resistance})^2 + (\text{effective reactance})^2} \qquad (4)$$

With both inductance and capacity in a circuit, the tendency is for them to balance each other and the net reactance is the difference between the two reactances. If the inductive reactance be greater, as is usually the case, the capacitive reactance is subtracted from it. If the capacitive reactance is greater than the inductive reactance, then the inductive is subtracted from the capacitive reactance to obtain the net or effective reactance. The current in amperes which flows in an alternating current circuit is equal to the number of volts divided by the number of ohms impedance, thus:

$$\text{Amperes} = \text{volts} \div \text{impedance}. \qquad (5)$$

NOTE.—It is not necessary for students to spend much time on the formulas given in this text book, but you may find them useful when studying advanced text books.

RESONANCE

The flow of alternating current in a circuit is opposed by three things: The resistance, the inductive reactance and the capacitive reactance. The resistance is due to resistance of the various conductors in the circuit and to the connections between them. It may be reduced by using conductors of the proper size and of good conductivity, but resistance cannot be completely eliminated from any circuit. The inductive reactance depends on the inductance in the circuit—the greater the inductance in the coils and other parts, the greater the resultant inductive reactance. The capacitive reactance depends on the capacity of the condensers and other parts in the circuit. The greater the capacity, the less the capacitive reactance.

When we speak of **adjusting the capacity and inductance to resonance,** we refer to **resonance at a certain frequency.** When the inductive and capacitive reactances are equal and their effects are neutralized the circuit is said to be in a state of resonance. In a simple circuit containing inductance and capacitance in series, at any given frequency, there are certain values of capacity and inductance which cause resonance at this frequency, but at no other frequency. If the frequency in the alternating current circuit should change, it would be necessary to make a different adjustment of either inductance or capacity in order that the resonant condition might again be obtained at the new frequency. This is why we must readjust dials for other stations. When a given adjustment of capacity and inductance or a given relation between their reactance will balance out for one certain frequency and a current at this frequency will then flow through the circuit in maximum volume, although currents at other frequencies still will be opposed by the reactances, the circuit is then said to be in resonance at that frequency.

If the frequency is lowered, either the inductance, the capacity, or both, must be increased to maintain resonance. If the frequency is increased, then the capacity, the inductance, or both, must be decreased to maintain resonance. In other words, the greater the frequency, the less must be the capacity and inductance, and the lower the frequency, the greater must be the capacity and inductance.

This is the principle of tuning a Radio receiving set to incoming signals, when we adjust the capacity of the variable condenser or vary the number of turns of wire on the tuning coil or both so that the reactance is as little as possible, or as we do generally, actually make it zero.

In other words, when we tune a circuit like the ones we have in Radio receivers, we adjust the reactances so that their sum is zero. Generally, we do not adjust the inductance (of the coil) but only adjust the capacity. That is why we always use a variable condenser for tuning. Suppose we are trying to receive a signal which has a certain frequency; then, when the current due to the signal flows through the tuned circuit, the coil has a certain reactance to it, and the condenser likewise has a certain reactance to it. In general, this reactance will be enormous, perhaps millions of ohms; but, as we turn the variable condenser dial, we change the capacity of the condenser so that we are at the same time changing its reactance to the incoming signal. Soon we find a position on the variable condenser dial at which we begin to hear the signals; this means that we have so adjusted the reactance of the condenser that when summed up with the reactance of the coil, the net reactance is no longer very great. In reducing the net reactance, we have permitted a much greater current to flow in the tuned circuit and on account of this greater current we are now able to hear the signals. Before, when the reactance was very high, there was most likely a very small current flowing in the tuned circuit, but this current was so small that we could not hear the signals properly.

Now, finally, as we continue to turn the variable condenser dial, we get to a position where the loudness of the signals is greatest. This is the condition of resonance, as we call it; the circuits are now tuned to the same frequency as the frequency of the incoming signals. If we turn the condenser dial still further, the signals will get weaker, indicating that the circuits are no longer in resonance.

It is clear, then, that there is one certain adjustment of the circuits when receiving signals of a certain frequency, which will result in the loudest signals. This is the condition of resonance as we have said, and is obtained when we make the net reactance of the circuit zero. We do this by making the **inductive reactance,** due to the coil, **exactly equal** to the **capacitive reactance,** due to the condenser, and since we have opposite algebraic signs (that is, one is plus and the other is minus), they sum up to zero. So now, in order to have resonance, we must have this:

Inductive reactance minus capacitive reactance equals zero. This is the same thing as saying that—

Inductive reactance equals the capacitive reactance.

This is the most important thing that we have to learn in connection with tuning and tuned circuits. This relation gives you the principle of resonance, and if you only get to understand it clearly, you will have little or no trouble in your study of Radio. You must first get into your mind the idea of what reactance is; after that, the idea of resonance comes easily enough.

Therefore, before you go on with the following lessons of this course, be sure you understand all that is in this lesson thoroughly. If you fail to understand it fully after the first reading, read over the lesson again.

We have now come to the end of this lesson. The material contained in it is of utmost importance to you in your study of Radio, so be careful that you learn it well and study it hard, for your ability to understand all of the other lessons chiefly depends on your ability to understand this one thoroughly. You have learned how to speak of the inductance of a coil and the capacity of a condenser. You have learned how to find out how much of these things are required in tuning circuits in order to tune these circuits to various wavelengths or frequencies. But you do not yet know how to build a coil so that it will furnish the amount of inductance you require, or the condenser that will have the required capacity. These things are reserved for a future lesson, so you have all you can do at this time to digest all that is in this lesson. Be sure you get out of it all that there is in it.

TEST QUESTIONS

Number your Answers 8—2 and add your **Student Number.**

1. Explain the difference in action between direct and alternating current.
2. What is the frequency of A. C. in cycles per second used for industrial purposes?
3. Upon what does the intensity of the field and the density of the magnetic lines of a solenoid depend?
4. What effect does an iron core have on a solenoid?
5. Who discovered the principle of electromagnetic induction?
6. State three ways in which a current can be induced in a coil of wire.
7. What kind of current is produced by induction?
8. Upon what will the voltage and current of the small generator, Fig. 10, depend?
9. Does the amperage as well as the voltage increase in the secondary of a step-up transformer?
10. What is the result of connecting condensers in Parallel? In Series?

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Radio-Trician

(Trade Mark Reg. U. S. Patent Office)

Lesson Text No. 9

3rd Edition

PRINCIPLES OF RADIO COMMUNICATIONS

Originators of Radio Home Study Courses

··· Established 1914 ···

Washington, D. C.

"Resolve to be Self Independence thyself; and know, that he who finds himself, loses his misery."—Coventry Kearsey Deighton Patmore.

ACCURACY HABIT

A Personal Message from J. E. Smith

Accuracy. The habit of accuracy is achieved by being careful. Inaccurate persons are usually careless. This habit can easily be formed because we have a ready check on it. The check is the number of mistakes made. Accuracy counts as much as or more than any other one thing. Mistakes mean dollars, serious mistakes may mean business failure. Accuracy is not limited to figures. It applies to principles as well.

How do errors arise? This depends on the kind of work being done. Fundamentally, all errors come from one or two sources. First, insufficient knowledge may be responsible for errors. The radio man should know where mistakes are liable to occur and be on the lookout at these points. Second, bad mental habits are responsible for most mistakes. The habit of skimming over one's work; the habit of inattention to details is the cause of much trouble.

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Radio-Trician's

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

PRINCIPLES OF RADIO COMMUNICATIONS AND PRODUCTION OF RADIO WAVES

To obtain a good idea of the nature of the electric currents which are induced in a receiving antenna by **electromagnetic waves**, it is necessary to have a general conception of the principles of Radio communications.

Radio communications depend upon the travel of Radio frequency waves **from** the transmitting aerial **to** suitable apparatus

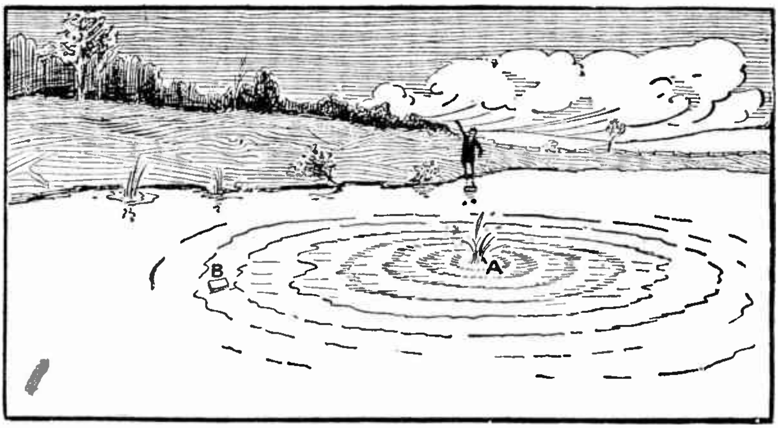

Fig. 1—Picture showing how waves are produced in a pond by throwing a stone in the water at "A." This stone starts a series of concentric ripples or waves, which spread out in all directions, affecting the piece of wood "B." The stone "A" may be compared to a Radio transmitting station and "B" to a receiving station.

at the receiving station. The receiving apparatus makes the signals, sent out from the transmitter, intelligible.

To understand how **code, speech, music** or **television signals** can be reproduced at a receiving station many miles away from the transmitting station, a study of wave **motion** and its characteristics is essential. A Radio wave may be defined as a propulsion of **motions** through a **medium** called the **ether.**

A false impression exists in many minds that it is the medium which actually travels away from the point of the original disturbance which caused the wave. It should be clearly understood that the **medium** as a **whole does not travel** and, except for an up-and-down or to-and-fro motion while a wave is passing, remains where it is.

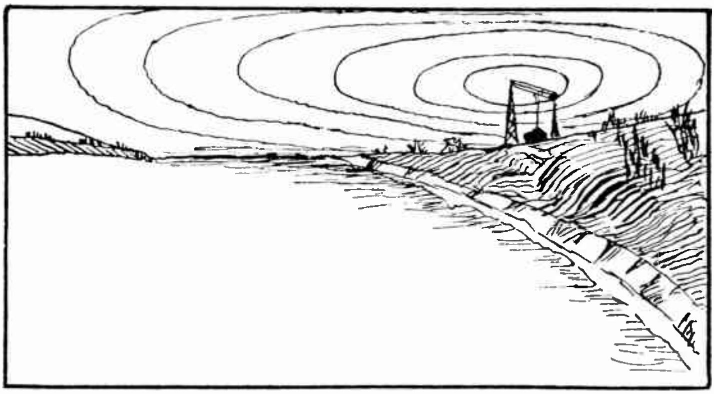

Fig. 1(a)—Picture illustrating how the electromagnetic waves from a Radio transmitting station, while not visible, are radiated in much the same manner as water waves.

Scientists have gradually realized that everything we see, hear and feel is due to waves generated in a **medium** which seems to be everywhere.

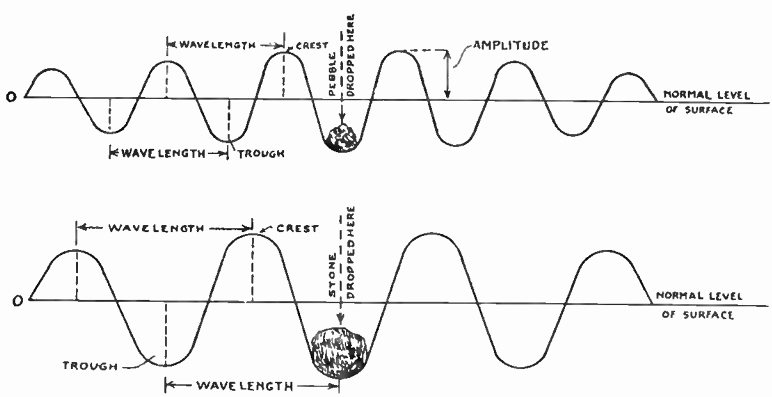

Fig. 2—Illustration showing what happens when a pebble and a large stone is thrown in still water. The pebble produces small waves; the large stone, large waves. Measured from crest to crest or trough to trough we obtain the length of the wave.

That such a substance actually exists has long been doubted, but the study of the phenomena in connection with the transmission of heat, light, and electricity shows that they are all due to wave action which cannot be explained unless we assume there is a medium through which, or on the surface of which, these waves travel.

PROPERTIES OF WAVE MOTION

Everyone is familiar with the "to-and-fro" motion of water, which we call "waves." When a stone is thrown into a quiet

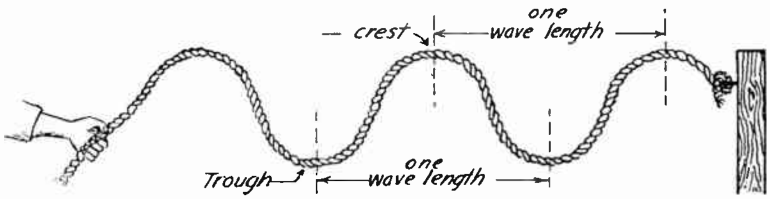

Fig. 3—Illustration using a rope to show a wave motion.

pond **little waves are produced,** which spread out from the starting point in all directions until they meet the shore, or die away. This is clearly illustrated in Figure 1.

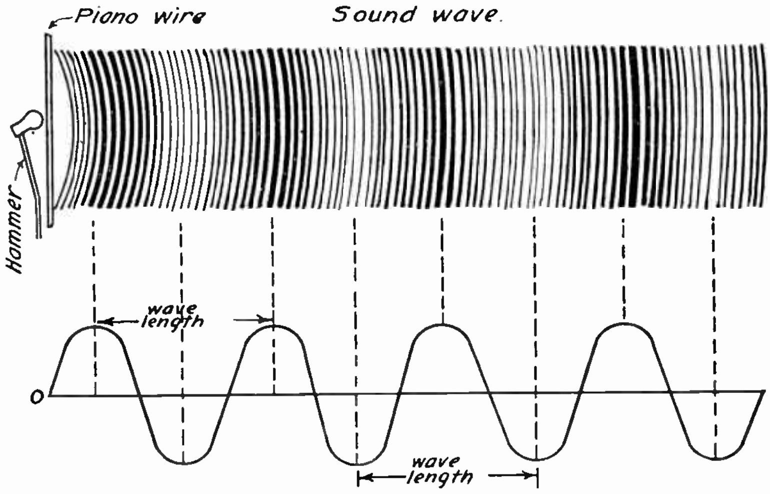

Fig. 4—Picture showing how a piano wire when struck by a hammer radiates waves set up by the vibrations of a wire.

We can **produce** "waves" in water by various methods, but whatever method we use, it is always done by something that will cause the surface of the water to move up and down. In other words, we must have some contact between a moving body and the water. For instance, wind will produce waves in water. The moving air comes in contact with the water and imparts motion to it.

If a rope supported at one end is shaken briskly up and down, a wave-like motion is given to it, which will travel down its length. If the rope is shaken twice, two waves will be started which travel away to the other end, keeping always the same distance apart. If the shaking is repeated rhythmically, a con-

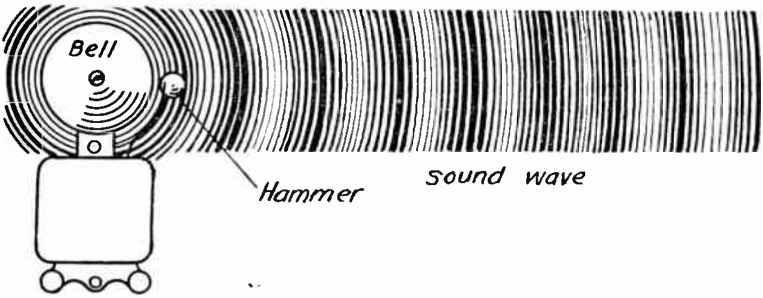

Fig. 5—Sound waves spread out in all directions from a bell.

tinuous wave motion is started which transmits the energy imparted by the hand to the other end of the rope. The **high points** of the wave are called the **crests**; the low ones, the **troughs**. The **distance between two successive crests is the wave length. The height of the crest above the normal or the**

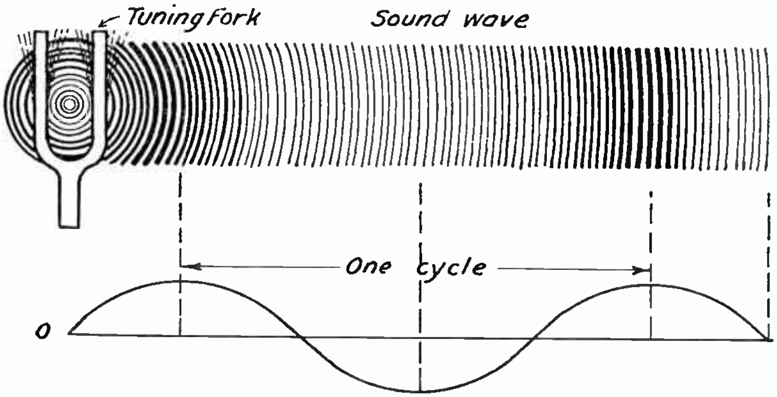

Fig. 6—Illustration showing how sound waves may be represented by using an alternating curve.

depth of the trough below normal is the amplitude, while the number of cycles (complete waves per second) at which the waves apparently travel is called the frequency. The latter is sometimes expressed by the number of waves passing a given point each second. Many of the most familiar phenomena of every-day life are caused by wave motions. Sound is transmitted by means of waves in the air. Every musical note is produced by causing the air to vibrate a certain number of times per second. Light and heat are transmitted by exceedingly short waves (high frequency).

NATURE OF RADIO WAVES

Radio waves in the ether are produced in a similar way to water waves—by the motion of something that affects the ether. The only known thing that is capable of affecting the ether is the **electron** and the only way that electrons can produce waves in the ether is by moving rapidly to-and-fro. Thus, to produce a Radio wave we must have a rapid to-and-fro movement of electrons. The moving electrons produce Radio waves and the

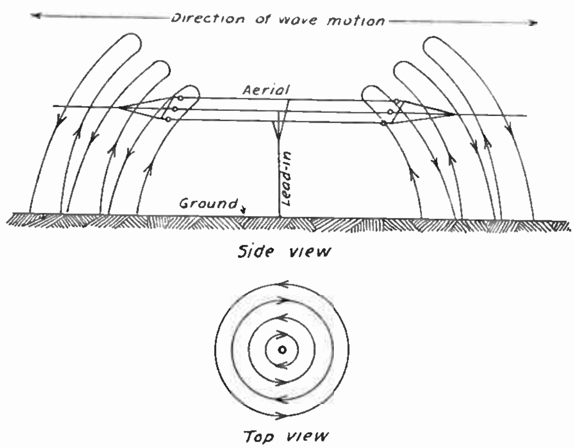

Fig. 7—Drawing illustrating how Radio waves are produced around a transmitting aerial.

Something very similar to the waves on a pond. If in some way they could be made visible they would look like this when looking down from above upon the aerial also from the side view.

Radio waves produced are similar in every respect to the motion of the electrons producing them. In other words, the Radio waves used for communication are **produced by electrical energy,** which is caused to move up and down in the transmitting aerial system so as to send out these waves in all directions. These waves become weaker the farther they go from the transmitting station, just as water waves become weaker the farther they go from the point where a stone is dropped in a pond.

To make electrical energy move up and down in an aerial system, the proper transmitting equipment must be used so as to cause a high frequency alternating current to flow in the aerial. This is another way of saying that the transmitting apparatus causes powerful electrical oscillations to be set up in the antenna, at a very high frequency. When the electrical energy is in the antenna, it produces an **electric field** between the aerial and ground which is at right angles to the direction of motion of the wave. When the electrical energy moves it produces a **magnetic field.** Thus, it produces both the **electric** and **magnetic disturbances** that go to make up the **electromagnetic waves.**

Figures 7 and 8 give two good illustrations of what is meant by the above paragraph.

Waves of all kinds travel with a **definite velocity.** However, the velocity of different kinds of waves vary to a great degree. Sound waves travel in air with a velocity of about 330

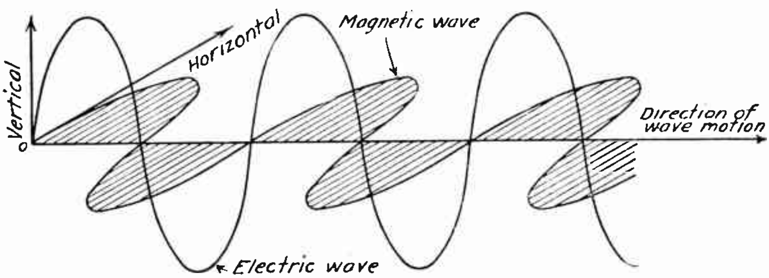

Fig. 8—Drawing showing how Radio waves are theoretically imagined to split into electric and magnetic components.

meters per second, or about 1,083 feet per second. The velocity of light waves in space is 300,000,000 meters (to be more accurate 299,820,000) per second, or about 186,300 miles per second.

It has been demonstrated in many ways that Radio waves are transmitted with the same velocity as light waves and the waves that constitute heat radiation, and that the three, Light, Heat, and Radio, are the **same kind** of waves, but **differ** in frequency. Electric waves, including Radio waves, light waves, and radiated heat waves, are all referred to by the general term **electromagnetic** waves.

ANTENNA SYSTEMS

In order to produce electromagnetic waves by using high frequency alternating current and have these waves radiated into space, it is necessary to use a radiating system known as the antenna.

(1) The condenser antenna. (See Fig. 9.)

(2) The coil antenna. (See Fig. 10.)

The **condenser type of antenna** consists of a system of wires suspended above the earth or above a counterpoise (a somewhat

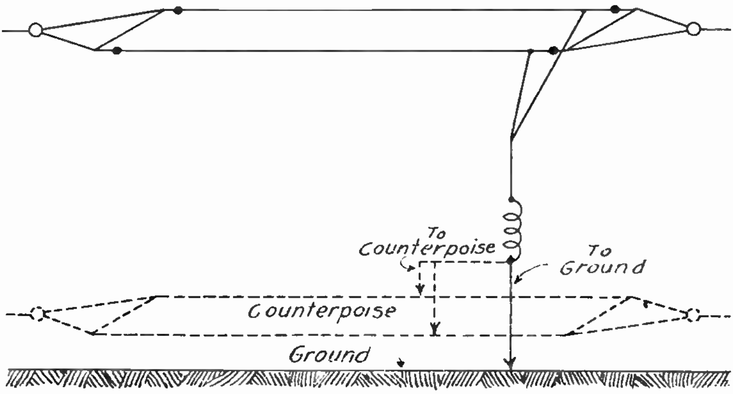

Fig. 9—Condenser antenna.

similar system of wires suspended below the antenna and insulated from the earth) as shown in Figure 9.

The elevated system of wires used in the condenser type of antenna is often called the aerial. The physical dimensions of

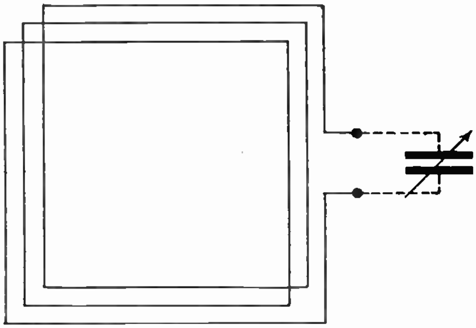

Fig. 10—Coil antenna.

a condenser antenna system will depend upon the use to which this system is to be put, whether for long or short waves (low or high frequency). **Coil antennas** consist of one or more turns of wire, such as illustrated in Figure 10, of varying dimensions and shapes, depending upon the frequency or wave length and use to which they are to be put. Coil antennas having only one turn of wire are usually referred to as loop antennas, although this term is often loosely used to designate coil antennas of any number of turns.

TYPES OF RADIO WAVES

Radio Communication, considered from the standpoint of the waves by which communication is established between stations, may be divided into two classes.

Undamped or continuous waves. (See Fig. 11.)

Damped waves. (See Fig. 14.)

Transmitters employing **"undamped waves,"** made use of Radio frequency waves which form a **continuous series of waves of constant amplitude.** As the generated wave is continuous, this system is also known as the continuous wave system, frequently abbreviated to CW system.

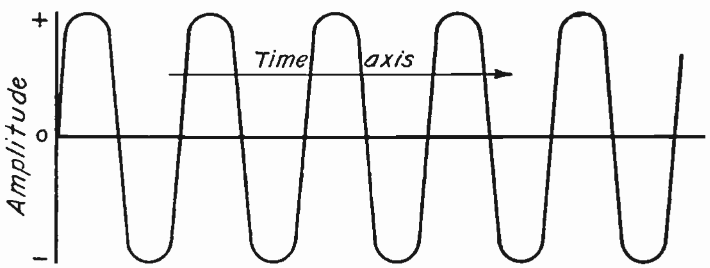

Fig. 11—Continuous (Class A) wave.

PRODUCTION OF UNDAMPED WAVES

There are **three main ways of producing undamped waves,** namely, with a very **high frequency alternator,** with the **oscillating arc,** and with the **vacuum tube oscillator,** the latter being most used at the present time. The theory, operation and construction of Radio transmitters will be taken up in advanced lessons. Undamped waves can be used for telephony and telegraphy. For telegraphy, the undamped or continuous waves are merely **interrupted** (I. C. W.) at intervals, in the form of dots and dashes of the International Telegraph Code (see Fig. 12). A short series of complete cycles of high frequency alternating current comprises a dot, while a longer period would form a dash. In telephony, the undamped waves are **modulated,** that is, **their amplitude periodically varies in accordance with the**

sound vibrations impressed on them by the action of the **microphone** (see Fig. 13) and modulating circuits connected to the vacuum tube oscillator.

A transmitter using **damped** waves for communication sends out a series of waves or wave trains, as they are often called. Each of these trains consists of a **group of damped Radio frequency waves.** (See Fig. 15.)

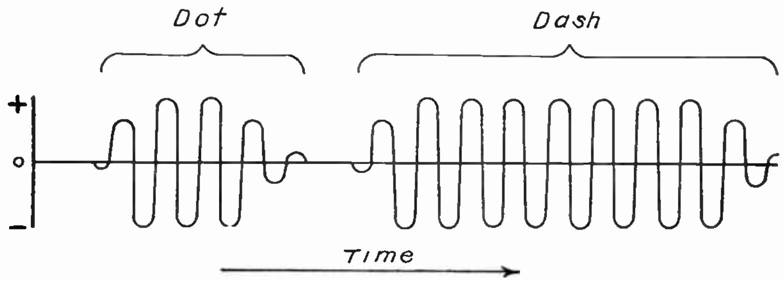

Fig. 12—Key modulated (Type A1) wave representing the letter A.

The **term damped** as used here means that the succeeding waves in the wave train are of **decreasing amplitude.** This type of wave is produced by the discharge of a condenser through a spark gap and an induction coil, one **train of damped waves** occurring for each spark or condenser discharge.

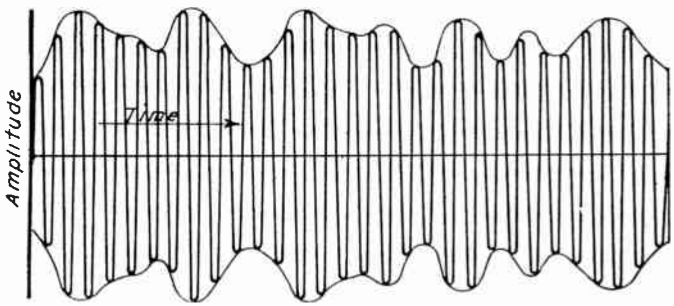

Fig. 13—Type of wave radiated by a radiophone transmitter during modulation (Class A3).

The operation of the entire arrangement is controlled by a transmitting key, which opens and closes the electric circuit. As long as the key circuit is open, nothing occurs. But as soon as the key closes the circuit, the high frequency oscillations are set up due to the rapid condenser discharge through the spark gap and induction coil. This sends waves out from the transmitting aerial. These waves are broken up into trains or groups, however, the trains do not overlap, or even join their neighbors.

An analysis of the radiation as produced by current in an antenna from a damped wave transmitter would show that a very **wide band or channel** in the ether is occupied. This band is many times wider than that produced by the modulated continuous waves of a Radio telephone transmitter. For this reason, spark transmitters, as they are called, which produce damped waves cause a great deal of interference even on frequencies widely removed from that alloted to the transmitting station. As a result, transmitters of this type are being rapidly replaced by more modern equipment radiating either an interrupted continuous wave or a continuous wave modulated at audio frequency.

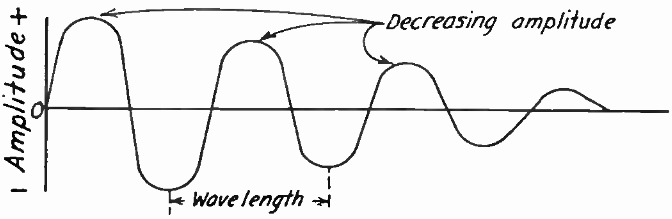

Fig. 14—Damped wave (Class B).

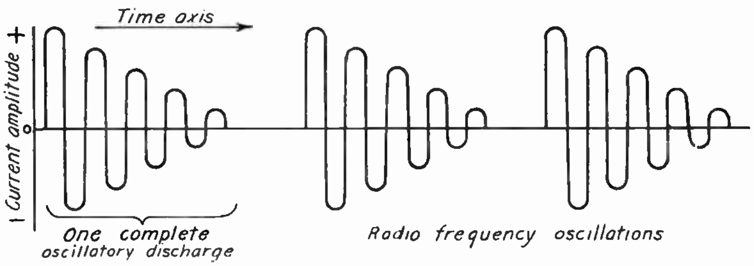

Fig. 15—Graph showing three complete oscillatory discharges as produced by a damped wave transmitter (Class B).

CLASSIFICATIONS AND TYPES OF RADIO WAVES

According to the Radio Telegraphy Convention and General Regulations between the United States and other powers, Radio emissions are divided into two classes (A) Undamped or Continuous Waves, (B) Damped Waves.

Waves of Class "A" include the following types, which are defined here:

Type A-1, Unmodulated continuous waves. Continuous waves, the amplitude or frequency of which is varied by means of telegraphic keying.

Type A-2, Continuous waves modulated at audio frequency. Continuous waves, the amplitude or frequency of which is varied in a periodic manner at audible frequency, combined with telegraphic keying.

Type A-3, Continuous waves modulated by speech or by music. Continuous waves, the amplitude or frequency of which, is varied according to the characteristic vibrations of speech or music.

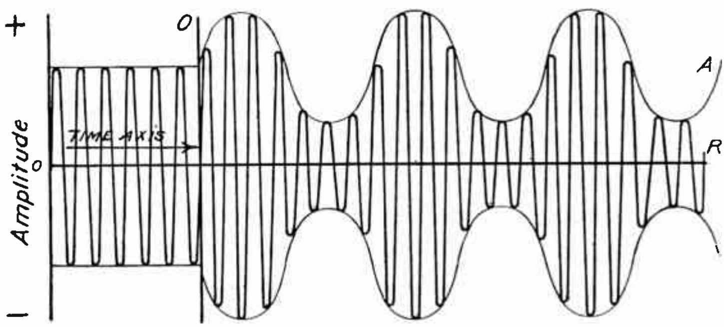

Fig. 16—Sine modulated Radio frequency type A-2 wave.

Let us consider briefly these types of Radio waves with regard to the way in which they are produced. If the high frequency current flowing in the transmitting antenna is a pure sine wave (a wave having amplitude of each separate cycle or oscillation as high above zero as the trough is below) of a single frequency such as shown in Figure 11, and if no peculiar fading phenomena disturb the transmission of energy from the transmitter to the receiving station, then the Radio wave is known as a Class "A" wave (continuous wave).

The drawing shown in Figure 11 may be considered as illustrating the variations of the current in the transmitting antenna as a function of time, or it may be considered as showing the variations of the intensity of the Radio waves as a function of time either near the transmitting station or at the receiving station. The amplitude, of course, will be much less at the receiving station, than close to the transmitting station. It is interesting to note that while the power radiated by a transmitting station may be as high as 50,000 watts (50 kilowatts), the power in the Radio waves at the receiving station is ordinarily only a few millionths of a watt. In other words, the Radio waves rapidly grow weaker as they travel from the transmitter.

KEY MODULATED CONTINUOUS WAVES

Class "A" waves as previously stated are **sub-divided on the basis of modulation.** By modulation we mean a variation in the amplitude (intensity) or frequency of the waves. Radio telegraphy, using continuous waves, is ordinarily accomplished by using dots and dashes made by interrupting the current somewhere in the transmitting system by means of a key. When the amplitude or frequency of a continuous wave is varied by means of telegraphic keying, these waves are known as Type A-1 waves. Figure 12 illustrates a typical Type A-1 wave so keyed as to transmit the letter A in the International **Radio Code.**

AUDIO FREQUENCY MODULATED WAVES

Figure 16 illustrates a second type of wave known as Type A-2, which we must give consideration as it is a continuous wave modulated at a single audio frequency. The portion to the left of the line O has been left unmodulated. If you follow curve A which determines the amplitude of this wave, you will note that this also is a sine wave, but of much lower frequency than the Radio wave. Such a continuously modulated wave is obtained by superimposing upon a Class "A" wave, a frequency somewhere within the range of the human ear. It is essential to consider the characteristics of Type A-2 waves in detail prior to the consideration of waves which have been modulated at different audio frequencies by speech and music.

The line to the left of the axis O, in Figure 16, represents the high frequency unmodulated wave. To the right of O, the line marked A, corresponding to the sine wave single audio frequency which is superimposed upon the Radio frequency wave. For the purpose of explanation, let us give specific values to the Radio frequency and audio frequency waves. Let us assume that the Radio frequency curve represents a wave having a frequency of 1,000,000 cycles per second. Let us further assume that the audio modulated component has a frequency of 5,000 cycles per second. Figure 16, therefore, represents a Radio frequency current of 1,000,000 cycles modulated by an audio frequency of 5,000 cycles.

Sound waves produced by the vibrations of the human voice and musical instruments as stated previously do not follow a pure sine wave like that shown in Fig. 16. Sound vibrations are made up of numerous frequencies (harmonics) and overtones resulting in the transmission of a wave of varying amplitude. Thus, the wave form of a single vowel sound, as pronounced by the vibrations of the voice, must produce a curve similar to that shown in Figure 17(A). In many cases the wave form is even more complicated, but it invariably repeats itself at regular intervals.

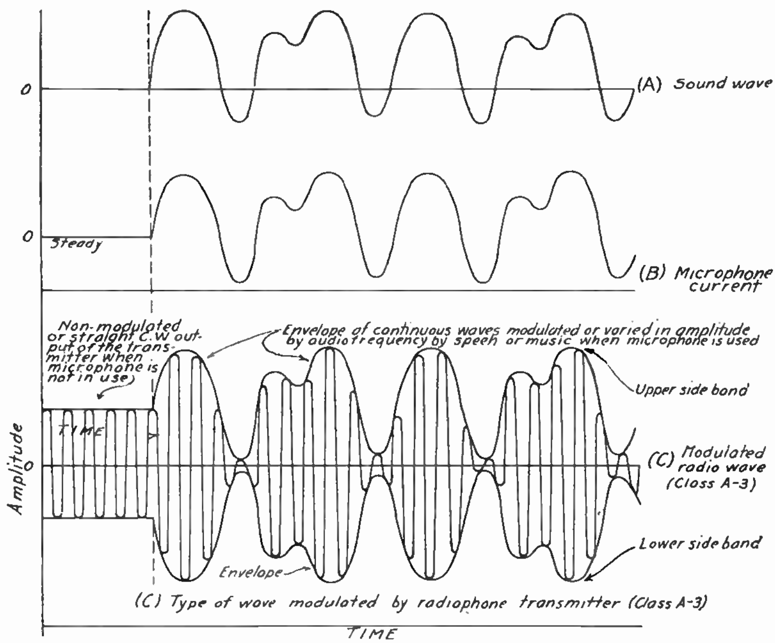

Fig. 17—This drawing shows how the high frequency oscillations are modulated according to the characteristics of the audio frequency sound waves impressed upon them from the microphone.

In the communication of speech or music by Radio, these complicated waves must be exactly transmitted and again reproduced at the receiving station. This would be practically impossible were it not for the great difference in frequency between Radio waves and sound waves.

The continuous high frequency waves act as the carrier of the low frequency sound waves. This is accomplished by varying the amplitude of the continuous high frequency waves and thus the variations in amplitude conform to the frequency in wave form of the sound waves.

The illustration shown in Figure 17(C) shows how the sound wave form and frequency are carried by the Radio wave. This type of wave is known as Type A-3.

At the transmitting station the transmitting apparatus **generates and radiates a constant stream of Radio waves of high frequency.** The **fluctuations** of the **microphone current** (see Fig. 17(B)), produced by the voice or music are **amplified** and applied to the generator of Radio waves in such a way that the amplitude of the **Radio waves rise and fall** at this **applied frequency**, thus preserving the **wave form** and frequency of the sound waves. In other words, the amplitude of the Radio frequency waves is varied only while sound waves are striking the microphone. At the receiving station the modulated high frequency wave is induced on the receiving antenna, amplified by the receiving vacuum tubes, the detector tube irons them out so to speak and leaves the audio frequency wave to be amplified so as to enter the loud speaker reproducing the audio signals. Reception of various waves and different receiving systems will be taken up in detail in advanced text-books.

MEASUREMENTS OF WAVES

In determining the character of the various Radio waves, we usually speak of their frequency expressed in **cycles** or **kilocycles** per second, or their **wave length,** which is the distance between successive wave crests measured in meters.

Any wave whatsoever, a Radio wave in the ether, a sound wave in the air, a water ripple on the surface of a pond, consists of a succession of pulsations moving along one after another. Most waves will have a succession of regular crests and troughs like ocean waves or like the electric waves as illustrated in Figure 18.

The part of the wave measured from the **crest of one wave to the crest of the next** following wave is called **one complete wave** or cycle. Its length, that is, the distance between successive wave crests, is one **wave length.**

The **frequency** of a wave is merely the number of crests in a complete wave that pass in one second, or what is the same thing, the number of **wave lengths** in the distance the wave moves in one second.

For example, let us consider the arrival of a moving wave at some fixed point, such as the arrival of a sound wave at your ear.

The wave reaches your ear as a succession of regularly timed pulsations, one pulsation for each wave crest. Each pulsation pushes slightly against your ear drum. This causes the drum of the ear to vibrate; inward for each pulsation, outward again during each interval between pulsations. The number of these back-and-forth vibrations of the drum a second is the same as the number of pulsations of the wave that arrive a second; that is, it is the same as the frequency of the wave. The higher the frequency, the higher the pitch of the sound seems to your ear.

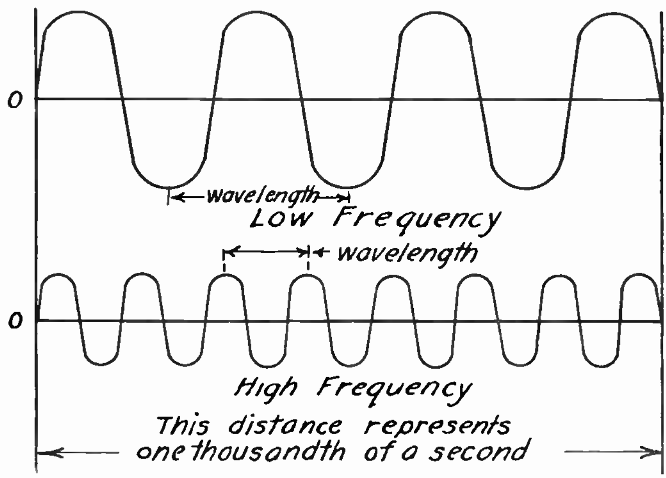

Fig. 18—This drawing illustrates the relation of frequency to wave length, The higher the frequency the lower the wave length. the lower the frequency the higher the wave length.

What you really hear, then, is the frequency, not the wave length. Frequency, indeed, is always a more characteristic property of waves than is length. **Wave length depends on the frequency of the wave,** and the speed depends not only on the kind of wave but on the medium in which the wave is traveling. For example, sound waves move faster in water than they do in air. The wave length of a sound wave will be greater in water than in air, but its frequency will be the same. It is the frequency, not wave length that is important to us.

Similarly, when you modulate or impress a sound wave onto a Radio frequency wave, the wave length of the two waves do not matter, because what is impressed on a Radio carrier wave is not a wave length—it is a frequency. The **"Radio"** wave is a high frequency wave in the ether. The **sound** wave is a low frequency wave in the air. The factors that really determine the relation of the two waves, the factors that you need to take account of in modulation calculations, are the respective frequencies of the two waves.

This is one reason why frequencies are used at the present time instead of wave lengths. The use of frequencies makes all kinds of waves directly comparable. Modulation calculations are easier. Interference, harmonics and all other mutual relations of waves are more directly discoverable.

A **cycle** is a reversal from zero to positive, to zero—then from zero to negative and back again to zero, when speaking of the path of electricity in an alternating current circuit or the impulses creating the field of a Radio wave. "Cycles" used as a measure of the rapidity of these changes implies always per second, and "kilocycles" is simply a short expression for thousands of cycles per second.

The **kilocycle**, therefore, is merely a unit of frequency, just as the meter is a unit of wave length. In electrical terms, a cycle means one complete wave, measured, as usual, from one crest to the next following one. The frequency may be expressed, therefore, in cycles. It is the number of cycles a second. An alternating current, for example, may have 60 cycles a second, which means the same as the frequency of 60 cycles.

One kilocycle is merely 1,000 cycles, just as one kilometer is 1,000 meters or one kilowatt is 1,000 watts. To say that a station is transmitting on a frequency of 1,000 kilocycles means that it is using a frequency of 1,000,000 cycles, that is 1,000,000 complete waves a second. In other words, it means that there will be one million double changes per second in the polarity of the Radio wave as measured at any point in its progress.

WAVE LENGTH FREQUENCY CONVERSION

To calculate the frequency or wave length requires a knowledge of the velocity or speed of the waves. Radio waves move with the speed of light. According to the most accurate experimental determinations, this speed (in vacuum) is 186,300 miles a second, or 299,820,000 meters a second. For ordinary calculations, Radio engineers use a round number of 300,000,000 meters a second.

A train of waves that has 1,000 kilocycles (which is the same as 1,000,000 complete waves) a second will move in that second 300,000,000 meters. The length of each wave will be,

TABLE NO. I.

TABLE OF ALL THE ETHER WAVES NOW KNOWN

		FREQUENCY	WAVE LENGTH	
		.02 KILOCYCLE (20 VIBRATIONS PER SECOND)	15,000,000 METERS	
AUDIO FREQUENCY VIBRATIONS	10.6 OCTAVES			THE AUDIO FREQUENCY AND THE RADIO FREQUENCY OVERLAP
		30 KILOCYCLES	10,000 METERS	
USUAL RADIO WAVES	6.7 OCTAVES			HERE BELONG ALL ORDINARY RADIO WAVES.
		3,000 KILOCYCLES	100 METERS	
SHORT ELECTRIC WAVES	16.7 OCTAVES			THESE WAVES HAVE BEEN USED ONLY EXPERIMENTALLY. HERE BELONG, ALSO, THE RADIO HEAT WAVES RECENTLY DISCOVERED BY DR. E. H. NICHOLS. ALL THESE WAVES WILL PROBABLY BE QUITE IMPORTANT IN THE FUTURE.
		300,000,000 KILOCYCLES	.001 METER (10,000,000 ANGSTROM UNITS)	
HEAT WAVES	10.3 OCTAVES			ALSO CALLED THE INFRA-RED RAYS.
		387,000,000,000 K.C.	7750 ANGSTROM UNITS	
LIGHT WAVES	1 OCTAVE			
		759,000,000,000 K.C.	3900 ANGSTROM UNITS	
ULTRA-VIOLET LIGHT	3.7 OCTAVES			
		10,000,000,000,000 K.C.	300 ANGSTROM UNITS	
X-RAYS	11.6 OCTAVES			RAYS THAT PENETRATE MOST KINDS OF MATTER.
		30,000,000,000,000,000 K.C.	.1 ANGSTROM UNIT	
GAMMA RAYS	3.3 OCTAVES			FROM RADIUM
		300,000,000,000,000,000 K.C.	.01 ANGSTROM UNIT	
UNEXPLORED REGION, WAVES STILL SHORTER THAN GAMMA RAYS				

(Note)—The Angstrom Unit used in the above table is the common unit for the length of light waves, equals one ten billionth of a meter. It is named after Dr. K. A. Angstrom who was the first to study and chart the spectrum of sunlight.

therefore, 300,000,000 meters divided by 1,000,000. This means the "crests" will be at points 300 meters apart along the path of a 1,000 kilocycle wave. We have here the idea of simple waves, corresponding to waves in water with approximately equal spaces between their tops or crests.

Here are the "rules" for conversion from "wave length" to "frequency" and vice versa.

To convert the wave length in meters into the frequency in kilocycles divide the wave length into 300,000.

$$F = \frac{300,000}{WL}$$

The reverse rule is the same:

To convert the frequency in kilocycles into the wave length in meters, divide the frequency into 300,000.

$$WL = \frac{300,000}{F}$$

The speed or velocity of Radio waves in air and in non-conducting materials is nearly the same as in a vacuum.

These "rules," therefore hold for all ordinary calculations.

By way of comparison, the speed of sound waves in air under ordinary conditions is about 1,083 feet a second (330 meters a second) not much over one millionth of the speed of Radio waves. The speed of sound waves in water is about 1,500 meters a second.

Not only Radio waves, but all kinds of ether waves are designated most conveniently by their frequencies. Table No. 1 gives in convenient form for reference all the ether waves now known with their frequencies and the corresponding wave lengths. The term **"octave"** is borrowed from music. **One octave means all the waves between any particular frequency and a frequency twice as great.** For example: The first octave includes all the waves between a frequency of 20 cycles a second and a frequency of 40 cycles a second; the second octave is from 40 to 80 cycles a second, and so on.

The entire series of ether waves, from the longest Radio wave to the shortest **gamma rays** is shown in the table No. I.

The divisions of the waves into Radio waves, heat waves and light waves are made merely for convenience. All the waves belong, really to one unbroken series. Many of the divisions overlap, just as the heat waves overlap the short Radio waves and the X-rays overlap the ultra violet. There is a similar overlap of the audio frequency and the Radio frequency waves.

The ether waves that have been most studied by scientists are those of light. These differ from the longer and shorter waves only in that they can be perceived by the human eye. Physically all the waves are the same. The color of light depends upon its frequency, and hence also upon its wave length.

ALLOCATION AND USE OF FREQUENCIES (WAVE LENGTHS) AND TYPES OF EMISSIONS

The Federal Radio Commission at Washington, D. C., assign the frequency or wave length for each individual station. Broadcasting stations in the United States are today assigned to frequencies which lie between 550,000 and 1,500,000 cycles per second approximately; that is, between 550 and 1,500 kilocycles (kc). We speak of those frequencies lying between 550 kilocycles and 1,500 kilocycles as lying within the broadcasting **band, or spectrum.** The broadcasting spectrum now consists of frequencies as indicated above, which correspond to wave lengths ranging from approximately 545 meters down to 200 meters. The entire Radio **spectrum** assigned to various services such as Ships, Aircraft, Army, Navy and Amateur Stations, etc., may be considered as extending in wave lengths from 30,000 meters down to about 5 meters, or in frequencies, extending from 10 kilocycles to 60,000 kilocycles per second.

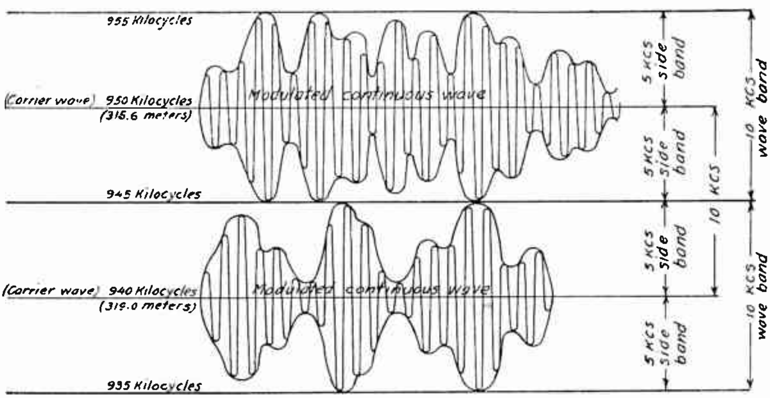

Fig. 19—Illustration showing the upper and lower side bands of modulated continuous waves and the relation of wave bands to each other.

UPPER AND LOWER SIDE BANDS

When a transmitting station sends out an **unmodulated** Class "A" wave, as stated previously, we are transmitting only

one single frequency. Thus, the energy radiated by a wave having the form given to the left of the axis O, as illustrated in Figure 16, consists of one frequency only and that frequency on the basis of our illustration is 1,000,000 cycles or 1,000 kilocycles per second. If, however, we were to analyze completely the frequencies present in such a wave, as shown to the right of the axis O, we would find an entirely different state of affairs existing. If the Radio frequency or carrier frequency, as it is usually called, is 1,000,000 cycles (1,000 kilocycles) and the modulating frequency is 5,000 cycles, then it can be proven that the wave radiated actually consists of **three separate frequencies.** These frequencies will be (1) 1,000,000 cycles known as the **carrier frequency,** (2) 1,005,000 cycles known as the **upper side frequency** and (3) 995,000 cycles per second, known as the **lower side frequency.** A very good illustration of the above statement is shown in Figure 16.

The fact that the modulation of a carrier wave tends to change the transmission from its single frequency characteristics and to consist of at least three frequencies, one on either side of the carrier frequency, as shown in Figure 16, is of great importance to Radio today. Every transmission takes up a good proportion of the Radio frequency spectrum. The width of the portion or channel occupied, will, of course, depend upon the kind of transmission, more particularly upon the nature of the modulating frequencies which are superimposed on the carrier wave. From this it can be seen that when we modulate a carrier wave by speech or music, there will be an **upper** and **lower** band of frequencies, one band on either side of the carrier frequency. It is this fundamental fact which definitely limits the number of Radio broadcasting stations which can be simultaneously operated between 200 and 545 meters (1500 and 550 kilocycles), without interference with each other. This fact is of such great importance to an understanding of the operation of Radio transmitting stations that we will now proceed to devote further consideration to it, particularly to the operation of Radio broadcasting stations.

AUDIO SIGNALS IMPRESSED ON THE CARRIER WAVES

When we consider the types of Radio waves which are transmitted from a broadcasting station, we must take into consideration the characteristics of speech and music and also the characteristics of the human ear. We have seen that we can associate the terms "frequency" and "wave length" with the Radio waves which are transmitted from a transmitting antenna. Wave lengths and frequencies are associated and one can be computed by making use of known formulas, as given in this text book. Since sound is a wave motion, we can do practically the same thing with sound waves. However, in this case, the transmitting medium is different. Radio waves are transmitted through a medium which we call ether, at a certain velocity per second. Sound waves can be transmitted through air, liquids and solids. The velocity of sound in air is approximately 1,083 ft. per second. The velocity will, to some extent, depend upon the temperature and pressure.

Another difference between Radio waves and sound waves

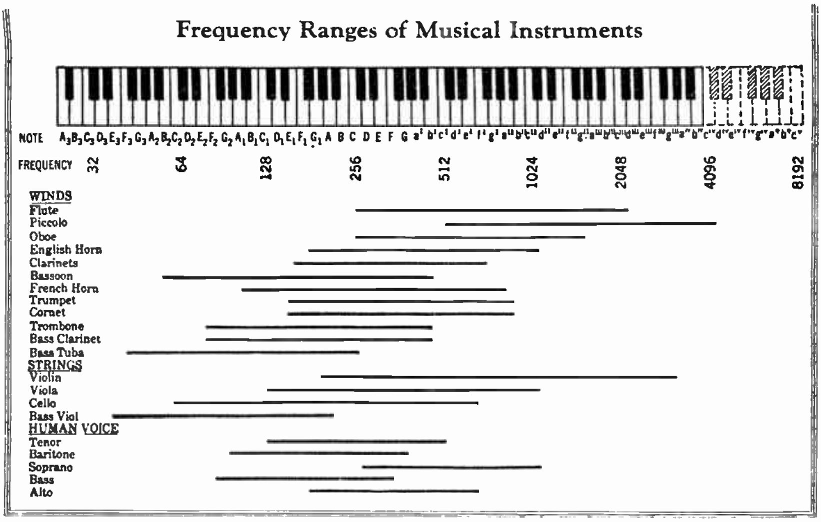

Fig. 20—Relation between frequency ranges of musical instruments, voice and the piano keyboard.

is the range of frequencies which are utilized. Radio waves can be considered as being produced by electrical disturbances of frequencies between 10 kilocycles and 60,000 kilocycles. Sound waves, however, are produced by vibrating mechanical bodies and the range of frequencies which we can classify as sound is considerably less and is composed of frequencies much lower than those given for Radio waves.

The sound spectrum must be confined to those frequencies capable of affecting the average human ear. The deepest organ pipe which can be heard produces a frequency of 16 cycles per second. The highest frequency which can ordinarily be heard by the human ear is somewhat around 15,000 cycles per second. The ability of various individuals to hear frequencies as low as 16 cycles a second and as high as 15,000 cycles per second varies greatly and these may be taken as extreme limits. But, few people can hear, or detect as sound, frequencies as low as 16 cycles, although a relatively large number can hear frequencies as high as 15,000 cycles.

PURE TONES AND HARMONICS

A vibrating source producing sound waves of a single frequency is best to produce a **pure tone.** The **frequency** of the fundamental **sound waves determines** the **pitch.** Musical tones, however, as produced by striking a piano string or bowing a violin string **do not** consist of pure tones, but ordinarily consist of a particular or **fundamental frequency** and in addition a number of other frequencies known as **harmonics.** Harmonics are frequencies which are **multiples of a given frequency** known as the fundamental frequency. Thus, if we strike a piano note, the fundamental frequency of which is 500 cycles, there are present in the air sound wave frequencies of 1,000, 1,500, 2,000, 2,500, etc., cycles. In Radio work, we refer to the frequency having the value twice that of the fundamental frequency as the second harmonic, the frequency having a value three times the fundamental frequency as the third harmonic, and so on.

PITCH AND TIMBRE OF MUSICAL TONES

While the **pitch** of a musical tone is determined by the frequency of the fundamental, **the tone quality or timbre,** as it is often called, depends upon the ratio of the amount of energy in the various harmonics to that in the fundamental. It is these ratios which enable you to determine, even though you may not be able to see the instrument, whether or not the tone is produced by a piano, violin, or a singer. A chart is shown in Figure 21, giving the relative amount of energy in the fundamental frequencies and the harmonics of a musical tone as produced by bowing a violin in a particular way. If the fundamental frequency produced by striking a piano string is 256 cycles per second (middle C in the musical scale), then the second harmonic will be 512 cycles, the third 768 cycles, and the fourth 1,024 cycles, etc.

LOUDNESS OF TONES

As we have pointed out, there are two characteristics of musical tones, pitch and timbre or quality. **Pitch**, as we have learned, depends upon the frequency of the fundamentals. **Timbre** depends upon the relative energy in the fundamental frequency and in the harmonics. There is, however, a third characteristic which we must be acquainted with and that is the term **loudness.** The **loudness** of a tone, of course, will depend upon the amplitude of the vibrating source which produces it. As far as the ear is concerned "loudness" depends upon the amplitude of the sound waves striking the drum of the ear.

When a musical selection is played by an orchestra, or an organ, it requires the utilization of a large number of fundamental frequencies. The range of these fundamental frequencies

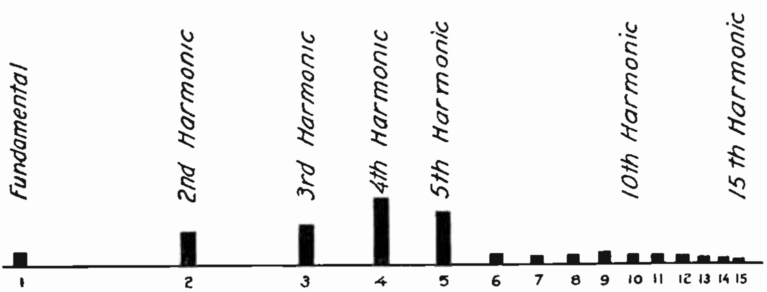

Fig. 21—Distribution of energy among fundamental and harmonics of a musical tone produced by bowing a violin.

which must be transmitted in the reproduction of a musical selection will ordinarily range from 30 cycles per second up to about 4,000 cycles per second. The satisfactory transmission of a selection of music over any Radio transmission system will require that the **harmonics of these frequencies be transmitted as well as the fundamentals, otherwise, the reproduction will not possess the characteristics of the original.** Speech does not require as wide a range of frequencies for intelligibility as does music. Engineers, therefore, have extensively studied the range of frequencies which must be accompanied by any system to meet various standards of reproduction.

FIDELITY

At this time it is well to discuss a term which we will use from time to time in describing the characteristics of Radio transmission, broadcasting equipment, receiving apparatus, etc. It is the term called **fidelity.** You often hear people who own

Radio receiving sets refer to the quality of reproduction of their sets. The term "quality" in this case is not a very good one. For example, suppose that a broadcasting station is putting on the air a very poor program and that you are listening to that program with an excellent receiving set. Would you say that the receiving set was reproducing a good quality program? The quality of a Radio program depends just as much upon what is put into the microphone as it does upon the characteristics of the receiving set. To avoid this rather ambiguous use of the term **quality**, Radio engineers today make use of the term **fidelity** to describe the faithfulness of reproduction of receiving apparatus. A very poor broadcast program may be faithfully reproduced by an excellent receiving set. You may, therefore, say that the fidelity of the receiving set is good, without saying that the quality of the program is good.

On the basis of the above discussion, let us consider briefly the standards which engineers generally agree to with respect to the range of frequencies which must be transmitted by a broadcasting station if "fidelity" is to be obtained. Extensive tests have shown that if a transmitting system is concerned only with the transmission of speech and if intelligibility only is desired, frequencies lying between 200 cycles and 2,000 cycles only need to be accommodated. The ordinary desk telephone, and all telephone exchange equipment as used for land line telegraphy are designed only to accommodate frequencies which lie between these two limits. When we come to consider the frequencies which must be transmitted for the satisfactory reproduction of music, we find it necessary to set rigid limits. A broadcasting system or a receiving set which satisfactorily handles all audio frequencies lying between 30 cycles and 10,000 cycles would give excellent fidelity. Such a receiving set would in general give satisfactory results, and there is no question but that the most highly trained musician would be entirely satisfied with its fidelity characteristics. In view of the present engineering limitations of broadcasting apparatus and governmental requirements receiving sets capable of satisfactorily reproducing all frequencies lying between 50 cycles and 5,000 cycles per second will be found to be entirely satisfactory to the average person. Accordingly, a large share of our Radio apparatus is today engineered to accommodate the frequencies which lie between these two limits. For the purpose of our study, we will, therefore assume in the next few pages of this text-book that a musical program as transmittd by a Radio transmitting station consists of a large number of frequencies lying between 50 cycles and 5,000 cycles. On the basis of this, let us now turn our attention to speech and music modulated waves which will be transmitted from a Radio broadcasting station.

SPEECH AND MUSIC MODULATED WAVES

If we consider that over a period of time a musical reproduction consists of a great number of frequencies lying between 50 and 5,000 cycles per second, then the Radio wave transmitted by a Radio broadcasting station must be somewhat similar to type A-2 wave illustrated in Figure 16, except that it will be much more complex due to the fact that the envelope as determined by the modulating frequencies will be continually varying

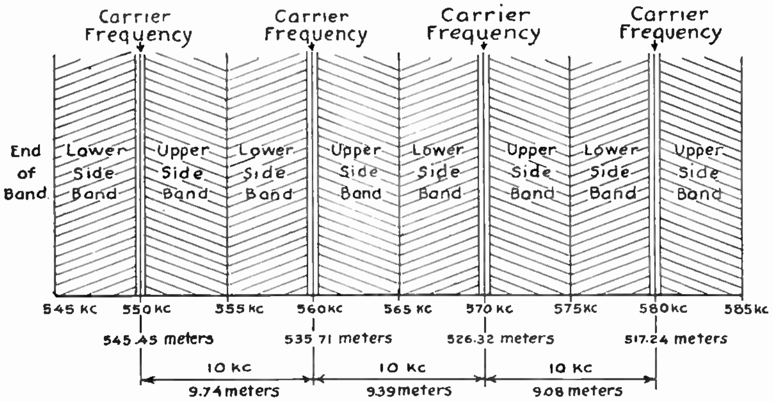

Fig. 22—The broadcast channels at the lower end of the frequency band.

and will take all possible values lying between the limits we have selected. Instead of consisting of a single frequency with an upper side frequency and a lower side frequency, the wave transmitted is said to consist of a **single frequency** and an **upper side band** and a **lower side band.**

Let us assume again that the carrier frequency transmitted by a broadcasting station is 1,000,000 cycles (1,000 kilocycles). And instead of being modulated by a single frequency of 5,000 cycles, the station is used to transmit a musical program such that over a period of time all possible frequencies lying between 50 and 5,000 cycles are present in the program.

The **carrier** wave transmitted from the Radio station will then be something like that shown in Figure 17. That is, it will consist of the carrier frequency as before but in place of the upper and lower side frequencies, we will not have upper and lower side bands. The upper side band will extend from 1,000,000 cycles (1,000 kc) upward to 1,005,000 cycles (1,005 kcs). The lower side band will extend downward from 1,000,000 cycles (1,000 kc) to 995,000 cycles (995 kcs). In other words, every broadcasting station capable of transmitting audio frequencies which extend as high as 5,000 cycles (5 kcs) may be considered as occupying space in the ether 10,000 cycles (10 kcs) wide, that is, twice the highest modulated frequency.

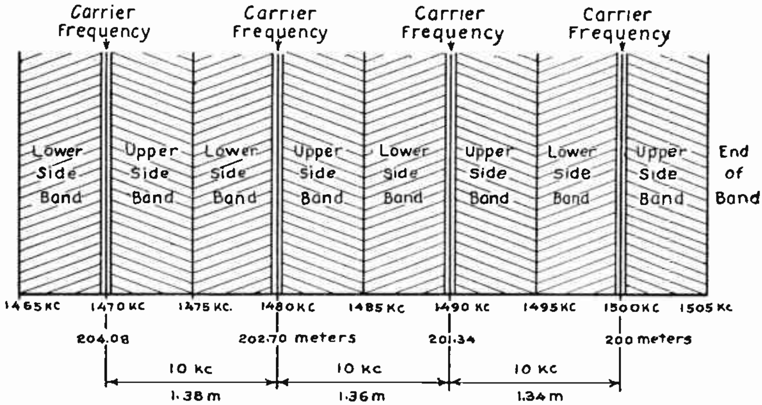

Fig. 23—The broadcast channels at the upper end of the broadcast band.

THE BASIS FOR BROADCASTING STATION ASSIGNMENT

Consider for a moment a Radio broadcasting station whose carrier frequency is assigned to be 550,000 cycles (550 kilocycles). Speaking in terms of kilocycles, the lower side band will then extend downward to 545 kilocycles and the upper side band up to 555 kilocycles. If the waves transmitted from this station are not to overlap those from a certain station which it is desired to operate simultaneously with the first, then the second station cannot be assigned a carrier frequency less than 10 kilocycles, removed from the first. In other words, the carrier frequency of the next station cannot be closer than 560 kilocycles, in which case the lower side band associated with it would just touch the upper side band of the station whose carrier frequency is 550 kilocycles.

To make the above statement clear, Figure 22 shows in graphic form the four broadcast channels nearest the lower end of the broadcast band (referring to the frequency band). The

TABLE NO. II.

Table for converting frequency assignments in the broadcast band to wave lengths.

Frequency in Kilocycles	Wave Length in Meters	Frequency in Kilocycles	Wave Length in Meters	Frequency in Kilocycles	Wave Length in Meters	Frequency in Kilocycles	Wave Length in Meters	Frequency in Kilocycles	Wave Length in Meters
550	545.45	750	400.00	950	315.79	1150	260.87	1350	222.22
560	535.71	760	394.74	960	312.50	1160	258.62	1360	220.59
570	526.32	770	389.61	970	309.28	1170	256.41	1370	218.98
580	517.24	780	384.61	980	306.12	1180	254.24	1380	217.39
590	508.47	790	379.75	990	303.03	1190	252.10	1390	215.83
600	500.00	800	375.00	1000	300.00	1200	250.00	1400	214.29
610	491.80	810	370.37	1010	297.03	1210	247.93	1410	212.77
620	483.87	820	365.85	1020	294.12	1220	245.90	1420	211.27
630	476.19	830	361.45	1030	291.26	1230	243.90	1430	209.79
640	468.75	840	357.14	1040	288.46	1240	241.93	1440	208.33
650	461.54	850	352.94	1050	285.71	1250	240.00	1450	206.90
660	454.54	860	348.84	1060	283.02	1260	238.09	1460	205.48
670	447.76	870	344.83	1070	280.37	1270	236.22	1470	204.09
680	441.18	880	340.91	1080	277.78	1280	234.37	1480	202.70
690	434.78	890	337.08	1090	275.23	1290	232.56	1490	201.34
700	428.51	900	333.33	1100	272.73	1300	230.77	1500	200.00
710	422.53	910	329.67	1110	270.27	1310	229.01		
720	416.67	920	326.09	1120	267.86	1320	227.27		
730	410.96	930	322.58	1130	265.49	1330	225.56		
740	405.40	940	319.15	1140	263.16	1340	223.88		

carrier frequency of the station assigned to the lowest channel should be kept at a frequency of 550 kilocycles. Its upper side band will then extend just to the point reached by the lower side band of the station whose carrier frequency should be set at 560 kilocycles. The next station then should have its carrier frequency set at 570 kilocycles, and so on. You can, therefore, see that for all practical purposes the space between 545 and 555 kilocycles is occupied by the broadcast station whose carrier frequency is adjusted to 550 kilocycles.

For reference, the wave length corresponding to the frequencies 550, 560, 570 and 580 kilocycles have been calculated and are given below the frequency in Figure 22. Note that while the carrier frequencies are spaced 10 kilocycles apart, in this illustration, the difference between the wave length of these carrier frequencies draws progressively less as we move from the lower frequencies towards the high end of the spectum, that is, from the higher wave length towards the lower wave length. The carrier frequencies 550 and 560 kilocycles are 9.74 meters apart. The carrier frequencies 560 and 570 kilocycles are 9.39 meters apart and the carrier frequencies 570 and 580 kilocycles are 9.08 meters apart. This decrease in separation between carrier frequencies in wave lengths draws progressively less and less until the high frequencies in the broadcast band becomes less than two meters apart.

In Figure 23 we show in graphic form the broadcast channels at the upper end of the broadcast band. You will note that the wave length corresponding to 1500 kilocycles is 200 meters, while that corresponding to 1,490 kilocycles is 201.34 meters. The separation in wave length between these two frequencies as shown by the Figures is 1.34 meters. Actually, however, a 10 kilocycle channel at the upper end of the broadcast band is just as wide as 10 kilocycle channel at the lower end of the band. The difference in separation, based on wave lengths, does not give a true picture of the situation which exists.

From the above explanation we are quite sure that you will fully understand why Radio engineers today recommend the use of frequencies to designate the transmission of Radio waves in place of wave lengths. It is surprising to note the confusion in the minds of many the relation between kilocycles and wave lengths and why kilocycles are used in allocating transmitting stations. If we were to confine ourselves to the term "wave length," we would have a cumbersome system of numbers to deal with and would find it necessary to make an involved calculation every time we wish to find the position of a particular broadcasting station in the spectrum. If we speak in terms of frequencies, we find our problem very simple. The entire situation can be described in a nut-shell by stating that the carrier frequencies in use by Radio broadcasting stations extend from 550 kilocycles up to 1,500 kilocycles and are spaced 10 kilocycles apart. With this information you can very easily calculate that there are 96 broadcast channels, available within this band if 1,500 and 550 kilocycle assignments are used.

Table No. II shows the carrier frequency assignment used for Radio broadcast stations in the band extending from 550 to 1,500 kilocycles, together with the corresponding wave lengths based on the use of the conversion factor, 300,000. If you are using a Radio broadcasting receiver which is calibrated in terms of meters, you will find the conversion factor given very useful.

TEST QUESTIONS

Number Your Answer Sheet 9—3 and add Your **Student Number.**

Never hold up a set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we will be able to work together much more closely; you get more out of your course and better lesson service.

1. Name and describe briefly the two types of antennas in common use.
2. Draw a diagram of an undamped or continuous wave, and also a damped wave.
3. Name the three ways of producing undamped Radio waves.
4. How are damped waves produced?
5. What is the fundamental objection to the use of damped waves for Radio telegraphic purposes, and why are transmitters which radiate such waves being rapidly discontinued?
6. Draw a diagram of a type A-3 Continuous Wave, and mark the details on the drawing.
7. Explain briefly the meaning of side bands.
8. What determines the pitch of a musical sound?
9. Define the meaning of the term "fidelity" of a receiving set.
10. Why is it better to designate assignment to Radio transmitting stations on the basis of frequencies rather than on the basis of wave length?

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DETECTOR ACTION OF CRYSTAL AND VACUUM TUBE

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THOROUGHNESS HABIT

A Personal Message from J. E. Smith.

Thoroughness. This is a set of habits. In fact, all that I have mentioned are sets of habits. For it is possible to be accurate, neat, thorough and regular in some things and not in others. Thoroughness comes from dissatisfaction with a job half done. There is a little verse in an old reading book that runs like this:

"If a task is once begun,
Never leave it till it's done.
Be the labor great or small,
Do it well or not at all."

A successful Radio man must not stop until he has all the facts. There is no such thing as a "half-way house" in Radio. You must have all the facts if you want to be a success in the Radio field.

This is not all. A good student masters everything as he goes. He is not satisfied with a lesson half-learned. This power of mastery of detail comes only with long and tedious practice. Like many other traits, it is habit.

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

DETECTOR ACTION of CRYSTAL AND VACUUM TUBE

Action of Crystal Detector.

Before considering the action of the detector in a Radio receiver, it will be well to look into the need for such a device. The average human ear will respond to vibrations varying from a frequency of 40 to 10,000 cycles per second. Vibrations occurring at a frequency higher than this are generally inaudible to the human range of hearing. Radio waves, as sent out from a

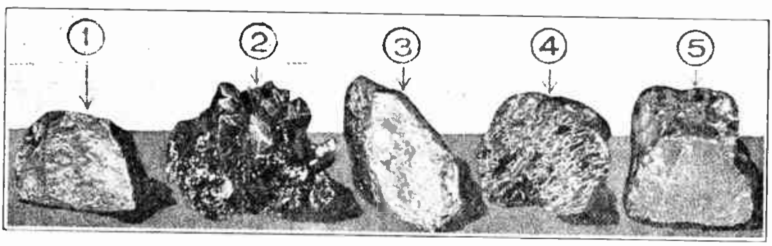


Fig. 1—Various forms of crystals. 1, Silicon; 2, Bornite; 3, Chalcopyrite; 4, Antimony; 5, Iron pyrites.

Broadcasting Station, oscillate at a frequency in the order of a million or more per second. It is, therefore, **impossible** to hear these radio frequency **oscillations** as they are sent out. They must be **transformed**, so to speak, to an **audible frequency** of wave groups which will fall within the range of audibility. **It is the function of the detector to do this and in so doing, it acts as a rectifier.** It is to be remembered that radio oscillations are alternating currents of a very high frequency. If it were possible to construct headphones the diaphragm of which would oscillate at such a high frequency, no sounds would be heard because the vibrations of the diaphragm would be above audibility. This is not possible, however, and the headphone does not reproduce radio waves directly as received. Then again, if the high frequency wave trains were merely tapped at inter-groups with intervals between each group, each oscillation in a single group arriving so quickly after its predecessor would have a neutralizing effect on the diaphragm.

For example, let us assume that the diaphragm is drawn toward the magnets of the telephone receiver during the positive alternation of the current. Before the diaphragm would have time to come back to normal position and be forced away from the magnet poles by the negative alternation, the negative alternation has taken place and other alternations have followed, perhaps several hundred times, and the result is that the diaphragm does not vibrate at all.

It is necessary, therefore, to rectify the current which means to allow only a flow of one side alternations of the alternating current, either positive or negative, causing a series of alternations which in effect are rapid pulsations of current in one

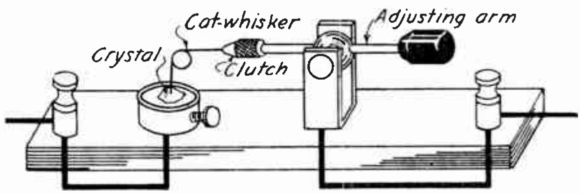


Fig. 2—Crystal detector using cat-whisker.

direction only. When damped waves such as those sent out from spark transmitters (code signals) or modulated undamped waves, such as speech and music, are sent out from a Broadcasting Station, these groups of oscillations, which build up from zero to maximum and down to zero again, as many times as 10,000 times per second, have the effect of an audible frequency current in the telephone receiver circuit due to the impedance or retarding effect of the circuit itself on the high frequency pulsations. The diaphragm, as a result of this, vibrates accordingly at an audible frequency.

There are several kinds of rectifiers used in radio receiving sets, but only two are in common use; one the so-called **crystal detector** and the other the **vacuum tube detector**.

Characteristics of Minerals Used for Detectors.

Crystal detectors are divided into two main groups, with some crystals possessing properties of both classes. In the first group are the crystals which possess the property of unilateral conductivity; that is, a current of electricity is able to flow through the crystal much better in one direction than in the other. In the second group are the crystals which do not adhere to Ohm's Law over a range of applied voltages. These crystals possess a non-linear voltage current curve. In both cases, detection is accomplished by a rectification of the incoming signal. The rectified current charges the phone condenser and is smoothed out therein before the condenser discharges through the telephone receiver, thus producing an audible sound.

The most sensitive crystals are furnished by the first group, but they are also accompanied by the disadvantage that they are easily jarred out of adjustment. Since they require an extremely light pressure of the cat whisker wire in making contact on the

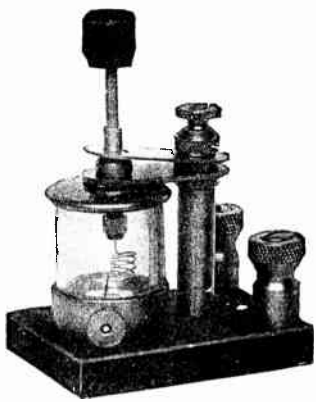


Fig. 3—The enclosed Galena detector.

surface of the crystal, if the table or set is subjected to even a small jolt, the adjustment is lost. This annoyance is rendered still more disagreeable by the fact that the whole surface of the crystal is not uniformly sensitive and more or less time is lost in finding a new spot which responds well to the incoming signals.

Crystals of the second group are more stable in operation as a heavier pressure is usually used at the point of contact. Galena is by far the most sensitive crystal of the first group with Iron Pyrite a close second. If a piece of galena be examined closely, it will be seen that the surface is covered with fine serrations running in but one direction. Upon breaking the crystal, the serrations can be seen running in a perpendicular direction. On a bright, smooth surface, it will be found that the sensitivity is usually zero, the maximum sensitivity occuring at places where the serrations are located or where a depression is formed by the criss-cross ridges.

Just what action it is that goes on in the crystal, which enables it to rectify high frequency current, is a subject open to dispute. Fleming found that this rectifying power is lost when the rectifying substance is crowded and molded into rods under great pressure. Heating the compressed rod in an electric arc could not restore its previous properties, the rectifying power seeming to depend on the crystalline structure. With other substances, rectification seemed to depend on a surface action which is called surface rectification. Electrolytic rectifiers operate in a manner very similar to these solid rectifiers.

Quite a number of hypotheses have been advanced to explain the action of crystal detectors, the assumptions being that the phenomena depend on thermo-electric properties, photo-chemical properties, electrolysis in solids, electrostatic attraction, etc. The thermo-electric theory seems to be the most plausible. With this hypothesis, the observed phenomena depend on three main conditions, viz:

1. Temperature variations of resistance.
2. The Peltier effect. (Absorption or generation of heat by the passage of a current through a junction of dissimilar metals.)
3. The Thompson effect. (The production of an EMF between different parts of the same substance at different temperatures.)

Just which phenomenon or combination of phenomena produces the rectification, and the considerations, pro and con of their effects, involves a discussion which cannot be entered into in this text book on account of its highly technical nature, being primarily a matter of pure physics.

In brief, the incoming signal traverses a point of very small cross-section (therefore of high resistance) and the energy in the wave train is dissipated as heat at the contact of the cat whisker wire and the crystal. The temperature of the locality of the contact is raised by this heat generation, introducing the Thompson and Peltier effects. Being a junction of dissimilar metals, a direct electromotive force is produced, giving rise to sound in the telephone receivers.

Most of the good rectifying substances are oxides or sulphides. Other good rectifiers use a metal and a non-metal contact. Among the list of the substances which give good results as contact detectors are **silicon, boron, graphite, tellurium, arsenic, chalcopyrites, bornite, molybdenite, zincite, brookite, etc.** Of these the most common types are **zincite** and **chalcopyrite** (Perikon), **zincite** and **bornite**, **iron pyrite** and **gold**, **carborundum** and steel, **silicon** and **gold**, **galena** and **graphite**, **platinum** or **copper.** Some of these crystals also come under the category of the second group, such as **carborundum** and **silicon.**

To explain how the crystal detector works in a receiving circuit: Refer to Figure 4. This diagram shows a simple crystal hook-up in which the lines representing the wires have been used as the axes of the characteristic curve of the crystal. These two axes are drawn heavily, and represent the current through

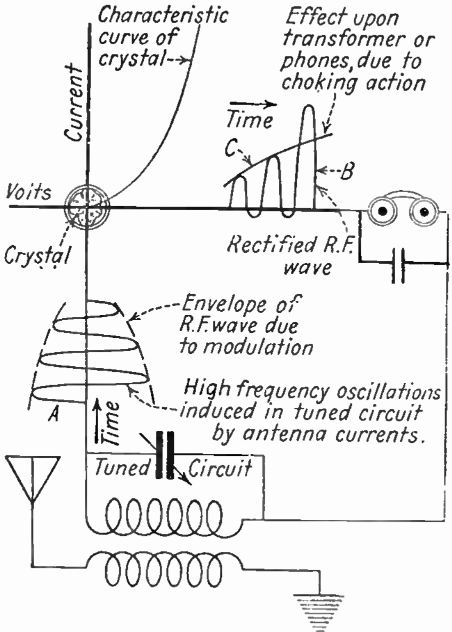


Fig. 4—This diagram shows in a schematic way how rectification is accomplished by means of the crystal detector.

the crystal and the voltage impressed on it. The explanation is as follows:

The current induced in the antenna by the traveling radio wave induces a high frequency wave in the tuned circuit. This secondary circuit has the form shown at "A" on the diagram and the envelope (or dotted curves) represents the variations in amplitude of the oscillations due to the modulation at the transmitting station.

When this high frequency current passes through the detector it is rectified, due to the symmetrical conductivity of the crystal, into the shape shown at "B." In the curve "A," it is seen that there is just as much of the oscillation on one side of the axis as on the other. At "B" there is more of the curve above the axis than below, so that the average value of the current in the phones will have a distinct direction, and a finite value.

The phones, however, due to their high impedance to the high frequency oscillations, as well as the sluggishness of the diaphragm, cannot respond to each individual oscillation, so they respond to the average value of the curve "B." In other words, the high frequency oscillations at "A" have been rectified by the crystal into the form "B" which is then "choked" into the form "C." The same thing happens when the phones are replaced by

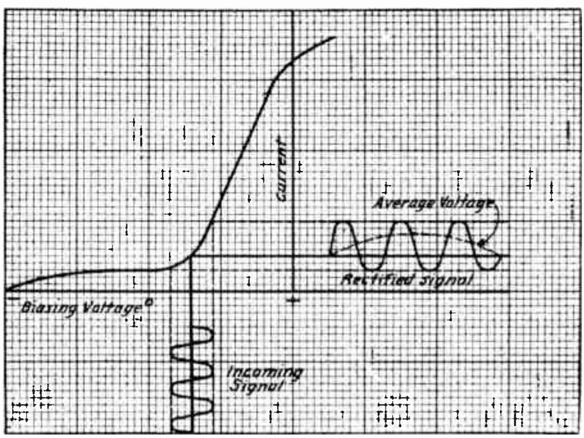


Fig. 5—Characteristic curve of carborundum crystal.

a transformer, when audio frequency amplification follows detection.

It will be noted that there is a loss of energy in the crystal due to its resistance. This is shown by the difference in size between "A" and "B." In vacuum tube rectifiers, there is an amplification, the losses being more than made up by the energy released from the "B" batteries.

Action of Crystals of the Second Group.

The best insight into the operation of these crystals is obtained from a study of their characteristic curves. Such a curve for carborundum is shown in Figure 5. This curve, except for numerical magnitudes, is typical of crystals of this type. It is seen from Figure 5 that when a small voltage is applied to the crystal and is gradually increased, the current through the crystal increases, but more rapidly than the voltage after a certain critical voltage has been applied. Up to the critical voltage, the increase in current is at a slower rate than the increase in voltage. When the voltage is reversed, the current is also reversed, but it is considerably less in value for the same potentials applied, unsymmetrical characteristic with respect to the current axis), showing that the crystal possesses unilateral conductivity also. It has been found that with carborundum, this rectifying power increases with increasing temperature, reaching a maximum sensitivity at from 400 degrees to 500 degrees Centigrade.

In operation, such a crystal is clamped between two electrodes and a potential is applied, being regulated by a potentiometer. Thus there is a certain amount of current always flowing through the crystal. The potential of the applied EMF

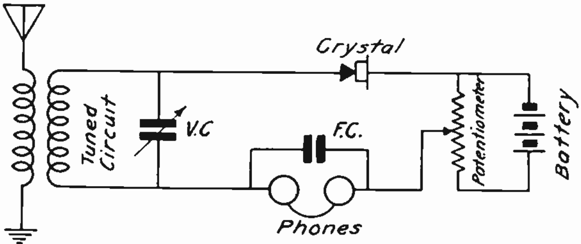


Fig. 6—Receiving circuit using a Carborundum crystal.

is adjusted so that the crystal operates on the bend of the curve, the potential being in the direction in which the crystal conducts best.

When electrical oscillations are impressed on this detector, they are superimposed on the unidirectional current already flowing through it, thus periodically increasing and decreasing the value of the effective EMF (Electro-motive Force). Since the current-voltage curve is non-linear, the current increases suddenly with the application of a small additional EMF. When the signal EMF is in the opposite direction so as to detract from the unidirectional voltage on the crystal, the decrease in current is small as compared to the increase produced by the same potential, if reversed in sign.

Figure 6 shows the circuit diagram of a carborundum crystal receiver.

The crystal detector receiving set is ideal where simplicity of apparatus is desired, and where the distance to be worked is not too great. The distance which a crystal detector receiver will cover is, of course, dependent upon the power of the transmitting station. The present commercial Broadcasting Radio Stations can be heard on a crystal detector receiver at distances of usually not over 50 miles. For greater distances than this, the more sensitive vacuum tube detector must be used.

Action of the Vacuum Tube Detector.

The outstanding invention that made Radio Communication forge ahead so rapidly—and has made possible the broadcasting of programs on a large scale—is the Vacuum Tube. The vacuum tube is an adaption of the incandescent lamp which was invented by Thomas Edison about the year 1883. It is based on the principle of utilizing the emission of electrons from a heated wire. A filament of carbon or tungsten wire is enclosed in a glass tube or globe, which excludes the air. When an electric current is passed through the filament, the resistance of the metal causes the wire to become incandescent.

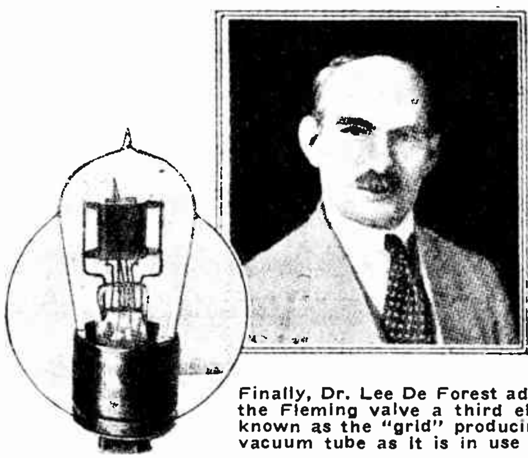
First, Thomas A. Edison, while experimenting with an incandescent electric light bulb, placed a metal plate inside the bulb near the filament and discovered the so-called "Edison effect," later applied by others to radio.

Next, Prof. J. A. Fleming, seeking to improve the wireless detector, produced the first vacuum tube, known as the "Fleming valve," using the "Edison effect."

Thomas Edison discovered that if a second element such as a second wire be placed within an electric light globe, and the filament heated to incandescence, electrons would flow between the filament and the second element when the second element was given a positive potential, and that the current through the space within the tube ceased when the filament current was cut off; this is now generally known as the Edison effect. Edison, although discovering this phenomenon, found no practical use for it, and it remained for Dr. J. A. Fleming of London, in 1904, to discover its rectifying characteristics and its adaptability to the reception of radio signals. For this reason, the first vacuum tube detectors were called Fleming Valves. The second element is generally now called the "plate."

Modern vacuum tubes contain a third element, known as the "grid." This element was added by Dr. Lee De Forest in 1906.

Taking up the operation of the vacuum tube more in detail, it is necessary to understand the electron theory. It is a well-known fact that when any piece of metal or wire is heated, it will throw off microscopic particles. These are called electrons. They



Finally, Dr. Lee De Forest added to the Fleming valve a third element known as the "grid" producing the vacuum tube as it is in use today.

carry a negative electric charge, while the heated body maintains a positive charge, caused by the lack of negative electrons. The negative electrons thrown off are immediately attracted back by the positive charge, and immediately dance off into space again. When the heated element is a filament enclosed in an air-tight globe, the space surrounding the incandescent filament is charged with negative electricity as long as the filament remains heated. Now, if a second element or electrode be inserted into this negatively charged space, and at the same time connected in series with the filament circuit and then given a positive charge from a battery, that which we generally speak of as a current flow will take place. The negative electrons which are thrown off from the filament are not attracted back to their source as when there was no second element within the space, but are drawn to the plate, on account of its positive charge being stronger than the positive charge of the filament. If the polarity of the plate battery is reversed, there will be no flow of current through the tube. The reason for this is that the negative charge on the plate will repel the negative electrons, and no current will flow between the two elements.

When a two-electrode tube is connected in an alternating current circuit, it functions as a rectifier, as current can only pass in one direction. Alternations in the opposite direction are simply cut off. The well-known tungar rectifier, used for charging storage batteries from an alternating current supply, utilizes a tube of this type. When a two-electrode tube is connected in a

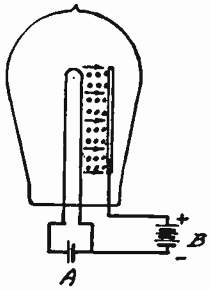


Fig 7—Two-electrode vacuum tube.

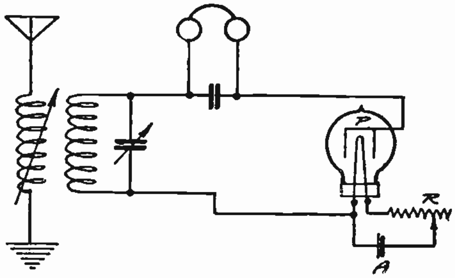


Fig. 8—Receiving circuit using a Fleming valve as a rectifier.

receiving circuit, we have a sensitive detector with unilateral conductivity.

If instead of using a plate battery in a two-element tube, we substitute the antenna as shown in Fig. 8, and oscillations are impressed upon the plate circuit, we have practically duplicated the condition for receiving when a crystal detector is used, and the heated filament taking the place of the crystal and the plate serving as the contact point. The oscillating current is rectified to a one-way pulsating current, and, if the received signals consist of damped waves or interrupted continuous waves, signals will be heard in the headphones. The signals heard will be about the same volume as those procured with a sensitive crystal and little has been gained by substituting this tube for the crystal.

Since the invention of the Fleming valve, with the simple construction and the two electrodes, many forms and variety of tubes have been placed on the market. The important point in the development of these tubes is the addition of the third element known as the "grid." This consists of a coiled or crimped wire which is placed in the tube in such a position that it is directly in the path of the flow of electrons from the filament to the plate.

In studying the action of the three-element vacuum tube as a detector, it is necessary to get a clear idea of the action of the three elements inside of the tube. The three-element vacuum tube consists of a container made of glass, from which the air has been pumped out. In this glass tube is mounted the filament, grid, and the plate. Each of these elements are

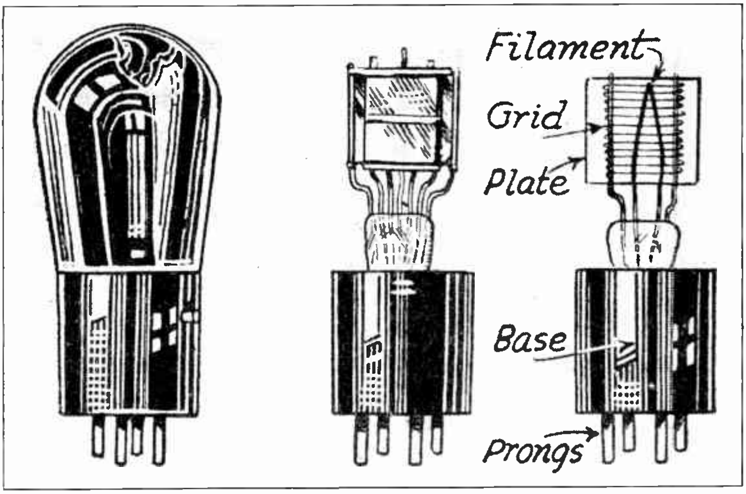


Fig. 9—Three-element vacuum tube showing details of grid filament and plate.

insulated from the other by a space. The filament has two outlet terminals, the grid one and the plate one. The filament is surrounded by the grid, which in turn is surrounded by the plate. These three elements may be distinguished by looking at Figure 9. The solid piece is the plate, the lattice-like piece is the grid and the fine wire in the center is the filament.

Action of a Vacuum Tube.

To understand the action of a vacuum tube, it is necessary to remember the following facts:

A current of electricity is simply a flow of electrons, electrons flow in one direction which makes a current. Electrons are small charges of negative electricity. All material contains electrons. These facts should be clearly understood by the student. The following additional facts must be grasped before the action of the vacuum tube can be understood.

It has been discovered that metals, if heated, will throw off into space some of the electrons which the metal contains. It has also been discovered that **the hotter the metal, up to a certain degree of heat, the more electrons it will discharge.** These electrons travel at a very high rate of speed. If air or any other gas is present in the space around the metal, the electrons strike the minute particles of the air or gas and are soon stopped.

The facts stated are applied in the vacuum tube. The air is pumped from the tube (hence, the name vacuum) so that the passage of the electrons will not be stopped. In Figure 10 we show a simplified diagram of the connections to the filament and plate of a vacuum tube. A wire called the filament is heated by

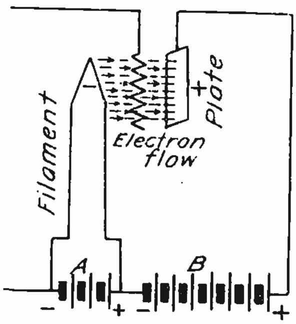


Fig. 10—Illustrating electron flow from filament to plate in vacuum tube.

means of electric current from a filament heating battery, which is called the "A" battery. If heated to a temperature sufficiently high (the necessary temperature depending upon the kind of wire of which the filament is made) a large number of electrons are emitted from the filament, like steam from boiling water. They are then drawn over to the sheet of metal called the plate which attracts them because it is kept at a potential more positive than that of the filament. This flow of electrons to the plate constitutes the plate current, and the battery or power unit that keeps the potential of the plate positive, and hence maintains the plate current, is called the "B" battery or "B" supply unit. The electrons leave the filament, are attracted through the vacuum to the plate, leave the vacuum tube, traverse the "B" circuit, re-enter the vacuum tube by the filament lead along with the filament heating current, and get boiled off the filament again for another round trip.

The filament of an electron tube may be heated by an alternating current. It is only necessary to use a step-down transformer to secure the correct voltage and amperage for the filament. If, however, the grid return is brought to one of the filament terminals, the alternating voltage impressed on the grid will cause a hum in the receiver. This hum can be, to a large extent, eliminated by connecting a potentiometer across the filament terminals, connecting the grid return to the arm of the potentiometer and adjusting the arm until the hum is reduced as much as possible as shown in Fig. 12. The grid return is then at the neutral point on the potentiometer, or the point at which the potential does not change.

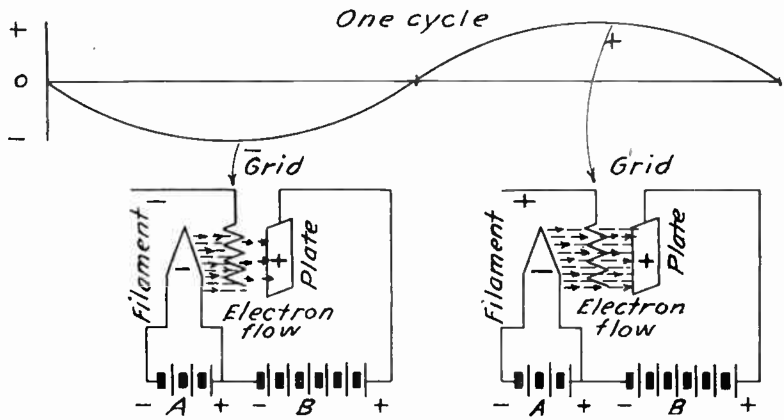


Fig. 11—Illustrating the effect on the electron flow in a vacuum tube when a negative and positive potential is placed on grid.

Unfortunately, the alternating voltage curve is irregular so that the neutral point is continuously shifting. This means that even with the best adjustment of the potentiometer, there is a slight variation of voltage acting on the grid.

The hum which results from this action is more noticeable when the tube is used as a detector and, therefore, this arrangement is not very satisfactory for detection. For use as a detector, the hum may be eliminated by designing the tube so that the filament through which the current flows heats another element which acts as the cathode. This is known as the **heater-type** of A. C. tube. **In the three-element vacuum tube, the filament itself is the cathode, but in the heater-type of A. C. tube, the filament becomes simply a heater.** The electron stream which forms part of the plate current is not given off by the filament but by the cathode which is heated by the filament. The grid return is also to the cathode and since the alternating current does not flow through the cathode, it does not produce a hum. The alternating current serves only to keep the heater at a sufficiently high temperature to heat the cathode. A circuit using a tube of the heater type as a detector is shown in Fig. 13.

Full details of A. C. tubes and various circuits in which they are used will be taken up in an advanced text book.

The Effect of Grid on Electron Flow.

The electrode, which is called the grid, is usually in the form of a lot of parallel wires close together and all connected together. When this structure (which is located between the filament and the plate) is given a potential more negative than that of the filament, it repels electrons coming from the filament and thus offsets some of the attractive force due to the plate.

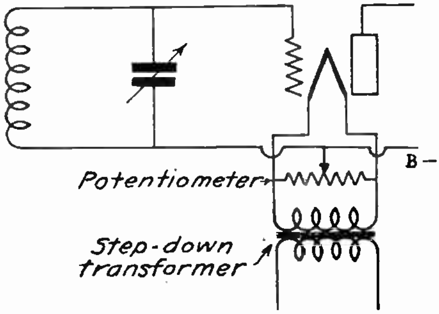


Fig. 12—Connections to grid and filament circuits for an alternating current vacuum tube.

Herein is a very important property of the tube because a small change in the grid potential may be as effective in changing the plate current as a large change in plate potential. If the grid is made more positive than the filament, it attracts electrons, so that the plate does not get them all. These electrons going to the grid constitute a grid current and to maintain this current power must be supplied by the source that is keeping the grid positive. Figure 11 illustrates the effect of grid potentials on electron flow.

We will now take up the action of the Vacuum Tube as a Detector. This detector when used with regeneration is very efficient and sensitive. When used with a non-regenerative circuit, its sensitiveness is only slightly greater than the crystal detector. Therefore, it is of interest to know how this device operates in a radio receiving set.

Conditions for Detection.

Before going into the subject, it is well to review so as to understand exactly what conditions a detector must fulfill in order that it will make radio waves audible.

There are two main reasons why the high-frequency radio current in a telephone receiver will not make the diaphragm move: First, the positive and negative halves of the radio cycle neutralize each other and hence will not influence the diaphragm; second, the frequency of the radio current is above audibility. In order that we may hear the audio signals impressed on the radio wave, the detector must then do at least two things to the radio wave: (1) **It must cut off either the positive or negative half of the radio wave so that they do not neutralize each other in their effects on the telephone diaphragm, that is, the** DETECTOR MUST RECTIFY THE RADIO WAVE. This is

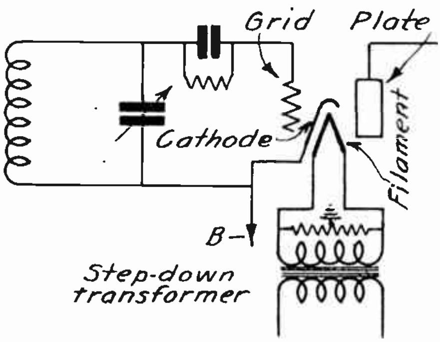


Fig. 13—Connections to grid, cathode and filament of an A. C.tube(Heater type).

NOTE.—In advanced Text Books we will go into details on A.C. tubes.

the first condition for detection. (2) **It must transform the radio frequency A. C. impulses of the radio wave into unidirectional impulses of R. F. so that these unidirectional impulses will have a chance to produce a magnetic force which acts in one direction only in the electromagnets of the phones, so that the diaphragm can respond to the force exerted by this magnetism.** This is the second condition for detection.

We are now ready to consider the action of the vacuum tube as a detector and see for ourselves just how the above two conditions for detection are met.

There are two principal methods of detection employing the vacuum tube and these are: (1) **Plate circuit rectification.** (2) **Grid circuit rectification.** Both of these methods are based upon the shape which the characteristic curve of a vacuum tube has, namely on the curvature of the characteristic curve. Figure 14 shows a typical characteristic curve of a three-element vacuum tube, which is obtained by applying different voltages to the grid and measuring the plate current corresponding to these voltages. It will be observed that at the beginning and end of the characteristic curve, there is a marked curvature, while between points "B" and "C" the curve is a straight line, and the middle of this curve is approximately at zero grid potential. Suppose now that a radio frequency voltage is applied to the grid, let us say this voltage is due to a radio signal coming

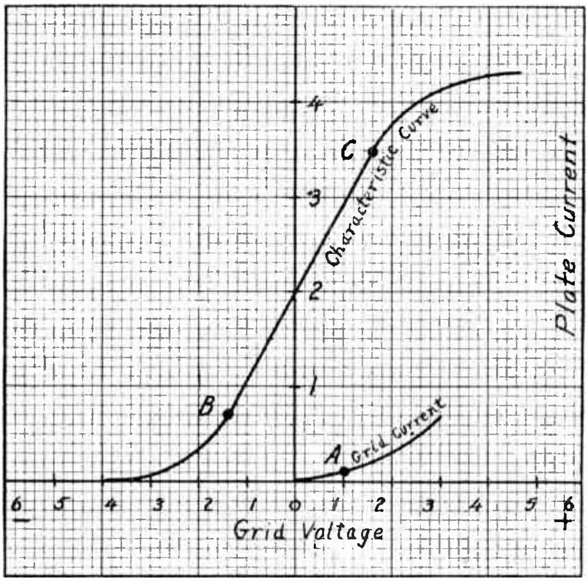


Fig. 14—Grid and plate current characteristics of a vacuum tube.

from the transmitter. This radio voltage is designated by the voltage wave A B C D E (Figure 15) which is one cycle of the wave.

Now let us see what happens when this radio voltage is thus applied to the grid. When no signal voltage is applied to the grid, namely, when it is at zero potential, the plate current is given by O, P, and is constant as shown by the straight line LL. When the radio voltage A B C D E is now applied, a change takes place. As the grid voltage rises from zero, i. e., point "A" to its maximum positive value point "B," the plate current also rises as seen from the characteristic curve, since a positive grid voltage produces a rise in plate current. The plate current thus rises from A^1 to B^1. As the grid voltage drops again to zero, i. e., point "C," the plate current does likewise and drops to its normal constant value, namely, C^1. The grid radio voltage now changes its direction and is negative and rises to its negative maximum value, namely to point "D." From this characteristic curve, we can see that a negative grid voltage produces a drop in plate current. Hence, the plate current now drops below its normal value to point D^1. When the grid radio voltage goes again to its zero value, the plate current also goes to its normal constant value. Now it will be seen that since the changes in

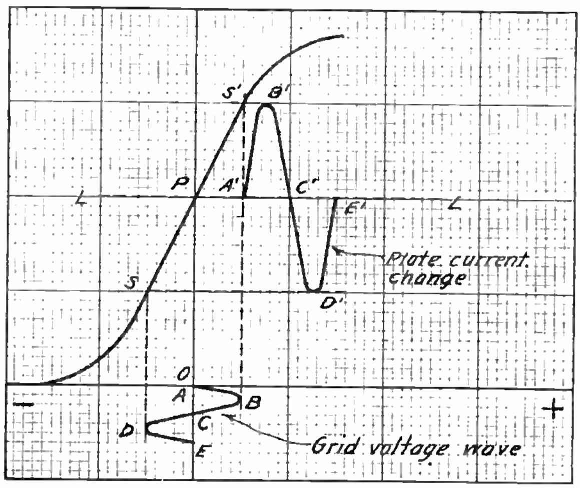


Fig. 15—Along straight part of curve equal changes in plate current are produced by equal changes in grid voltage. Hence positive and negative changes neutralize.

the plate current take place along the straight line part of the characteristic, namely, between points SS^1, equal changes in grid voltage will produce equal changes in the plate current. In other words, the average value of the plate current does not change, hence a headphone placed in the plate circuit will not record any signal since it operates only when the average value of the plate current changes. We have here a case where the rises in plate current are the same as the drops in plate current each thus neutralizing the other's effects on the telephone.

Suppose, however, that the circuit in Figure 16 is changed to that of Figure 17 by inserting a small battery in series with the grid, connecting the negative pole of the battery to the grid. Suppose that the value of this negative potential which is applied to the grid is one volt, and that again we have a radio signal voltage applied to the grid. The state of affairs is now much different and is represented by Figure 18. Since the grid is permanently given a negative potential of 1 volt, the zero axis is shifted over to the left by the amount of one volt, and the normal plate current is now lower than before and is given by RR^1. Suppose now that the grid radio voltage rises from "A"

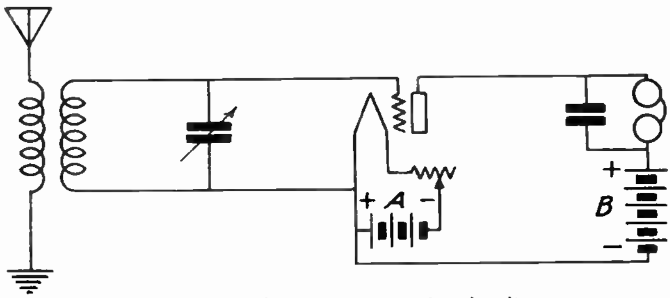


Fig. 16—A simple vacuum tube circuit.

to its maximum positive "B" and then falls again to zero or "C." The plate current will rise and fall proportionately, according to the characteristic curve; namely, it will rise to B^1 and fall to C^1. Now, when the grid radio voltage swings to the negative half of the cycle, it goes to the same maximum, only negative,

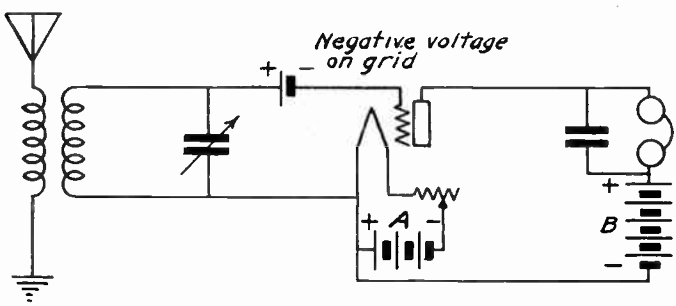


Fig. 17—Receiving circuit using a negative voltage on the grid of the tube for the purpose of rectification.

and then comes back to zero. The plate current does likewise again following the characteristic curve, namely, it falls to D^1 and then comes back to its normal value E^1. However, observe this important point: On account of the curvature of the characteristic curve at "P," equal grid voltages on positive and negative sides do not produce equal plate current changes. Thus the positive grid voltage AB produces a greater change in plate current than the same negative voltage does. Hence, the negative changes do not neutralize the positive changes in plate current, as they did before in Figure 15, but since the positive change is greater than the negative change, there will be a change in the average plate current.

Now let us see how the second condition is fulfilled, namely, securing an audible effect from the radio frequency changes. In order to understand this best, consider a radio wave applied to the grid which wave has varying amplitudes as in Figure 19. The grid is again made negative by one volt, hence the axis is at

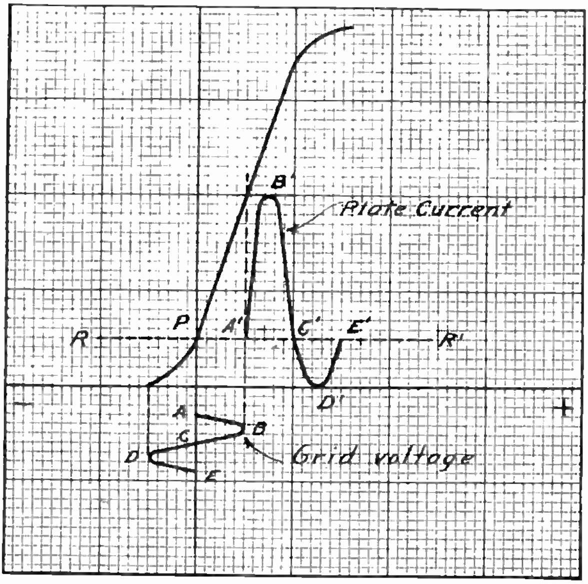


Fig. 18—At P, where curvature is greatest, a positive grid voltage produces greater change in plate current than an equal negative voltage. Hence, negative and positive halves do not neutralize each other and telephones will respond.

minus one volt, Figure 19. This is frequently called **"biasing the grid potential."** When the grid voltage varies according to the wave form shown, the plate current likewise varies, as previously explained, only the increases are greater than the decreases. As explained at the beginning of this text book, the diaphragm of the telephone cannot follow the rapid radio changes in the plate current. However, since the increases in plate current at radio frequency are greater than the decreases, the average plate current will rise according to the shape shown in Figure 19. This average change takes place at an audio frequency rate and hence will be recorded by the telephones, and a signal will be heard. It is thus seen that the second condition is met by a sort of integrated effect of all the radio frequency changes combining to produce one audio frequency change. For every wave this occurs and thus signals are heard. No matter what the shape of the incoming wave is, the above effects will be produced as explained.

It will be observed that the plate current action is really due to the fact that the characteristic curve is not symmetrical at the lower part, namely, equal voltage variations on the grid do not produce equal plate current variations, but it will also be observed that the curve is likewise not symmetrical at the top. Hence, rectification should also be possible at that part of the curve, say, by applying a positive potential of one volt to the grid. This is the case. However, detection is very poor at this part of the characteristic curve, for applying a positive potential to the grid causes a grid current to flow to the grid, which always results in high losses of power and hence very poor efficiency in detection. It is always best to use a negative potential on the grid for this purpose. This method is sometimes called "**plate circuit rectification**" because the current is apparently rectified in the plate circuit.

The second method of detection is the so-called "**grid circuit rectification**" method so named because we now deal with the current flowing from grid to filament, which current is rectified. In the characteristic curve of Figure 14 it will be observed that there is a small curve on the positive side of the current axis. This curve is the grid current characteristic—that is, it shows how the current in the grid circuit varies with the grid voltage. It will be observed that for negative grid voltages there is no grid current, while for positive grid voltages there is a small grid current. Just as the plate method depends upon the curvature of the plate current characteristic, the grid circuit rectification method depends upon the curvature of the grid current characteristic. However, the difference between the two methods is the following: (1) While for plate current rectification, we always use a negative voltage on the grid, for grid circuit rectification, we must use, by some means to be described later, a positive potential on the grid, for the grid current only flows when the grid has a positive potential. (2) Grid current rectification requires the use of a so-called "grid condenser and leak" seen in the circuit diagram of Figure 20, where Cg is the grid condenser and Rg is the grid leak.

The explanation for the detecting action of the tube when it employs a grid condenser and leak is a little complicated, but if the student will pay close attention to the following explanation and follow each point carefully, he will obtain a very good idea as to what happens under these conditions.

Suppose that we are operating our detector set without the grid leak resistance Rg, and are only using the grid condenser Cg, as in Figure 21. Figure 22 (a) represents the incoming radio wave which is part of a modulated radio telephone wave such as might be sent out from a Broadcasting Station. The individual

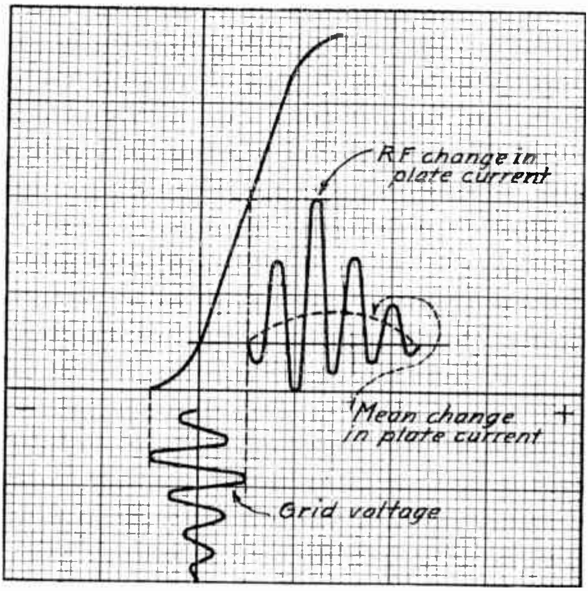


Fig. 19—Radio frequency changes in plate current result in a mean or average change of plate current shown by dotted line. This average change takes place at an audible frequency.

cycles such as A B C D E are the radio frequency cycles, while the dotted line (which is really the modulating frequency) is the audio frequency. Now let us see what occurs when this wave is impressed on the grid. When the upper or positive part of the cycle, namely, ABC, is applied to the grid, the grid is charged with a positive potential. As a result, there is a flow of electrons to the grid in accordance with the grid current characteristic of Figure 14. These electrons accumulate on the grid, since the condenser Cg insulates the grid from the rest of the circuit; hence the electrons cannot flow off the grid. Consequently, the net result of this flow of electrons to grid is that the grid is left with a negative charge, as all electrons are negative. When the lower or negative half of the cycle, namely, C D E, is applied, the grid has a negative potential impressed on it, and this negative potential simply prevents any more electrons from the filament flowing to the grid. As the electrons which are already lodged on the grid cannot leak off in any way, the ultimate result of the first cycle of radio voltage applied to the grid is that the grid is left with a certain negative charge. When the next positive half-cycle of the wave is applied to the grid, there is again a flow of electrons from filament to grid these electrons are again lodged on the grid and prevented from escaping, due to the fact that the grid is insulated by means of condenser Cg. This results

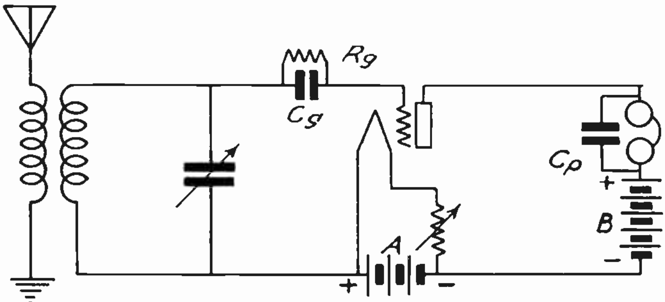


Fig. 20—Receiving circuit using grid leak and grid condenser for rectification.

in the negative charge on the grid increasing. When the next negative half-cycle of the radio wave is applied to the grid, it prevents further flow of electrons from filament to grid, but the negative electrons already on the grid cannot leak off. This process increases until the negative charge on the grid increases to a high value. Now, if nothing is done to reduce this negative charge on the grid, the plate current will decrease to extremely low values, as seen from the characteristic curve of Figure 14, which shows that for high values of negative grid voltage, the plate currents are low or zero. This would result in making the detector tube inoperative, which is contrary to our aim.

Suppose now that we connect across the grid condenser Cg a high resistance Rg as in Figure 20. It will immediately be seen by the reader that the negative electrons which are lodged on the grid by the previous process now have an opportunity to leak off by way of this high resistance, or leak, flowing to the filament. The lower the resistance of this leak, the shorter time it will take for this negative charge to leak off. If it is made too low, this negative charge may leak off in the time it takes to complete one radio frequency cycle, in which case the grid will always be at the same potential. However, if the resistance is made sufficiently high, it will take a longer time for the negative charge on the grid to leak off. By selecting the proper value for the grid leak, we can so arrange it that the grid negative charge leaks off in the time in which it takes to complete one audio frequency cycle, as MN, Figure 22 (a). The effect of this would be as shown in Figure 22(b). Due to the effect of the electrons flowing to the grid, the negative charge on the grid increases as shown by the curve A^1B^1. At B^1, the grid is already

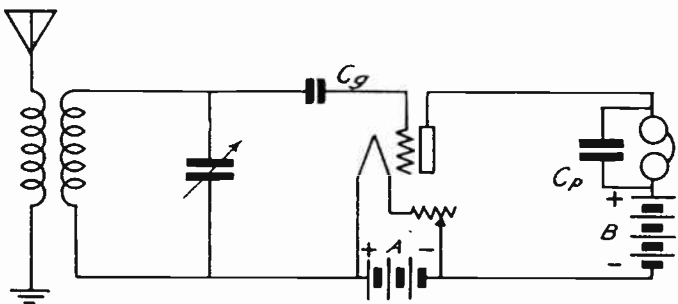


Fig. 21—The grid condenser Cg insulates the grid from the rest of the circuit.

charged to its maximum negative potential. However, when this potential has been reached, the charge begins to leak off by way of the leak resistance Rg (Fig. 20) and when the end of the audio cycle is reached, the entire negative charge has leaked off and the grid is again at its original potential.

The above entire process repeats itself all over with the succeeding radio waves. When the grid voltage varies, as shown in Figure 22 (b), the plate current likewise varies, since according to the plate current characteristic, the plate current follows the grid variations. As a result, Figure 22 (c) shows that the plate current likewise decreases as the grid voltage increases, and as the leak begins to work the plate current rises again to its original value. However, the telephones do not follow the radio frequency variations of the plate current for reasons given at the beginning of this text book, but it does follow the mean or average audio variations in current as shown in Figure 22(d).

Hence, the telephone will respond to this change in current and signals will be recorded. Since the telephones only respond to the audio frequency component arrangements are made whereby the radio frequency current is prevented from flowing through the telephones. This is accomplished by the use of the stopping condenser Cp (Fig. 20) across the phones, which offers a low reactance to the radio frequency current and thus by-passes it.

Experiment shows that best results are secured when the grid is given an initial positive charge, contrary to the plate rectification method which requires a negative charge. This initial positive charge on the grid serves, as it were, to start the electrons flowing to the grid. The positive charge is generally secured by way of the grid leak by connecting the grid return to the positive terminal of the filament battery as in Figure 20.

The reason that this particular method of detection is so extremely efficient and sensitive is that the amplifying properties of the tube are brought into play. Thus from Figure 14 we see that for small positive voltages on the grid, where it is usually worked, as at point "A," for best detection, the plate currents used are on the straight-line portion of the plate curve. Thus very small changes in grid voltage produce the maximum change in the plate current, resulting in high sensitivity.

Now both of the above methods of detection apply to such radio waves whose amplitudes vary such as are sent out by spark or Broadcasting Stations.

RECEPTION OF CONTINUOUS WAVES

For detection of radio waves whose amplitudes do not vary, but are constant, such as are sent out by arc sets, high frequency alternators and vacuum tube oscillators, other methods must be used whereby these continuous waves are broken up into audio frequency groups, otherwise they will not be detected by either a crystal or vacuum tube detector, and no response will be heard in the headphones. The manner by which the continuous waves are made audible is known as the **heterodyne method of reception.** This method consists of combining with the receiver radio frequency wave another locally generated radio frequency wave of the same amplitude, but of a different frequency, the two frequencies acting upon each other produce what is known as a beat frequency, which is the numerical difference between the two frequencies.

The principle of beat frequencies can be explained by the phenomenon which is produced when two keys close together on a piano are struck simultaneously. Due to the fact that the frequencies of the two keys are nearly the same, the listener will hear a periodic increase and decrease in the intensity of the sound as the waves from one key add to, then neutralize, the waves from the other.

The Beat Method.

Now let us see what the application of this is to the reception of continuous waves which are used for code communication. Suppose that we are able to impress two Radio waves on a receiv-

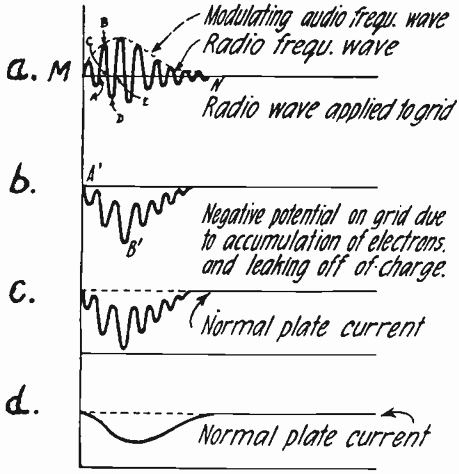


Fig. 22—Illustrating the effect and resultant plate current produced by a radio frequency wave collected by a receiving set of the vacuum tube type.

ing set, one of these waves having a frequency of say 500,000 cycles per second, and the other having a frequency of 499,000 cycles per second. Due to the fact that they are superimposed on each other, they will interfere at some point, opposing and nullifying each other, at other points assisting and reinforcing each other. The resultant wave of current which is produced has a number of zero points due to the fact that at these points the two waves oppose each other, and there are large points due to the fact that at these points the two waves assist each other. This rising and falling of current amplitude constitutes the beats of the system. The opposition and assistance in beats takes place at a definite frequency, namely, the difference between the two interfering frequencies. In this case, the difference in the two frequencies is 1000 cycles per second.

Hence, when this resultant current wave is rectified, the telephone current will have a frequency of 1000 cycles per second, which will then be heard. It is, therefore, seen that by properly coordinating two different waves and rectifying the resultant wave, a signal will be heard. The rectification of the resultant wave takes place in the manner described for damped and modulated waves, for the characteristic of radio modulated waves is that the amplitude is continuously varying, and it will be observed that the resultant wave has its amplitude continuously varying also.

This system of superimposing another radio frequency wave on the incoming signalling wave, the difference between the two wave frequencies being an audible frequency, is known as the "heterodyne" system.

The Autodyne Method.

In practice, there are two ways in which this may be accomplished. First, **self-heterodyne** or **autodyne system**, and second, the **external heterodyne.** In the self-heterodyne system, the **tube which rectifies is also employed to generate the oscillations which are to be superimposed on the received oscillations.** In Figure 23 is illustrated one of the simplest types of regenerative receivers, employing a tickler coupling coil T. The antenna picks up the incoming signals which has a frequency say of 500,000 cycles per second. The secondary circuit (grid circuit) is tuned to this frequency by varying the inductance or capacity or both.

Suppose now that the tickler coupling coil T is moved closer to the secondary coil L until the circuit begins to oscillate. We will then have two currents flowing through the secondary circuit, the first being the incoming signal, and second, the oscillations developed by the detector tube. The frequency of the oscillations developed by the detector tube will be that of the secondary circuit LC. Hence, by varying the capacity of condenser C, we can vary the frequency of the oscillations generated in it so that it is either 499,000 or 501,000 cycles, or 1000 cycles more or less than those of the incoming signal. Hence, beats will be produced at the frequency of 1000 cycles per second and the signals heard.

Now, when the capacity of the secondary condenser C is varied so that the frequency of the oscillations generated is 499,000 cycles per second, it means that we have detuned the secondary circuit from the incoming wave frequency. However, this detuning is only 1000 cycles in 500,000 cycles, the frequency of the incoming wave, which is seen to be at only 0.2% which is negligible and has very little effect on the strength of the incoming signal.

By alternating the capacity of the condenser C, the frequency of the generated oscillations may be varied, and in this way the beat frequency also varied, thus permitting the operator to secure a signal note of whatever pitch he desires.

In the self-heterodyne system, the student will see that a very heavy burden is placed on the single detector tube. The vacuum tube must detect or rectify the signal, it must also act as the generator of the superimposed oscillations, and before it can oscillate it must amplify, hence, it acts as an amplifier. This is asking a little too much for a single tube, and it is difficult for

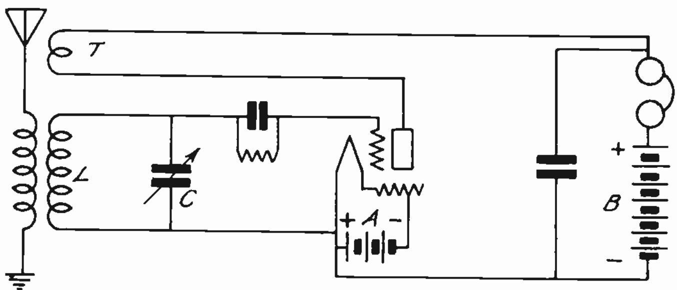


Fig. 23—Circuit of a simple Heterodyne receiver of the Self-Heterodyne type.

one tube to perform all of these functions at maximum efficiency. Thus, it is possible that the conditions for maximum efficiency as a detector are different from the conditions for maximum efficiency as an oscillator. The tube may do one function well and not the other, for the operator has not the same lee-way in adjusting his circuits. If he changes it so that he gets very good oscillation efficiency, he may get, as a result, very poor detection efficiency. In other words, such a circuit is not very flexible as it does not permit a wide latitude in adjustment.

Separate Heterodyne Methods.

In order to avoid throwing such a load on one tube, **the external heterodyne system is used.** In this case, **the detector tube simply rectifies, while an external generator of the radio frequency oscillations is used.** See Figure 24. It will be readily seen that this system has many advantages over the self-heterodyne system. In the first place, the detector tube can be adjusted so that it detects at maximum efficiency without any fear as to disturbing any other adjustment, for that is all the detector tube has to accomplish. In the second place, the oscillating circuit may also be adjusted to its best efficiency without any fear as to disturbing the detection efficiency. In the third place, there is no danger of the detector circuit stopping oscillation, hence, stopping reception, as in the case of the self-heterodyne system, for sometimes adjusting the detector tube results in causing the oscillations to cease. Finally, since an external heterodyne is employed, the receiving circuit need never be detuned to generate different frequency waves, for the external heterodyne generates these waves in its own circuit. Thus, from every point of view, the external heterodyne is the best.

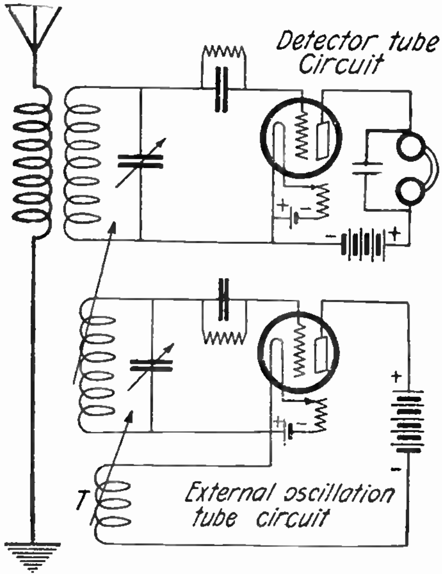


Fig. 24.—Heterodyne receiving circuit employing an external oscillator for producing the Heterodyne effect.

The **Heterodyne System** of reception is far superior to all the other methods of reception and detection of continuous waves. Its selectivity is excellent, that is, it is able to discriminate between waves and omit those that are not desired.

Its selectivity is unequaled by any other system. With respect to its sensitivity, it has a most unusual characteristic, it is tremendously sensitive to currents of weak strength, while it is not so sensitive to currents of strong strength. This makes possible loop reception with the heterodyne and it is also very useful in the reduction of static and other strong interferences.

for while the signal may be very weak it is amplified a great many times by the heterodyne action, but if a strong static or other interfering wave is imposed on it, the amplification is very weak and in this way the signal response is greatly increased over the static or interference response.

A student now has a fair idea of the principal methods employed in detection of all types of radio frequency waves. In advanced text books we will take up the different receiving circuits used in modern receivers and go into details on Radio frequency and audio frequency amplification.

TEST QUESTIONS

Number your answers 10—2 and add your **Student Number.**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What is the purpose of using a detector in a receiving set?
2. Name some minerals used for crystal detectors.
3. Who discovered the rectifying action of a vacuum tube and its adaptability to the reception of radio signals?
4. What is the relation between the temperature of metal and the escape of electrons from it?
5. What happens if a negative charge is placed on the plate of a two-electrode tube?
6. What type of tube is used for a detector when alternating current is applied to the filament?
7. Draw a circuit diagram showing the connection to an A. C. detector tube.
8. Name the two principal methods of detection using the vacuum tube.
9. What method is used for the reception of continuous waves?
10. Draw a circuit diagram of a heterodyne receiver employing an external oscillator.

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(2nd Edition)

THE VACUUM TUBE AS AN AMPLIFIER

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Washington, D. C.

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—*Woodrow Wilson.*

SOME GOOD STUDY HABITS

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Clearness. The habit of insisting on clearness of thought is essential to study. Mental vagueness is mental weakness. Never leave a lesson with a vague idea of it. A good way to overcome mental cloudiness is to establish the habit of writing out the vague points. If you can express your thoughts in writing, it will help you clear them up.

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

THE VACUUM TUBE AS AN AMPLIFIER

Thus far in the study of "Practical Radio", our study of elementary principles has built a foundation preparing us to take up one of the most important subjects connected with Radio—the action of a three element vacuum tube as an amplifier. In the previous lesson, the action of the vacuum tube as a detector was studied. In this lesson, *the action of the three element vacuum tube as an amplifier will be discussed.* Without this adaption, the usefulness of the vacuum tube in radio would be confined to detection or rectification.

Before proceeding with a detailed study of the action of a vacuum tube as an amplifier, let us briefly review some facts. To understand the action of a vacuum tube, the following facts should be borne in mind. A current of electricity is simply a flow of electrons, the electrons flowing in one direction, which makes a current. Electrons are small charges of negative electricity. All material contains electrons. There are two kinds of electricity—positive and negative. Like electricity repels and unlike attracts.

The following additional facts must now be grasped before the action of the vacuum tube can be thoroughly understood. It has been discovered that metals, if heated, will throw off into space some of the electrons which the metals contain. Furthermore it has been discovered that the hotter the metal, up to a certain degree of heat, the more electrons it discharges. These electrons travel at a high rate of speed. If air or any other gas be present in the space around the metal, the electrons strike the minute particles of the air or gas and are soon stopped.

At this point, it would be well to bring out a point in regard to the direction of flow of current and the direction of flow of electrons. The direction in which electric current is said to flow is a matter of arbitrary decision. The electric current is said to flow from positive to negative in the exterior part of a battery circuit. When the early scientists decided which way the electric current flowed, they did not have knowledge of the existence of electrons so they called one terminal of a battery positive and the other negative, and since the positive value indicates a stronger force than a negative value, the current was said to flow from positive to negative. Since that day, the electron theory has been definitely established. It has been definitely established that the electrons flow from the negative terminal of a battery to the positive terminal in the exterior part of the battery circuit. The student should firmly bear this in mind and not become confused as to the direction of flow of electrons because this is definitely settled. To prevent any seeming contradiction we shall adhere to

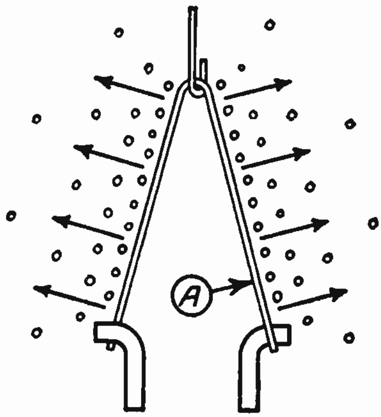

Fig. 1—The Electron Discharge from the Ordinary Filament. The arrows on this much-simplified drawing show the direction taken by the electrons that are emitted from the heated tungsten filament, A.

the popular way of expressing the direction of flow of current—that is, from the *positive to the negative* in the exterior part of a battery circuit.

THE FILAMENT

There are at present *three general types of materials used in the construction of the filament: tungsten wire filament, the oxide coated tungsten filament and the thorium coated tungsten filament.* Formerly, all vacuum tubes used the tungsten type of filament. It was later discovered that by coating the tungsten filament with the oxide of certain metals that the number of electrons given off by the filament for a certain amount of current passing through the filament would be materially increased.

For a given number of electrons thrown off, less current would be required to heat the filament naturally, the filament could be operated at a much lower temperature, with a considerable increase in the life of the filament, before burning out. The latest advance in filament construction consists in coating the tungsten filament with thorium. This gives a further increase of electron emission, and in order to have a certain amount of electron emission, a further saving in the amount of current required to heat the filament is obtained.

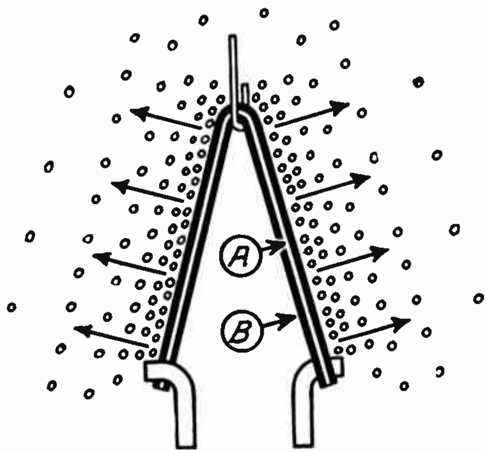

Fig. 2—The Electron Discharge from the Thoriated Filament. Note the greatly increased emission of electrons from the tungsten filament, A, which has been coated with a minute layer of thorium, B.

This is illustrated in Figures 1 and 2. In Figure 1, it will be noticed that the number of electrons, represented by the small circle, is not nearly as great as the electrons represented in Figure 2.

ACTION OF THE VACUUM TUBE

A vacuum tube consists of a container, usually glass, from which the air has been pumped. In this glass tube or bulb is mounted the filament, the grid, and the plate. In some A. C. tubes the usual filament is replaced by an indirectly heated cathode consisting of a metal oxide coated cylinder; this throws off the electrons as it is heated by an internal filament.

By applying some facts previously learned, we can now take up in detail and understand the action of the vacuum tube. Since the air is pumped from the glass tube or bulb (hence the name vacuum), the passage of the electrons thrown off from the filament will not be stopped. Since there is only a very small amount of air or gas within the glass tube, electrons thrown off by the filament will be accelerated, because there are no small air particles which impede the electrons in becoming detached from the filament.

In Fig. 3, the filament is heated so that it becomes red or white hot. This is done by the electric current furnished by the "A" battery or by a step-down transformer with AC tubes. Suppose that the filament is hot and the grid and plate are not connected to outside circuits. The electrons are thrown off from the filament and strike both the grid and the plate. These acquire a negative charge, as they have acquired electrons, which are negative charges of electricity. The space inside the tube has also a negative charge as the space is filled with negative electrons. Like charges repel each other and hence the negative charge on the plate, the negative charge on the grid, and the negatively charged space inside the tube are all repelling the electrons which the hot filament is trying to throw off. As each electron is thrown off of the filament, it adds its charge, either to the plate, grid, or space. The stronger charge causes a stronger repulsion of the escaping electron. In a very short while, the repulsion is strong enough to prevent the escape of any more electrons from the filament.

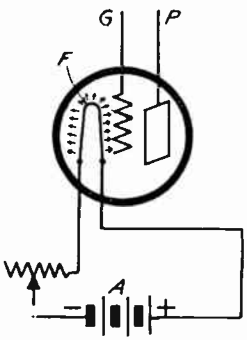

Fig. 3

Figure 4 shows an "A" battery, used to heat the filament and a "B" battery, with its positive terminal connected to the plate of the tube, and its negative terminal connected to the filament circuit. (The use of the grid will be shown later). By connecting the battery as shown in the figure, two things have been done. First, a positive potential has been placed on the plate; second, a metallic circuit containing a battery has been made outside of the tube from the plate to the filament. This leaves only the space between the filament and the plate inside the tube to complete the circuit. The "A" battery is used simply to heat the filament.

The heated filament throws off electrons. *The plate is positive and attracts the electrons which are negative.* The electrons travel through the space (no air or gas particles being present to hinder them as it is a vacuum) from the filament to the plate. There is then a flow of electrons from the filament to the plate and a flow of electrons is an electric current. Thus, the combination of the heated filament, the vacuum, and the positively charged plate, has caused a current to flow; that is, in effect, it has completed the circuit which contains the "B" battery, plate and filament.

The action of the "B" battery is comparable to a pump. When it forms part of a circuit, it pumps electrons out of its negative terminal and into its positive terminal. In the circuit arrangement shown in Fig. 4, the "B" battery pumps the

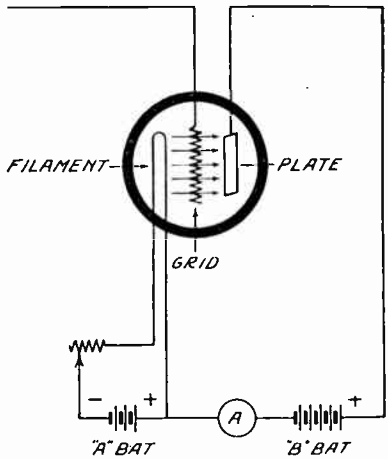

Fig. 4—Diagram of the Insulated Grid in the Vacuum Tube.

electrons coming from the filament, to the plate to the + terminal of the "B" battery and out of the — terminal of the "B" battery to the filament. The filament again throws them off and they go to the plate, being attracted by it as it is positive and the electrons flow around the circuit. This flow of electrons constituting a current of electricity can be measured by the ammeter, A, placed as shown. This ammeter could also be placed between the plate and the positive terminal of the "B" battery.

Consider the effect of changing the number of cells in the "B" battery. Changing the number of cells in the battery would change the positive potential on the plate. If the positive potential on the plate became greater, it would have a greater attraction for the flying electrons in the tube, and hence in a given time, more electrons would arrive at the plate and be pumped around the circuit by the "B" battery. An increased flow of electrons means an increased flow of current. In the same way, a decreased potential on the plate would cause a smaller current to flow. This change in current with a change in plate potential does not follow Ohm's Law; that is, doubling the plate potential does not double the current as it does in a wholly metallic circuit. If there is not an increase in filament current and temperature, only a certain amount of electrons can be thrown off by the filament, and hence a point will be reached when the plate potential is raised, where no more electrons can be attracted from the filament to the plate.

Since the electric current is said to flow in the opposite direction from the electrons, this electric current is then said to flow from the positive terminal of the "B" battery, through the plate, and then by means of the electron current, through the filament, and back to the negative terminal of the "B" battery. The electrons pass from the filament to the plate and grid. Neither the plate nor grid can emit electrons as they are not heated. This means that the electrons can pass only one way through the tube; an electric current can pass only one way through the tube. This is exactly what the crystal detector does. A vacuum tube with only a filament and plate (grid connected to the plate or not built into the tube) may be used as a detector in place of the crystal. Such a tube may also be used as a rectifier of alternating currents, because it allows current to pass only in one direction. Now we will explain how the grid greatly improves the action of the tube, before taking up the action of the vacuum tube as an amplifier.

ACTION OF THE GRID

As has been explained, the plate current may be controlled by variation of the filament current and temperature and also by variation of the plate potential. It was discovered by DeForest that putting a third element in the tube gives a more sensitive method of control. This third element is the grid. It must be remembered that the grid is a lattice-like construction which surrounds the filament and is, therefore, between the filament and the plate.

The illustrations so far do not show any connection to the grid. The electrons, which are emitted by the filament, pass through and around this grid and are not impeded in their passage to the plate. Now, suppose we should connect a small battery (shown as "C" in Fig. 5) across the filament and grid with the negative terminal connected to the grid and the positive terminal connected to the filament. This would make the grid negative with respect to the filament, or in other words, a negative charge will be placed on the grid. Let us study the effect of this charge on the grid in the diagram. The electrons trying to leave the filament represented by the arrows are negative. The grid is charged negatively by the "C" battery. Remembering the fact that *"like charges repel and unlike charges attract,"* we readily see that the electrons are repelled and forced back to the filament; a small number, or

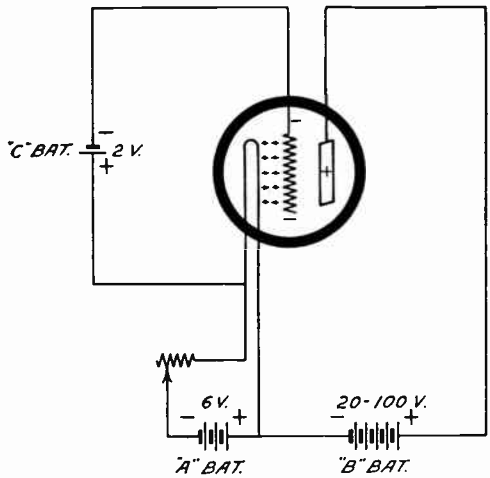

Fig. 5—This Diagram Illustrates the Action of the Negative Charge on the Grid.

none, ever get across to the plate. Hence, in this connection, the tube lets little or no current across from the plate to the filament.

What would happen if we suddenly were to reverse the terminals of the "C" battery which is charging the grid? Let us investigate this in Fig. 6. In this case, the grid would have a positive charge and the negative electrons would be strongly attracted across from the filament to the grid. When they get this far on their journey, they begin to feel the greater attraction of the higher positive voltage charge on the plate and they pass through the spaces in the grid in a flying effort to get to the plate, which receives them "with open arms", so to speak.

The attraction of the positive charge on the grid draws many times more electrons from the filament than would ordinarily leave it, and thus the density of the stream is increased many times. The current flowing across from the plate to the filament, of course, is a direct current, and is known as the plate current of the tube. To sum up the action of the tube in a few words, we might say that the plate current of the vacuum tube can be controlled by the voltages applied to the grid.

In Figures 5 and 6, the "C" battery allows a potential to be placed on the grid. This can be made stronger or weaker by changing the potential of the battery. It can be made positive or negative by reversing the connection of the battery. *Making the positive potential of the grid higher causes it to attract the electrons with more force, and causes a greater current*

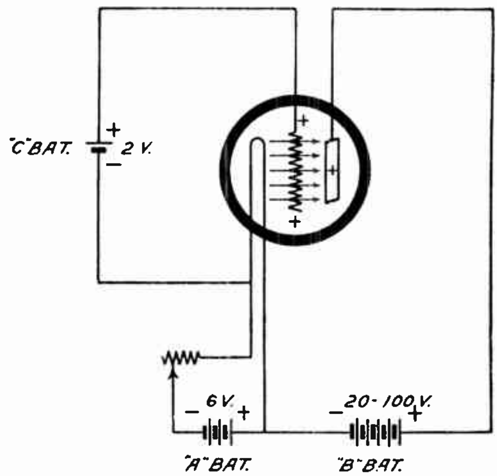

Fig. 6—The Action of the Positive Charge on the Grid.

to flow in the tube. By making the negative potential of the grid higher, the electrons are impeded in their progress, resulting in a decreased amount reaching the plate and a corresponding decrease in the plate current. Since the grid itself has a very small surface and does not catch many of the flying electrons, most of the electrons go past the grid and reach the plate when there is a positive potential on the grid. If the negative potential is made large enough, its repulsion of the electrons will entirely stop their flow and hence stop the passage of any plate current. Because of the nearness of the grid to the filament, a slight change in the potential of the grid makes a large change in the plate current. The effect of changing the grid potential is, therefore, much greater than obtained by changing the plate potential. Thus, it is possible to have a small amount of energy acting on the grid control a greater amount of energy in the plate circuit.

In Figure 7, we have an arrangement whereby it is possible to quickly vary the amount of voltage and the polarity of the voltage that is applied to the grid. When the movable arm of the potentiometer, P, is at C, there will be a negative potential applied to the grid, equal to the potential difference between the points A and C. When the arm is at B, a positive potential will be applied to the grid. Since the grid-return, filament end of the grid connection or circuit, connects to the filament, at point A, which corresponds to the middle cell of the "C" battery, the grid voltmeter will not indicate any potential difference between the grid and filament when the arm of the

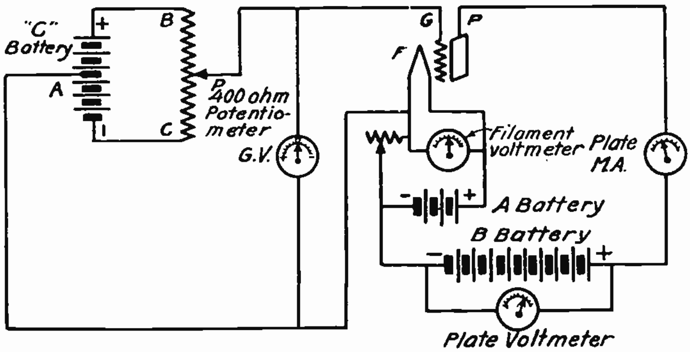

Fig. 7—Circuit Diagram of Testing Set for Obtaining Tube Characteristics.

potentiometer is half-way between C and B. The opposite voltages between AB and AC just balance each other.

As the potentiometer arm is moved along the resistance, the voltage applied to the grid, which is usually called bias voltage, causes a change in the plate current as registered by the plate milliammeter. By changing the applied grid or bias voltage, the plate current is changed. Suppose that no current is flowing in the plate circuit when the potentiometer arm is at C in Fig. 7 and when the arm is at B, a flow of 6 milliamperes. At intermediate points between C and B, the grid voltmeter and plate milliammeter reading could be recorded for future reference. The readings could be recorded something like that shown in Table No. I.

In the left-hand column, the grid voltages are shown and on the same line in the right hand column, the corresponding plate current is shown.

Different tubes of the same type, or different types of tubes will give different readings. Later on in this lesson, we are going to make use of this table and the figures therein in order to learn more about the action of the vacuum tube.

So far in our study of the action of the vacuum tube, we have found that with a negative potential applied to the grid, the electrons passing between the filament and plate are retarded, resulting in a decrease of plate current. Furthermore, with a positive potential applied, we found that this positive potential assisted the plate in attracting the negative electrons, resulting in an increase of plate current. However, we overlooked an important fact. In Figure 6 when the positive terminal of the "C" battery is connected to the grid with a positive charge applied to the grid, it can be noted that a few

TABLE No. I

Grid Volts	Plate Current Milliamperes	Grid Volts	Plate Current Milliamperes
—13.5	0.0	+ 1.5	3.5
—12.	.1	+ 3.	4.0
—10.5	.18	+ 1.5	4.5
— 9.	.25	+ 6.	5.0
— 7.5	.5	+ 7.5	5.45
— 6.	1.	+ 9.	5.7
— 4.5	1.5	+10.5	5.8
— 3.	2.	+12.	5.9
— 1.5	2.5	+13.5	6.00
0	3.		

of the electrons will be stopped by the grid, and since the "C" battery positive is connected to the grid, these electrons will pass from the grid to the positive terminal "C" battery, and thence to the filament, completing a circuit. This results in a very few of the electrons which should go to the plate being utilized in the grid circuit. If there were only a certain number of electrons being given off by the filament and some were utilized in the grid circuit, when the grid becomes positive, then, this would result in less electrons reaching the plate and a very slight reduction in the plate current. This, we want to overcome because when the grid is positive with respect to the filament, the plate current will be increased in the same amount that the plate current is decreased when a negative potential having the same value as the positive potential is applied to the grid.

Before proceeding further, it will be well to clear up another statement for the student. When the grid is spoken of as being positive, or negative, with respect to the filament, the negative end of the filament is referred to as this is the end which the electrons enter in their passage through the filament from the "A" battery. Remember this, as it is a very simple but important fact.

We have not yet settled our problem of preventing a current from flowing in the grid circuit when the grid is positive with respect to the filament. How can we arrange things when the grid becomes positive with respect to the filament, a grid current will not flow? Simple enough, but read these next few sentences carefully. We found that when the grid was slightly negative that the grid repelled some of the electrons and prevented them from reaching the plate, resulting in a very slight decrease in plate current. The more the grid became negative, the more the plate current was decreased until finally the plate current could be cut off entirely. However, it is not desirable to do this. Suppose that the grid is permanently maintained at some negative value so that any changes in the potential applied to the grid never allow the grid to become positive with respect to the filament. To make this point clearer, let us say that we apply a negative potential of two volts to the grid. If the negative grid potential is increased one volt more or to three volts, we would have less plate current flowing than when two volts negative were applied. Also, if the negative grid potential is decreased from two volts to one volt negative, there would be more plate current flowing than when two volts negative were applied to the grid.

Now refer to Fig. 8. Here we have an alternating current generator, G, connected to the grid and filament of a vacuum tube. A cell, C, which delivers, let us say, two volts, is inserted in series in the grid connecting wire. Notice that the negative terminal of the cell, C, is connected to the grid of the tube. As in the case given in the preceding paragraph, let us say the generator delivers one volt of alternating current. When the voltage of the generator is trying to force current from A in the direction of C and to the grid, it is opposed by the voltage of the cell, C, which is trying to force current in the opposite direction. When the voltage of the generator is trying to force current from B in the direction of the filament, it is assisted by the cell, C. As the cell, C, delivers more voltage than the generator, then the grid is always negative with respect to the filament. The voltage of the generator merely adds to and subtracts from the effective voltage of the cell which is applied to the grid. Here, then, is the solution of our problem. By always keeping a negative potential applied to the grid, the grid never becomes positive in respect to the filament, whenever changes in potential occur. Changes in the grid potential will cause corresponding changes in the plate current.

In Figure 8, the alternating current generator causes the voltage applied to the grid to vary between minus one and minus three volts. Since the normal negative voltage of the

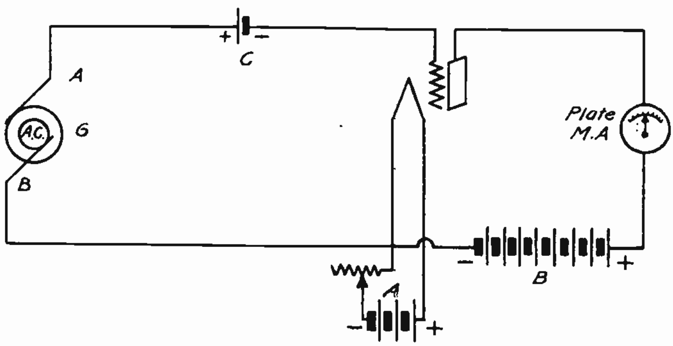

Fig. 8

cell, C, is decreased and increased by the action of the generator voltage, the voltage that is actually applied to the grid is said to vary or swing in a negative and positive direction with respect to its normal voltage. This being the case, we come to an important fact. When a three element vacuum tube is used as an amplifier, the grid must always be maintained at such a negative potential that any variance of this potential will never allow the grid to become positive with respect to the filament. This for the purpose of preventing grid current from flowing. Later we shall learn more about how this is done in a receiving set.

THE CHARACTERISTIC CURVE

Here we have a drawing of a curve on a piece of cross-section paper from which we are going to make use of the reading of the grid voltage and corresponding plate current readings which were shown in Table No. I. The base line CB corresponds to the voltage that is applied to the grid by moving the potentiometer arm along CB in Fig. 7. We found that as the arm was moved toward B, the plate current increased, so we let the line CD of Fig. 9 represent this increase.

From Table No. I, we found that with the arm at C or the maximum negative voltage, we did not have any plate current flowing. Now in order to make these values serve another purpose, we will plot them on the sheet of cross-section paper.

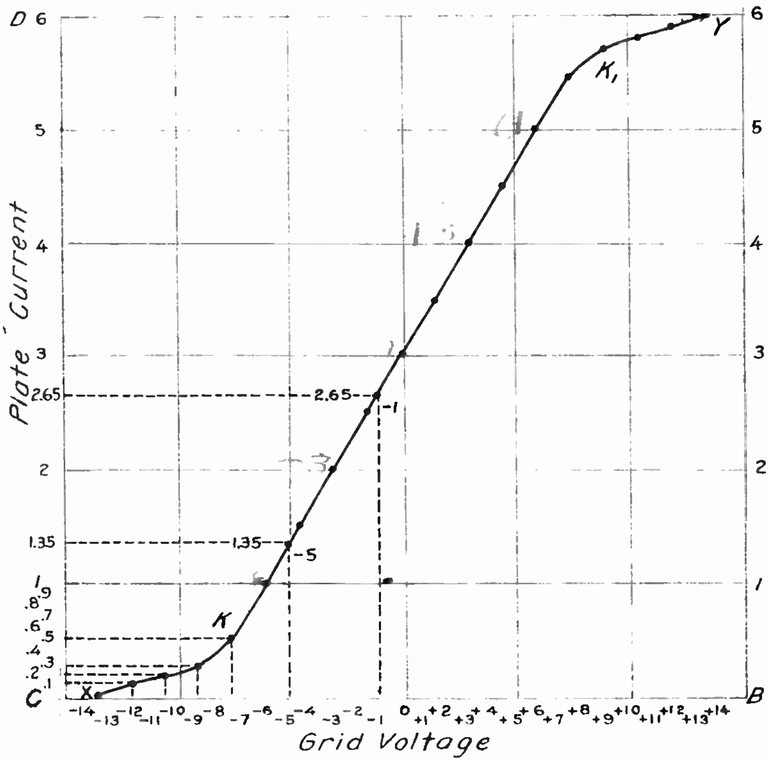

Fig. 9

Locate —12 on the base line CB and go up on this line until the horizontal line opposite for .1 on CD is intersected. This is the first horizontal line above the base line. Stop here and make a dot as shown in Fig. 9. The horizontal lines, represent values of plate current and the vertical lines grid voltages. Now locate the remaining points as obtained from the values given in Table No. I. When all the points have been located, draw a line connecting all the points and the curve XY is the result.

This is called a characteristic curve of the plate current and grid voltage. It is obtained as just explained. First, it is necessary to have a circuit arranged such as in Fig. 7; then, make note of the values such as in Table No. 1, and finally, plot the curve as shown in Fig. 9.

The important point about this curve is that it is not a straight line. The lower portion of the curve to the left of and above and corresponding to —7.5 grid volts is more horizontal and not as steep as above and corresponding to zero grid volts. Also, again, above and corresponding to +10 grid volts, it is more nearly horizontal than between —7.5 and +7.5 grid volts.

In our study of detection, in the previous lesson, we found that the tube operates on one of the bends or "knees" of the curve, such as at K or K1, when using the "C" battery method of detection. Should we desire to operate the tube as an amplifier, it is necessary to operate it on the straight portion somewhere between these points.

Why and how do we do this? First, we learned earlier in this lesson that when a vacuum tube was worked as an amplifier, we wanted changes in the grid potential to cause corresponding changes in the plate current. If the grid voltage is increased and decreased in a like amount, we want the plate current to increase and decrease in the same manner. Next, we learned that it was necessary to keep the grid at a permanent negative value in order to prevent a grid current from flowing which would interfere with the plate current increasing in the same proportion that it was decreased for various changes of the grid voltage.

By referring to Fig. 9, we see that between K and K1, the line is almost straight. At the point on curve above and corresponding to —3 grid volts, the tube could be satisfactorily operated as an amplifier. If the grid bias negative voltage is decreased to —1 volt, the plate current would be increased from 2 milliamperes to 2.65 milliamperes. If the negative grid voltage is increased to —5 volts, the plate current would be decreased from 2 to 1.35 milliamperes. We then have the condition under which an amplifier must operate; the grid is maintained at such a negative voltage that any changes which might occur in this potential will never allow it to become positive

TABLE No. 2
AVERAGE CHARACTERISTICS OF RECEIVING TUBES

Tube	Filament Terminal Volts	Filament Current (Amps.)	Detector: "B" Volts	Detector: Plate Current (Ma.)	Amplifier: Plate Volts	Amplifier: Grid Bias Volts		Amplifier: Plate Current (Ma.)	Amplifier: Voltage Amplification Factor	Amplifier: Max. Undistorted Output (M'lw't)
CX-12 UX-12	1.1	.25	22.5 to 45 V	1.5	90.0	4.5		2.5	6.6	7
					135.0	10.5		3.5	6.6	35
CX-299 UX-199	3.3	.063	22.5 to 45 V	1.5	45.0	1.5		1.0	6.6	
					67.5	3.0		1.7	6.6	
					90.0	4.5		2.5	6.6	7
CX-220 UX-120	3.3	.132			90.0	16.5		3.2	3.3	
					135.0	22.5		6.5	3.3	110
CX-322 UX-222	3.3	.132	Screen-Grid Voltage+45		90.0	1.5		1.4	175	—
					135.0	1.5		1.5	290	
					135.0	3.0		1.0	300	
CX-300A UX-200A	5.0	.25	45	1.5					20.	
CX-301A UX-201A	5.0	.25	45	1.5	45.0	1.5		.9	8.0	
					67.5	3.0		1.7	8.0	
					90.0	4.5		2.5	8.0	15
					135.0	9.0		3.0	8.0	55
CX-340 UX-240	5.0	.25	135	.3	135.0	1.5		.2	30.	*
			180	.4	180.0	3.0		.2	30.	*
CX-326 UX-226	1.5	1.05			90.0	6.0		3.7	8.2	20
					135.0	9.0		6.0	8.2	70
					180.0	13.5		7.5	8.2	160
C-327 UX-227	2.5	1.75	45	2.0	90.0	6.0		3.0	9.0	
					135.0	9.0		5.0	9.0	
					180.0	13.5		6.0	9.0	
C-324 UX-224	2.5	1.75	Screen-Grid Voltage+75		180.0	1.5		4.0	420	
						D. C.	A. C.			
CX-112A UX-112A	5.0	.25			90.0	4.5	7.0	5.5	8.0	30
					135.0	9.0	11.5	7.0	8.0	120
					157.5	10.5	13.0	9.5	8.0	195
					180.0	13.5	16.0	9.5	8.0	300
CX-371A UX-171A	5.0	.25			90.0	16.5	19.0	10.0	3.0	130
					135.0	27.0	29.5	16.0	3.0	330
					157.5	33.0	35.5	18.0	3.0	500
					180.0	40.5	43.0	20.0	3.0	700
CX-310 UX-210	7.5	1.25			250	18.0	22.0	10.0	8.0	340
					350	27.0	31.0	16.0	8.0	925
					425	35.0	39.0	18.0	8.0	1540
CX-345 UX-245	2.5	1.5			180	33.0		26.0	3.5	780
					250	50.0		32.0	3.5	1600
CX-350 UX-250	7.5	1.25			250	45.0		28.0	3.8	900
					300	54.0		35.0	3.8	1500
					350	63.0		45.0	3.8	2350
					400	70.0		55.0	3.8	3250
					450	84.0		55.0	3.8	4650

*When used in resistance-coupled amplifier with .25 megohm plate resistor.

with respect to the filament. By applying this negative potential and operating the tube upon the straight portion of its characteristic curve, the changes in grid voltage produce corresponding changes in the plate current.

It will be well to note here that it is not necessary to have a circuit such as shown in Fig. 7 and plot a curve such as shown in Fig. 9 before we can use a particular tube as an amplifier in a receiving set. The manufacturer does all this for us in the laboratory and tells us just what grid voltage to apply for a certain plate voltage. This information is usually given in the sheet of directions which accompanies the tube when it is bought, or else given in a tube chart. Such a tube chart is shown in Table No. 2. Take for instance the UX-201-A tube. Under the column "Amplifier Plate Voltage," we find the figures 90; under the column for "Amplifier Grid Bias Voltage," the figures 4.5. When a plate voltage of 90 volts is applied to the tube, a negative voltage of 4.5 volts should be applied to the grid, and for 135 volts on the plate, 9 volts negative should be applied to the grid. By applying the proper negative grid voltage to the tube, when a certain plate voltage is applied, the tube is caused to work upon the straight part of its characteristic curve where proper amplification takes place.

ACTUAL WORKING CONDITIONS

Now let us refer to Fig. 11. Here we have the circuit diagram of part of a receiving set. The approaching signal wave which is sent out by the transmitting set strikes the antenna, induces a voltage in it, and causes a current to pass through the coil L to the ground. The current in passing through the coil L sets up a magnetic field which changes according to the changing signal voltage in the antenna. This changing field induces a voltage in the coil L2. The variable condenser C connected across the coil L2 tunes or causes the circuit L2 C to be responsive to the same frequency as the signal voltage induced in the antenna. There is then a corresponding alternating voltage in the circuit L2 C and since one terminal of the coil L2 and the condenser C connects to the grid, and the other terminal of the coil L2 and condenser C connects to the negative terminal of the "C" battery and then to the filament, this alternating voltage causes changes in the applied potential between the grid and filament. Any change in the grid potential will cause changes in the plate current, therefore, the amplifier tube V.T. merely repeats the changes of the grid potential in the plate circuit. As the "C" battery always maintains the grid at a negative potential, as previously explained in regard to Fig. 8, the plate current rises and falls in proportion to the changes in the grid voltage.

There are two important things to remember here. First, the antenna signal current, which flows through L merely induces a voltage in the secondary circuit L2 C and this in turn is impressed on the grid, resulting in a change in plate current. The antenna current does not flow through the secondary circuit and then through the tube and plate circuit. In flowing through the primary coil L, a voltage is induced in L2 C circuit which affects the grid potential resulting in a change in plate current. Each part of the circuit "repeats" the changing currents and voltages.

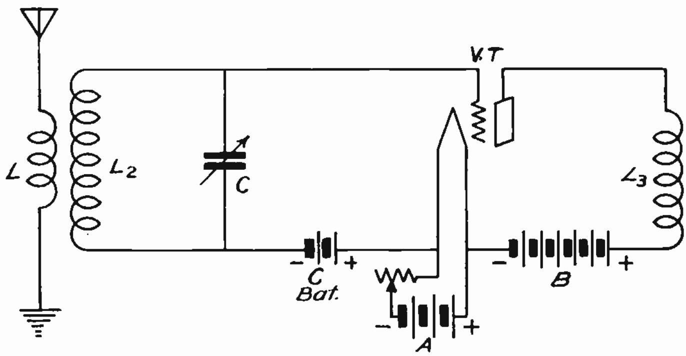

Fig. 11

The *second* point is that the vacuum tube amplifier V.T. is a voltage actuated device. By this, we mean that what we desire is to have a change in the potential that is applied to the grid. The "C" battery maintains the grid at a certain negative potential when there is no signal voltage on the antenna. When a wave approaches, the net result is that the effective voltage of this "C" battery is changed, resulting in a changed grid potential and a corresponding change in plate current. Thus, it can be seen that the change in plate current depends upon a change in the voltage applied to the grid.

It is not always necessary to use a "C" battery in order to maintain the grid at a slight negative potential or bias. This negative bias can be obtained in another way, illustrated in Fig. 12. Notice that the "C" battery is left out, and the grid-return connects to the negative terminal of the "A" battery.

Previously, it was stated that when the grid was spoken of as being negative or positive in respect to the filament that the negative end of the filament was referred to. Since this is true and the grid-return in Fig. 12 connects directly to the negative terminal of the "A" battery, then the grid is slightly negative with respect to the negative end of the filament. This is true due to the voltage drop in the filament rheostat.

The main point to remember about the amount of negative "C" battery or bias voltage is that it must always be greater than the signal or alternating voltage that is applied between the grid and filament in order to prevent a grid current from flowing.

FORM OF PLATE CURRENT

Earlier in this lesson, we learned that the plate was maintained at a positive potential by being connected to the positive terminal of the plate or "B" battery in order to attract the electrons thrown off by the filament. *The electrons flow in one direction only, from the filament to the plate.* Therefore, any change in the grid potential merely causes a rising and falling of the plate current. The plate current never reverses its direction of flow.

Some writers refer to the plate current as "alternating". This is misleading to the student, as the word alternating indicates a reversal in direction of flow. A better way is to say "the alternating component of the plate current".

This varying or alternating component of the plate current comes in due to the fact that when a vacuum tube is properly used as an amplifier, the form of the plate current resembles the form of the alternating voltage applied to the grid.

By referring to Fig. 13, this can be more easily understood. In this figure, we have illustrated a characteristic curve of a tube. The grid is maintained at a negative value of 3 volts. This is shown as the point B on the curve. This point also represents the steady plate current of 2 milliamperes flowing. Suppose that while the grid is maintained at this potential, we impress on the grid an alternating voltage causing its potential to vary between minus 1 and minus 5 volts. In order to illustrate the changing values in grid voltage and corresponding changes in plate current, the "wavy" curves Eg and Ip have been used. Since the letter E usually represents volts, then to indicate grid voltage, the letter g is added. The letter I is used to represent current, hence Ip represents plate current. As the grid negative voltage is decreased from —3 to —1 volts caused by the applied alternating voltage, then the part of the wave or curve from B to D represents this change. The effect of decreasing the negative grid voltage results in an increase of plate current as shown by the part of the plate current curve from B to E. As the effective grid voltage begins to increase, due to the applied alternating grid voltage, it reaches its maximum negative value at A, so that the part of the curve or wave from D to F represents this change. Due to this increase in negative grid potential, the plate current decreases from E to G. By carrying this explanation further, the balance of the grid voltage and plate current curves are completed.

The main point to note about these curves is that the plate current curve Ip is larger than the grid voltage curve Eg, and

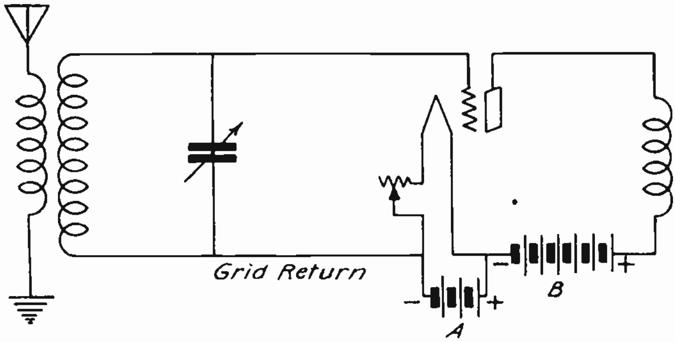

Fig. 12

that it also is the same general shape. Since this varying plate current has the same shape as the curve Eg representing the alternating grid voltage, it is common to speak of the varying plate current as "alternating", or better yet, "the alternating component of the plate current".

AMPLIFICATION FACTOR

The amplification factor of a vacuum tube is its theoretical voltage amplifying power. The symbol μ used in representing this amplification constant is known as "mu" which resembles our small letter "μ" as used in the alphabet. The amplification factor of a tube depends, for example, on the mesh of the grid, diameter of the grid wire, and resistance between the grid and the plate. In practice, it is generally found that the amplification constant does not vary. For extreme limits of grid voltage and plate voltage, this constant does change slightly. The voltage amplification factor or amplification factor, as it is usually called, is generally given in the direction sheets which accompany a tube and in tube charts, such as in charts shown in Table No. 2. As a practical example, suppose the amplification factor of a certain tube is given as 8 as determined by examining Table No. 2. This simply means that whenever a grid voltage is applied to the grid-filament

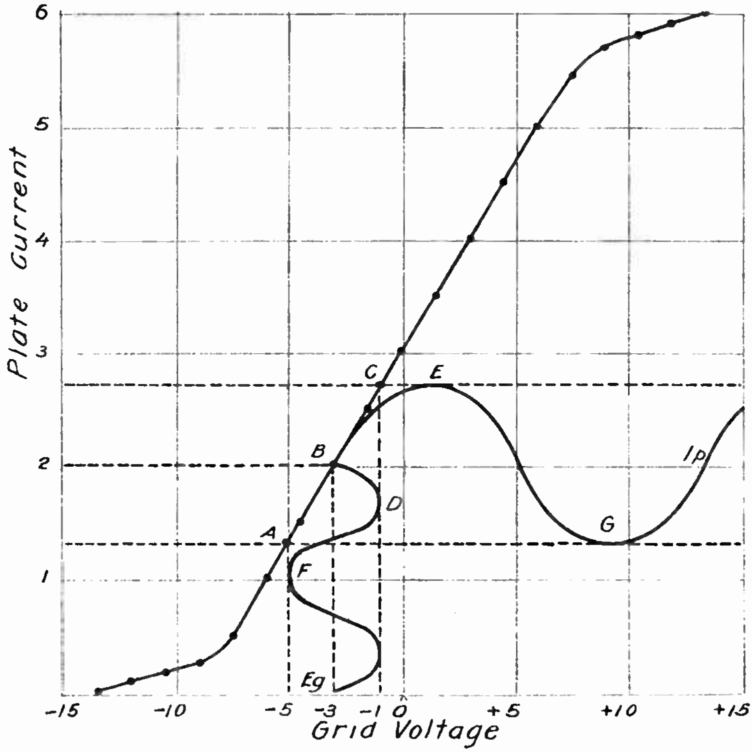

Fig. 13

circuit, it is increased eight times in the plate circuit. The amplifying power of the tube is eight times. This amplification factor is regarded as the constant because it cannot be changed by altering any of the circuit arrangements or parts within the circuit. It depends upon the geometrical arrangement of the elements within the tube.

SPACE CHARGE

In Fig. 14 is shown in elementary fashion the distribution of electrons between the plate and the filament; we will consider the electric forces acting on two of the electrons A and B. The electron A is urged to the plate by two forces, the attraction from the plate and the repulsion from all of the electrons between it and the filament; it will undoubtedly go to the plate. Electron B, although attracted by the plate, is repelled by all the electrons between the plate and itself; whether it will move towards the plate or re-enter the filament depends upon the relation between these two forces. It is evident that close to the surface of the filament, the effect of all the electrons in the space between the filament and the plate (constituting the space charge) will practically neutralize any effect on the plate, unless the plate voltage is high enough to give a force of attraction greater than the repulsion force exerted by the space charge. Thus, it can be seen that it is necessary to use a high voltage applied to the plate of the tube in order to overcome this space charge effect which causes the electrons near the filament to be repelled to a certain extent. As the electrons progress in their travel from the filament to the plate, they are naturally accelerated due to the attraction of the plate and due to the fact that the electrons which have overcome the space charge assist them.

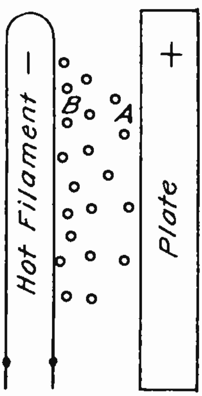

Fig. 14

PLATE RESISTANCE AND IMPEDANCE

The plate resistance of a tube is due to the work which the electrons emitted from the cathode (filament) must perform in moving from the cathode to the anode (plate). Let us consider the case of a single electron emitted from the cathode. In moving through the cathode surface, it has to do an amount of work equivalent to the electron affinity, and in moving from the cathode to the anode, it has to do work in overcoming the space charge effect and difference in potential between the cathode and anode. This may sometimes assist the electrons in moving from cathode to anode. If these were the only forces exerted on a large number of electrons escaping from the cathode, the application of a small voltage between cathode and anode would almost immediately give rise to the saturation current (total amount of plate current obtainable) and the resistance of the tube would be very low for all values of current less than the saturation current. This is not the case, since the electrons in the space exert a mutual repelling force on one another. This is the space charge effect previously explained and causes by far the greatest expenditure of energy on the part of the electrons in moving to the anode. This expenditure of energy causes a slight heating of the anode. In small receiving tubes, this heating of the anode never becomes enough to be visible unless excessive voltages are applied to the anode.

The true direct current resistance of the tube is, of course, given simply by the ratio of the total amount of work done to the square of the current, that is, by the ratio of the plate voltage to the plate current. The alternating current resistance, on the other hand, is given by the slope of the plate current characteristic curve, and since the characteristic curve is non-linear, the alternating current and direct current resistances are not the same. The impedance (alternating current resistance) of the tube is given by the ratio of the alternating voltage acting between the filament and the plate, to the alternating current component in the plate circuit.

CASCADE AMPLIFICATION

From our discussion so far, we have learned that the vacuum tube amplifier merely increases and repeats changes in voltage applied to the grid in the plate circuit. The real advantage of the vacuum tube as an amplifier is due to the fact that several amplifier circuits or stages can be properly connected, one following the other, and the original signal voltage repeated and amplified many times. Where several stages of amplification are to be used, it is commonly referred to as cascade amplification.

If oscillations (alternating current of high-frequency) are applied to the grid of one tube, we have learned that this creates variations in the plate current. If the plate current of this tube passes through the primary coil of a suitable transformer, then variations of current through it create corresponding changes of potential at the terminals of the secondary circuit of the transformer (see Fig. 15).

We can apply this amplified potential to affect the grid of a second tube, and again couple the transformer of the second tube to the grid of a third tube and so on. The great importance of this cascade arrangement is that the resultant amplification of the stages is the product, and not merely the sum, of their separate amplification. Now, suppose each tube and its transformer amplifies the potential variations ten times, then two in series or cascade, amplify 100 times, and three, 1,000 times and so on. Hence, by the use of several stages of amplification, we can obtain enormous amplification of the original potential acting on the antenna. By this means, then, it is possible to have voltages acting on the detector which otherwise might be so weak as to be ineffective in operating the detector.

It might appear to the student that with such enormous values of amplification that the latter tube would be overloaded. This would be the case if it were not for the fact that the voltage induced in the antenna by the radiated wave is so very small. In fact, this signal voltage acting on the antenna is

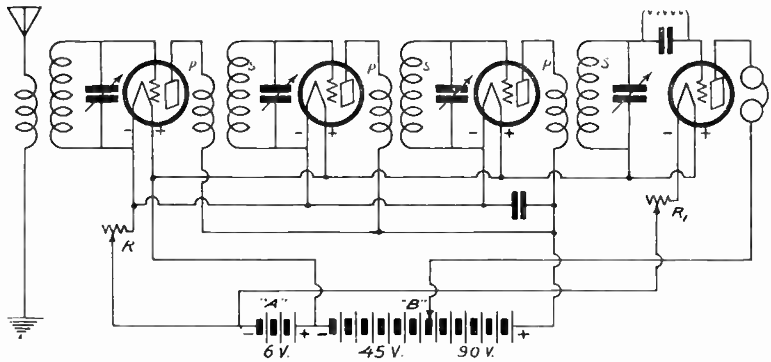

Fig. 15—Three Stages of Radio-Frequency Amplification and Detector Circuits.

represented in microvolts (millionths of a volt). Ordinarily, it takes about 5 microvolts (.000005) to actuate the grid of a vacuum tube so as to give an appreciable change in the plate current. From this, then, it can be seen that with 5 microvolts acting on the grid of the first tube in a cascade amplifier, the amplification could be increased by several stages by 1,000,000 before 5 volts would be acting on the grid of the last tube. In cases where considerable voltage is acting on the grid, it is necessary to use larger tubes which require higher grid bias in order to prevent overloading. Remember, always, that it is necessary to have a tube which will require a negative bias great enough in order that the applied signal voltage is never greater than the bias voltage. If the signal voltage should be greater than the bias voltage, then the grid would become positive with respect to the filament, resulting in a slight grid current, which would result in a slight decrease of the plate current instead of a proportional increase when the grid is positive. It is highly desirable that the plate current should never be decreased by a grid current, and for this reason, tubes of varying characteristics are manufactured so as to provide tubes which will allow a greater amount of grid signal voltage to be applied without drawing a grid current, resulting in a form of distortion.

CLASSIFICATION OF AMPLIFIERS

An amplifier generally consists of two or more vacuum tubes so arranged that the varying signal voltage is impressed upon the grid of the first tube, thus producing a variation of the plate current in this tube; this varying plate current is made to produce a varying voltage between the grid and filament of the second tube, and, similarly, the varying voltage is relayed from the second tube to the detector tube wherein detection takes place. Since the function of the detector changes the form of plate current, making the audio-frequency part of the signal voltage available, it can be followed by several stages of audio amplification. The stages which precede the detector are usually referred to as *radio-frequency amplifying stages,* because the frequency of the signal voltage is varying at a radio-frequency or above the range of audibility, which is in the neighborhood of 10,000 cycles. The stages following the detector are usually referred to as *audio-amplifying-frequency stages* that amplify the signal voltage which is varying at an audio-frequency, or below something like 10,000 cycles.

From this brief description, it is plain that the signals must be "repeated" from one tube into the next. Amplifiers, either for radio-frequency or for audio-frequency, are divided into the following classes, according to the arrangement used for "repeating": (1) *Transformer-repeating amplifiers.* (2) *Resistance-repeating amplifiers.* (3) *Inductance-repeating amplifiers.*

A tube, together with all co-acting apparatus used for amplifying purposes, is known as "a stage of amplification"; an amplifier consisting of a certain number of stages of amplification.

The two terminals of the amplifier upon which the incoming signal voltages are impressed are known as the "input" terminals, while the two terminals across which exists the amplified signal voltages are known as the "output" terminals.

TRANSFORMER-REPEATING AMPLIFIERS

Transformer-repeating amplifiers are used for amplifying both radio-frequency and audio-frequency signals, and we will discuss their principle of operation by referring to Fig. 16 which is intended to represent an audio-frequency transformer repeating, two stage amplifier. The radio-frequency transformer practically always uses a tuning condenser across the secondary coil, and thus this coil has quite an appreciable current; whereas the secondary of the audio-frequency transformer has very little current.

The audio-frequency varying potential is connected at Pb and stepped up by means of the transformer T1, after which it

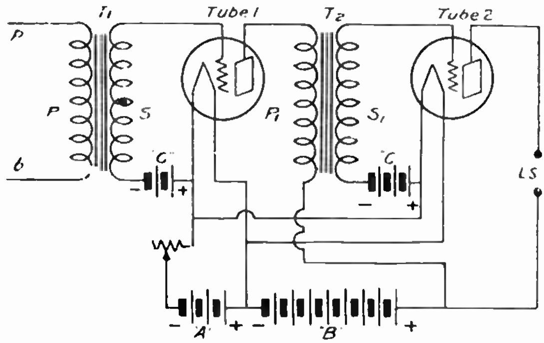

Fig. 16—Circuits of Two Stage Audio-Frequency Amplifier.

is applied between the grid and filament of the first tube; this produces a corresponding variation of the plate current of tube 1. The varying current flowing through the primary P1 of the transformer T2 induces an alternating voltage in the secondary S1. This voltage is applied to the grid and filament of the second tube, and thus the varying signal voltage is repeated from the first into the second tube, and finally from the second tube, varying plate current is caused to affect the loudspeaker (L.S.)

RESISTANCE-REPEATING AMPLIFIERS

The circuit diagram of Fig. 17 shows a three stage resistance-repeating or resistance-coupled amplifier. The incoming signal voltage is applied to the point Pb and is caused to affect the grid of Tube 1 through the means of the high resistance R. The grid and filament of Tube 1 are connected across the resistance R, through the comparatively large condenser C1; a grid leak resistance r1 is connected from the grid to the filament.

In an amplifier of this type instead of using transformers to pass the energy from one tube to the next, the voltage drop across a resistance in the plate circuit (R, R1 and R2) supplies the change in potential to the grid of the next tube.

In order to insulate the grids of the amplifying tubes from the "B" battery, blocking condensers C1, C2 and C3 are inserted between the plate and grid. Grid leaks r1, r2 and r3 are also necessary to provide a leakage path for the charges which would otherwise accumulate on the grids of the tubes.

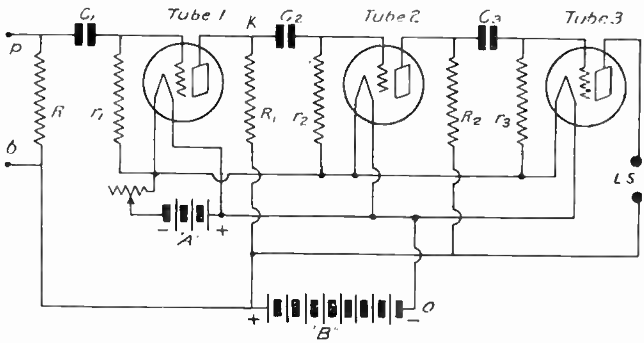

Fig. 17—Circuit Diagram of Three Stage Resistance Coupled Audio-Frequency Amplifier.

The variation of the grid potential of Tube 1 will cause a corresponding variation in the plate current in this tube, and hence a varying difference of potential will exist across the high resistance R1. Since the point 0 is at constant potential, it is plain that the potential difference between the points K and O will be varied and, as the battery resistance is comparatively low, the variation of this potential difference must necessarily be very nearly the same as that across R1.

The grid and filament of tube 2 are connected across K and O through the comparatively large condenser C2, and any variation in the potential difference across K and O will be impressed on the grid of tube 2; in other words, the signal will be repeated into the second tube by means of the repeating resistance R1.

In a similar manner, the signal will be repeated from tubes 2 to 3 where it will be picked up on the speaker.

The resistances R, R1 and R2 are generally in the order of 100,000 ohms. The capacity of the condensers C1, C2 and C3 generally lies between .01 and .1 microfarad. The larger the capacity of these condensers, the better the low-frequency currents will be passed. The leak resistances r1, r2 and r3 which make the tubes stable depends upon the type of tubes used. they may be anything between 250,000 and 1,000,000 ohms for tubes now generally used as amplifiers.

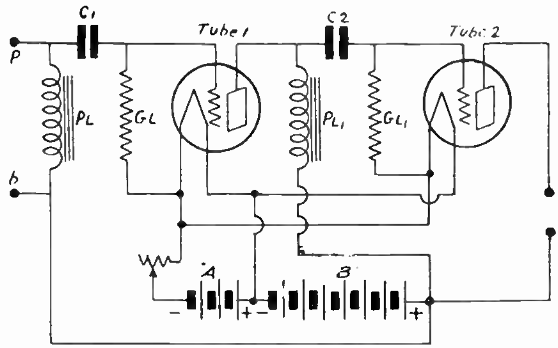

Fig. 18—Circuits of an Inductance Coupled Audio-Frequency Amplifier, Sometimes Called Impedance Coupling.

INDUCTANCE-REPEATING AMPLIFIERS

This type is similar to the resistance-repeating amplifier, except that instead of a resistance in the plate circuit of each amplifying tube, an *inductance or impedance* coil is used whose reactance, at the frequency for which the amplifier is designed, is high. The theory upon which the repeating action from tube to tube is based exactly the same as for the resistance-repeating amplifier. This method of repeating has an advantage over resistance-repeating in that the repeating inductance offers but little opposition to the flow of direct current through the plate circuit, and hence the "B" battery may be of lower voltage than if resistance-repeating were used. The inductance type of repeating amplifier circuit is shown in Figure 18.

PUSH-PULL AMPLIFIER

When a large amount of volume is required from a radio receiver or loud-speaker, the set must amplify the signal sufficiently to produce the required signal energy to be delivered to the speaker. The power is the last stage of an amplifier and may be so large that the vacuum tube in that stage of amplification is overloaded, resulting in distortion. One way to avoid distortion of the signal frequency is to use a power tube. The most popular method, however, is to use the push-pull amplifier, as shown in Fig. 19, which generally replaces the second stage of amplification.

The input transformer T1 uses a split secondary winding having a tap used as a common filament terminal at the electrical center. This center-tap is connected to a "C" battery to the filaments of the tubes in the usual way. The two grid

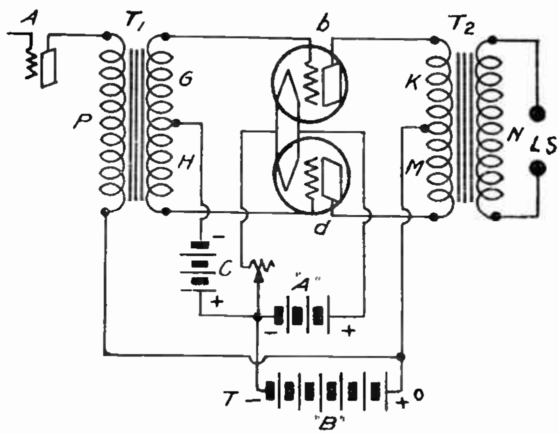

Fig. 19—Circuits of Push-Pull Audio-Frequency Amplifier.

terminals are connected to the grids of the two tubes. The output transformer T2 has a split primary winding with plate terminals at its two ends and a "B" battery terminal brought out from the electrical center of the primary winding. This output transformer has a single secondary winding which is connected to the loud-speaker.

Since the signal potentials on the grids of the two tubes B and D are 180 degrees out of phase (one is always + or — with respect to the other), the fundamental plate currents in the two plate circuits differ by 180 degrees. It will be evident from the foregoing that the current directions at any instant in the primary of T2 add together since an increasing current through the upper half of the winding produces the same effect as the decreasing current in the lower half, and vice versa.

The current that flows to the loud-speaker from the secondary of T2 is the result of the voltages of the two tubes acting together. With two power tubes connected as shown, the distortion is smoothed out, as this arrangement produces a current curve almost perfectly symmetrical. However, true push-pull action can only be obtained when the two tubes have the same characteristics (matched tubes), and the input and output transformers have accurately located center taps.

TEST QUESTIONS

Number Your Answers 11—2 and Add Your Student Number

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Name the three general types of materials used in the construction of the filament of vacuum tubes.
2. What effect does placing a negative charge on the grid have on the plate current?
3. Upon what portion of the characteristic curve should the tube act when used as an amplifier?
4. In Fig. 13, what is the plate current when the grid voltage is 3 volts negative?
5. What is the meaning of the amplification factor of a vacuum tube?
6. What is cascade amplification?
7. Name three classes of amplifiers.
8. What are the input and output terminals of an amplifier?
9. What is the purpose of the blocking condenser in a resistance-coupled amplifier?
10. Draw a circuit diagram of an inductance-coupled audio frequency amplifier.

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LESSON TEXT No. 12

AUDIO-FREQUENCY AMPLIFICATION

Originators of Radio Home Study Courses
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SOME GOOD STUDY HABITS

A Personal Message from J. E. Smith

Cheerfulness. In the army there is a motto, "Do It Well; Do It Cheerfully; Do It Now." This would be a good motto for every student. It requires more energy to frown than to smile. It has been said that a frown brings into use something like sixty-four muscles, and that a smile requires the use of about fourteen. Hence, it is more efficient to smile than to frown. But how can cheerfulness become a habit? Just as anything else can—by practice. Go through the motions of being cheerful and you will soon feel that way.

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

AUDIO-FREQUENCY AMPLICATION

In our previous study of radio reception, we learned that a typical radio receiver consists of several important parts. These parts are as follows:

(a) *Collector* of radio energy, or antenna.

(b) *Selector*, or tuning system, by means of which waves of various lengths are selected.

(c) *Radio-frequency amplifier*, which adds to the strength of the waves, so that they can effectually operate a detector.

(d) *Detector*, which so modifies the radio-frequency waves that when put into a loud-speaker, sounds will result that the ear can perceive.

(e) *Audio-frequency amplifier*, which strengthens the output of the detector, so that the ear can hear the output of the loud-speaker with comfort.

(f) *Reproducer*, or loud-speaker, which converts the output of the audio-frequency amplifier into sound waves.

This outline is given here for the purpose of helping you to locate yourself mentally before we go into the study of the audio-frequency amplifier. As you can see in this outline above, by the time the radio waves have entered the detector circuit, and have been *rectified*, they are in such a condition that they would operate a loud-speaker as to enable the ear to hear the sound waves generated by it. In other words, we could connect a loud-speaker to the output of a detector, and, if we would hold our ears close enough to it, we could hear the signals that we are tuning the receiver to.

Nevertheless, notice that we said you must hold your ears pretty close; this is generally true excepting in the case of very strong signals, as for instance, if we should tune the set to a powerful nearby broadcasting station. Generally the output to the loud-speaker, when connected directly to the detector, is not sufficient for comfortable listening. The degree of loudness, or the *volume* of sound that we require from a loud-speaker, is about the same as the original volume of the sounds when they originate at the studio of the broadcasting station. When we listen to a man speaking, for instance, it is desirable that we hear the same volume of sound coming out of the loud-speaker that we would hear if we were listening to the man himself.

You might ask, "Can we not amplify the radio-frequency currents sufficiently so that when the loud-speaker is connected directly to the detector, the volume would then be this great?" The answer is: "Sometimes, but not generally; in fact, only rarely." The volume in that case might be great enough, as we said before, only where we were tuned to a powerful nearby station.

The reason for this is that there is a limit to the strength of signal that the detector tube will handle without overloading. When the detector overloads, the volume does not increase, but as a matter of fact, sometimes it may be decreased. Then, too, the quality of the music or speech, or whatever we may be listening to, is generally spoiled when the detector is overloaded. In our previous lesson you have learned the general principle of the electron tube as it is used in radio receivers. You learned something about the way in which it acts when it *detects* or *rectifies* the radio-frequency currents coming out of the radio-frequency amplifier. Let us first review briefly what goes on in a detector.

In Figure 1 we have drawn in very heavy lines, the wiring diagram of an electron tube used as a detector of radio-frequency oscillations. The input is on the left of the diagram, and the head-phones are connected in the output circuit, which is on the right of the diagram. These head-phones are shunted by a by-pass condenser.

We have impressed on the input of the detector circuit a high-frequency alternating voltage, which comes from the tuned circuit which is generally connected to the input of the detector. As you learned before, these high-frequency oscillations have a frequency ranging anywhere from 500,000 to 1,500,000 cycles per second, in the broadcasting range of wavelengths. These are plainly too rapid for the human ear to respond to, or even, for a loud-speaker to respond to.

Furthermore, these oscillations are not *regular* or *uniform*, for they are modified or changed in accordance with the sound entering the microphone at the broadcasting station. Glance for a moment at Figure 2. This illustration shows a radio-frequency wave as we might picture it in order to let our eyes help us in understanding it. Suppose we start out at the point o and travel to the right. We can imagine that at the instant

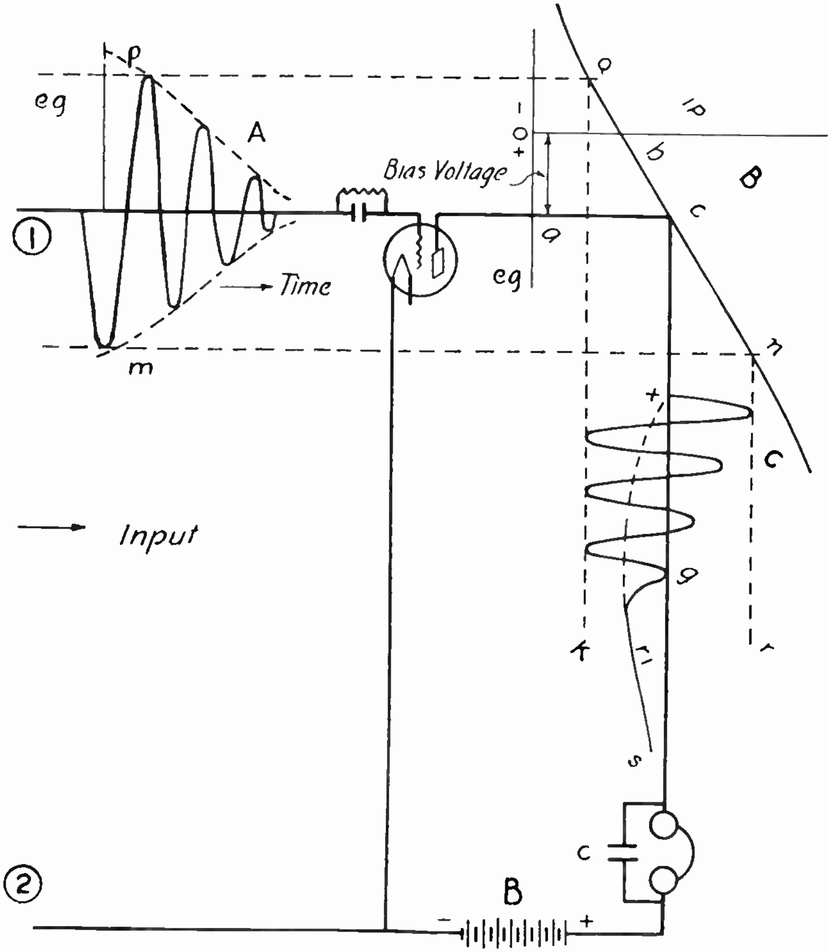

Fig. 1—This Diagram Shows in a Schematic Way How Rectification is Accomplished by Means of the Vacuum Tube.

we start out, the radio wave has no voltage, or there is no current flowing in the circuits. As time goes on, that is, as we travel to the right, the voltage increases steadily, along the line oa in the direction of the arrow. Then, as time goes on, we find that the voltage decreases, as it does at the point a.

We are letting the height of the curve above the horizontal line represent how great the voltage is at any instant. For instance, as we have shown in Figure 2, after 1/1,000,000th of a second the value of the voltage is represented by the height of the point a above the point b.

Now, as time still goes on, the voltage decreases, until at the end of 2/1,000,000ths of a second, we find that the voltage has decreased to zero, as at the point c. After this, as time still goes on, we find that the voltage changes its direction. Instead of the current flowing in the same direction it flows in the opposite direction. We can represent this state of affairs by drawing our curve below the line instead of above

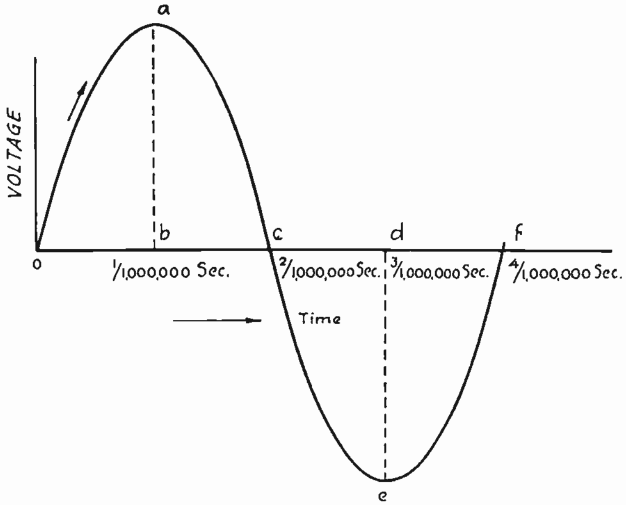

Fig. 2

it. Thus, after 3/1,000,000ths of a second the voltage is in a direction opposite to what it was after 1/1,000,000ths of a second, but its value is the same. We represent this by making the line de the same length as the line ab, but extending below the horizontal line instead of above it. Then, as time still continues to go on, the voltage again decreases, until after 4/1,000,000ths of a second it has again become zero, and after that the whole (action or cycle) is repeated as time goes on. From the point o, which represents the instant when we started to count time, to the point f, which is an instant 4/1,000,000ths of a second later, we have what is called a *cycle;* it is called a cycle because we start out at a certain value of voltage and after a certain length of time come back to the same value again; we started out at o with zero voltage, and after 4/1,000,000ths of a second come back to zero voltage again at f.

This cycle of events repeats itself continuously; if we should represent the voltage wave over quite a few millionths of a second, it would look as shown in Figure 3. In that illustration we have shown eight cycles of a radio-frequency wave; these cycles are numbered. For convenience, we have taken 4/1,000,000ths of a second for a complete cycle, but of course you know that this varies considerably. For instance, table

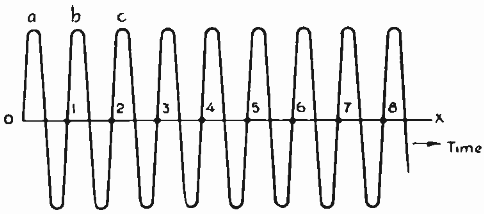

Fig. 3—A Continuous (C W) Radio Wave.

No. 1 gives you some idea of how the time for a cycle varies with the wave-length of the radio wave:

Table No. I

Wave-length (meters)	Period (sec.)	Frequency (cycles per sec.)
200	1/1,500,000	1,500,000
300	1/1,000,000	1,000,000
400	1/750,000	750,000
500	1/600,000	600,000
600	1/500,000	500,000

The time of a complete cycle is called its *period.* That is to say, a complete cycle requires a certain *period* of time. In Table No. I we have also included the frequency; it is clear enough that if the time taken by a complete cycle is one millionth of a second, there must be one million of these cycles occurring in a second.

The wave shown in Figure 3 is the wave as it comes from the radio-frequency generator at the broadcasting station. But it is not the wave you hear. There is another wave to consider, and this is the wave of sound that enters the microphone at the broadcasting station when someone talks or when music is played before it. The sound waves are very much slower; their period may be anywhere from 1/32nd to 1/20,000th of a second. In other words, the frequency of sound waves is only from about 32 to 20,000 per second. Furthermore, these waves vary in strength. The wave in Figure 3 does not change in strength; the *peak* voltage, or the maximum voltage, of the wave during each cycle is always the same, just as the points a, b, c, are shown the same height above the line ox. The peaks of the curves below this line ox are also the same distance below as the upper ones are above.

This is not so with sound waves. The waves may have any shape and any strength; Figure 4 shows a sample sound wave. The frequency of the sound wave changes from one instant to the other. When the frequency is high the person at the microphone is singing a high pitched note, or is speak-

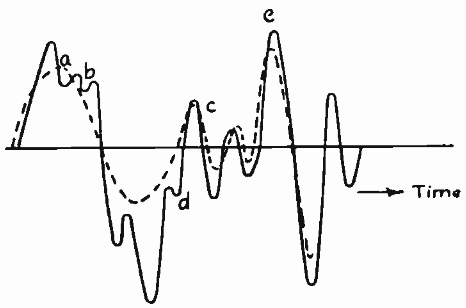

Fig. 4

ing in a high pitched voice; when the frequency is low the pitch of the tones going into the microphone is low. And the strength of the sounds is changing from one instant to another, one moment the person is talking softly or singing loudly.

There is another thing that you must notice, for this is very important. Notice that the waves of Figure 4 are not at all regular. There are kinks in them, as pointed out by the letters a, b, c, etc. These kinks tell us that there are other waves there besides the main one which we have drawn in broken lines. Any irregularity in the wave indicates that there is another wave present. These other waves are called *harmonics;* they are called *overtones* by musicians. The frequencies of these harmonics are always an exact number of times the frequency of the main wave, which is called the *fundamental frequency.* That is, a wave which has a fundamental frequency of 1,000 cycles per second, may have a second harmonic of 2,000 cycles, a third harmonic of 3,000 cycles, and so on. Not all the harmonics may be present; for instance, there may be in a certain wave only the second, third and seventh harmonic. Another wave may have the second, third and fourth, or any other combination.

The harmonics, and the strength of the harmonics, are different in sounds coming from different sources. For instance, in the sounds coming from a violin, there are many harmonics; the third and seventh harmonics are especially strong. The rest are much weaker. In the sounds coming from a flute, there are very few harmonics; the third is the principal one. All the other harmonics are very weak. A child's voice has very few harmonics, or at least they are very weak. A grown person's voice may have many harmon-

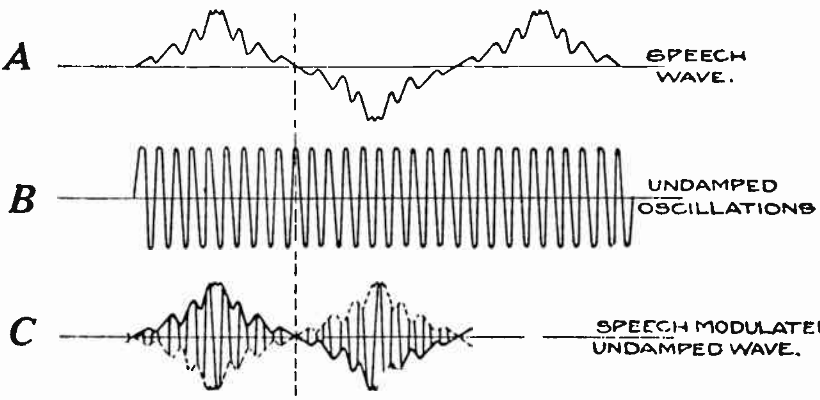

Fig. 5—Carrier Radio Wave Modulated by Sound Waves.

ies of varying strengths. It is on account of the different harmonics and the strength of these that we are enabled to distinguish different musical instruments from another by the sounds they give out, or one person's voice from another.

Now to get back to our complicated wave of Figure 4. As we have said, in the radio-frequency generator of the broadcasting station, we have the radio-frequency waves like Figure 3. Then we have going into the microphone sound waves as pictured in Figure 4. The two are combined together; the sound wave is said to *modulate* (or change) the radio-frequency wave. Let us see how they are combined. Look at Figure 5.

In Figure 5-B, we have the radio-frequency wave. Immediately above it, we have the sound wave. When the two are combined in the transmitting station, we finally get a wave like that shown in Figure 5-C. You see, the sound wave has merely increased or decreased the strength of the continuous radio-frequency wave. The waves in Figure 5-C are the same waves as in Figure 5-B, but in some places they are made stronger and in other places weaker. To show this we have drawn a heavy line through the peaks of the waves or oscillations of Figure 5-C, which we call the *envelope*. This envelope has exactly the same shape as the sound wave. Moreover there are two parts to it, one above the line and one below the line. This is because the radio-frequency currents reverse during each cycle, and we can have the voltage increased in one direction as well as increased in the other direction, and the same as regards decreasing.

This is the kind of wave that comes to the detector tube in a radio receiver. It is called a *modulated* wave. It is the job of the detector tube to *demodulate* it, separating the radio-frequency wave from the sound wave, and then we can pass this *audible* wave on to the audio-frequency amplifier to be strengthened. The word "audible" means capable of being heard, and the word "audio" refers to frequencies that can be *heard*.

Now, let us go back to Figure 1 and see how the detector tube demodulates this complicated Radio wave. You will notice that the wiring diagram has been drawn in heavy lines, but that we have also drawn some light lines in the illustration. For instance, at A in Figure 1, we have drawn a modulated radio-frequency wave. The height of the curve at any point indicates the strength of the voltage at that instant. This is supposed to be the radio-frequency voltage impressed on the input of the tube, and comes from the tuned circuit connected to it between (1) and (2).

In the output circuit, we have drawn the characteristic curve of the electron tube used as a detector. You will have to look at this curve from the left-hand side of the page, in order to see it properly. In other words, when you look at this characteristic curve, turn the book around and look in the direction of the arrow at the input. The line marked e_g represents the voltage impressed on the grid of the tube. The line marked i_p represents the current which flows in the detector output circuit. The distance of a point on the curve from the

e_g line shows how much current is flowing in the plate circuit when there is a certain voltage placed on the grid.

For instance, suppose we have no voltage at all on the grid, in other words, suppose the grid voltage is zero. The plate current will then have a value represented by the line ob. This current is flowing from the plate of the filament, through the "B" battery and phones and back to the plate. We do not actually have a zero voltage at any time on the grid. As you remember, we connect the grid-return to the positive side of the filament, so that we always have a small positive bias on the grid. This positive bias is represented by the line oa, and is marked "bias voltage." On account of this bias, the steady current flowing in the plate circuit has a value greater than it would be if the bias were not there. Instead of having a value represented by the line ob, it has the greater value represented by the line ac. Remember this is the *steady* plate current. It is the current which flows when there is no signal, radio-frequency, or voltage on the grid.

Now, suppose we have an alternating signal voltage on the grid. What happens? Well, as you learned before in a previous lesson, the current in the plate circuit fluctuates just as the grid voltage fluctuates. When the grid voltage is positive, the plate-current increases; when it is negative, the plate current decreases. This is shown by drawing a few broken lines which we may call *projection* lines. Starting at m (Figure 1), we draw a broken line which cuts the characteristic curve at n. Then going at right angles we draw the line nr. We do the same thing starting at p, going through q and ending at k. You would think from this that the wave of the plate current would be included between the two lines qk and nr, but it is not. Let us see why.

This brings us to the matter of the grid condenser. The grid condenser more or less prevents the negative charge from leaving the grid. The grid is in the path of the electrons which go from the filament to the plate, so it can't help but capture a few, and as a result, it acquires a negative charge. Now, when the signal voltage coming onto the grid is negative, the negative charge of the grid is greater. When the signal voltage is positive, it tends to reduce the negative charge of the grid, which enables the grid to take on more electrons, and in that way again increase its negative charge.

At any rate, the negative charge on the grid becomes greater and greater. As a result, as you have already learned in a previous lesson, the plate current becomes less and less. All the while it is deceasing, the oscillations are still going on. The outcome of the whole matter is that the wave of the plate current takes a form like that in the curve C of Figure 1. As the oscillations continue, they gradually drop down as the grid accumulates its charge of electrons, until finally, if the oscillations persist long enough, the peak of the last oscillation in that particular group drops down to the value of the steady plate current. This is the point g in the curve C of Figure 1.

Now you must understand that the grid cannot go on forever collecting electrons and thereby having its negative charge increase continuously. There comes a time when the voltage of this grid charge becomes great enough for the charge to *leak off the grid* through the grid leak resistance. When this happens the grid loses its high negative voltage and the plate current at the same time rises again to its normal original steady value. This action is represented by the section ri, s, of curve C, of Figure 1.

Now you know the complete action of the detector tube using the grid leak and condenser; the condenser blocks the electrons which the grid collects. As the charge due to these electrons increases, the steady plate current decreases; all the while the oscillations are continuing, but gradually drop as the plate current drops. When the grid charge becomes great enough, it leaks off the grid through the grid leak and the plate current rises again to its original value. This is briefly the story of detection.

Notice that we still have radio-frequency oscillations—not audio-frequency. On account of this, the by-pass condenser C must be provided for the radio-frequency current cannot flow through the telephone receivers, due to their high impedance. Of course, it is often possible to operate the detector without the by-pass condenser, but this is made possible only because the receivers have enough capacity in their windings, and in the cord to the telephones, to act as a by-pass condenser. If this capacity in the phones were not present in the phones, we could not operate the detector without a by-pass condenser.

How do we get the audio-frequency out of this? The answer is simply this: the impedance of the telephone receivers responds to the low (or audio) frequency part of the train of oscillations; the phones act as if a current is flowing through them, whose wave shape is represented by the curve x, ri, s, which is a sort of average curve for the wave-train C in Figure 1. This average wave corresponds to the *envelope* of the radio-frequency wave originally impressed on the grid, which envelope contains the audio-frequency (or sound) waves which we want to hear. The final wave is not exactly the same as the original wave; the detector introduces a certain amount of *distortion* in the signals, which is what we call a change of wave form. As a result, the sounds coming out of the loud-speaker will not be *exactly* the same as the sounds that went into the microphone, but this distortion is not very noticeable in well-designed receivers.

All this may sound very complicated to you, but it is not very difficult to get a fair understanding of it if you keep in mind the different steps in our description. We have gotten

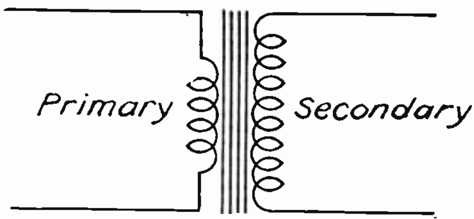

Fig. 6—A. F. Connections to Coils (P) and (S).

Fig. 7—A. F. Transformer.

as far as obtaining the audio-frequency currents in the telephone receivers. It certainly must be clear to you that instead of connecting in these head-phones, we can connect in an audio-frequency amplifier in order to strengthen these audio-frequency currents, and then at the output of the amplifier we can attach our phones or loud-speaker.

We spoke of *overloading* at the beginning of this lesson. What may cause this "overloading" of the detector? Why simply this: suppose we have a *very* strong signal impressed on the input of the detector. When the detector grid "swings positive," the positive grid will attract so many electrons that its negative charge will become very great owing to the fact that the accumulated electrons on the grid do not have sufficient time to drain off before the grid swings in the other direction. As a result, the plate current will be "depressed" (or decreased) considerably. When the grid charge is sufficiently great, it will leak off through the grid leak with a "bang" instead of leaking off gradually, and a lot of extra noises will be heard in the loud-speaker. Also when the *grid swing* is too great, there will be additional distortion of the wave form due to the curvature of the characteristic curve at the top and bottom. This effect must be guarded against whenever we use an electron tube. We shall learn a great deal more about it as we proceed.

Now we have learned how the detector acts, and have seen why we must not overload it. We now come to the matter of amplifying the audio-frequency currents so that they can operate a loud-speaker satisfactorily. We shall develop the audio amplifier step by step, so that you shall learn the reason for each thing in the circuits. A few pages before this you learned that the impedance of the telephone receivers in the plate circuit of the detector is acted upon by a sort of average curve of the plate current. (See Figure 1, curve x, ri, s). So it is clear we must have some kind of apparatus which has impedance, connected in the plate circuit of the detector.

Besides this, we have to transfer the audio-frequency energy to another circuit where it can be amplified in an electron tube. A transformer which has an iron core will do both these things well. Figure 6 shows the diagram of an audio-frequency transformer, and Figure 7 shows a photograph of one. It consists of a primary winding wound upon an iron core, and a secondary winding wound over both. The iron core consists generally of a number of thin sheets, called *laminations*, which are stacked in a pile. These laminations are so shaped that they form a closed path for the magnetic field of the transformer.

The secondary winding has a great many more turns than the primary winding, generally about 3 or 3½ times as many turns. Now when audio-frequency current flows in the primary of the transformer, a varying magnetic field is established which cuts or links the secondary turns. On account of this a voltage is *induced* in the secondary winding, which is something like three times as great as the primary voltage. In some instances it may be more; at other times it may be less. We shall learn more about this later on, but at least the secondary voltage is always greater than the primary voltage. So you see the transformer can help considerably in amplifying the audio signals.

Furthermore, the primary of the transformer has the impedance we require in the plate circuit of the detector. We simply connect the audio transformer in place of the headphones in Figure 1, and we get the circuit of Figure 9, where the primary is marked P and the secondary is marked S.

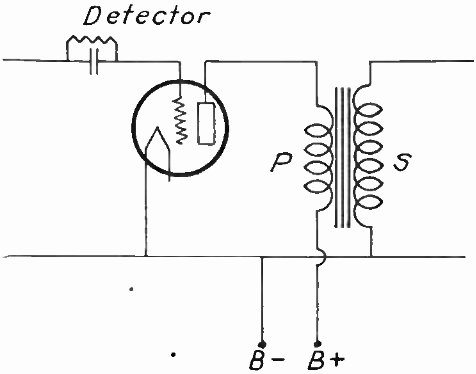

Fig. 9—Connections from Detector to First A. F. Transformer.

Now, if we wanted to, we could connect our head-phones to the secondary winding of the transformer, but this would not work very well, as we shall learn later on. Besides we would not get enough amplification. So the next thing to do is to connect another electron tube to the secondary of the

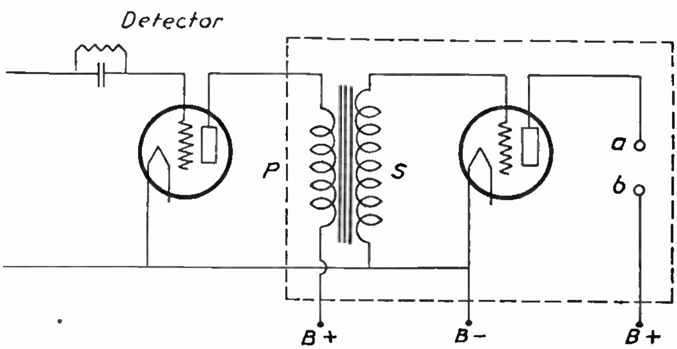

Fig. 10—Connections from Detector to First A. F. Transformer and A. F. Vacuum Tube.

transformer, and we could connect our head-phones or loud-speaker to the terminals ab in the plate circuit of this tube. The signals would then be pretty loud on the head-phones, but would not generally be loud enough on the loud-speaker. The part of Figure 10 which is included by the dotted lines is called an audio-frequency amplifier "stage." You will remember that it is very much like a radio-frequency amplifier stage except that it is not tuned, and the transformer is designed very much differently.

Well, to make a long story short, if we want still more amplification, we can add another complete "stage" to the amplifier, and get the circuit of Figure 11. This is the complete circuit of the detector and two stages of audio-frequency amplification as generally used in present day radio receivers. The loud-speaker is connected in the output of the last stage. Notice that different "B" battery voltages are connected to the plates of the different tubes. The detector tube is generally operated with 45 volts on the plate, the first audio stage with 90 volts, and the second audio stage with 135 volts. In the last stage a "C" battery of about 4 to 6 volts should be connected in the grid circuit. This is shown in the diagram, and we shall learn why in a few moments.

COUPLING SYSTEMS

Now, before we get into the detailed study of the various parts of an audio amplifier, we must first consider the various types of *coupling systems* that are employed between the tubes. Figure 11 shows transformers being used for coupling the tubes together. Other things can be used as well as transformers. You see there are two important parts to any stage of an amplifier. One of these is the tube itself, and the other is the device used for coupling two stages together. We shall continue with the different forms of coupling.

We will begin this part of our discussion in explaining why other coupling systems are used at all. This will not be very difficult if you will read carefully. In the first place, what we require of an amplifier is that it shall *amplify*. Second, it must always *amplify equally*. These are the two main requirements in an amplifier. The third requirement is that the amplifier shall not cause distortion of any kind while it is amplifying the signals; it must not introduce any frequencies (harmonics) which are not in the original sounds going into the microphone at the transmitter, nor shall it permit any of the original sounds to be lost. Of course, as you know, nothing in this life can be perfect, but we always try to have things as nearly perfect as possible. So, since there are certain recognized failings of transformers, investigators have been trying to find means of eliminating these shortcomings, or of avoiding them by using other systems of coupling.

The main shortcoming of the transformer is that it does not amplify very low frequencies well. The frequencies of sound waves are from about 30 cycles per second to above 10,000. In the average transformer used today, frequencies above about 500 or 1,000 cycles are amplified pretty nearly equally. Currents of frequencies lower than this are not amplified as well, and the lower the frequency the less is the amplification. The reason for this is that the voltage input to the transformer depends on the *impedance* of the transformer, and the higher impedance for a certain amount of current the greater will be this voltage. Finally, the higher the frequency of the current, the higher the impedance.

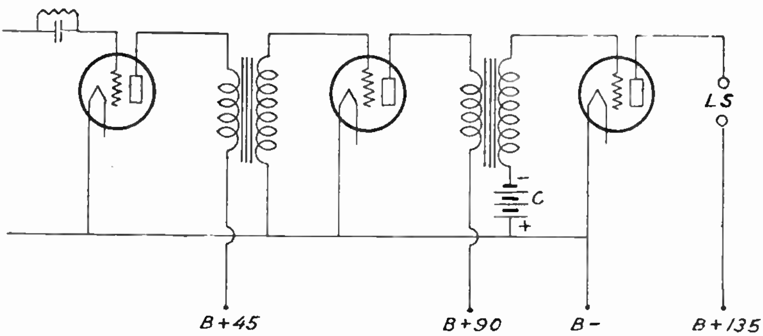

Fig. 11—Connections from Detector to Two Stages of Transformer Coupled A. F. Amplifier.

AMPLIFICATION CONSTANT

You can see from this without going much further, that the transformer is going to amplify the high frequencies better than the low ones. There is one thing that you must not forget; the voltage across the transformer cannot be greater than the voltage which drives the current through it. This voltage is the voltage that is developed at the plate of the tube connected to the primary winding. Look at diagram A Figure 12. Here we have shown a simple amplifier stage; the batteries are left out for simplicity. There is a certain voltage input to the tube, which we have marked e_g. This is the signal voltage. The tube has an *amplification constant* which we shall call μ (this is the Greek letter pronounced mu). It tells us how many times the tube will amplify. Thus a 201A tube amplifies voltages 7 times, so its amplification constant is 7.

So, with a voltage e_g impressed on the grid, and an amplification constant of μ in the tube, there is developed in the plate circuit of the tube a voltage equal $\mu \times e_g$. This is the total voltage in the plate circuit. If we have a voltage of 2 millivolts (0.002 volts) impressed on the grid, and a μ of 7, then the voltage in the plate circuit will be 0.002x7 or 0.014 volts (or 14 millivolts).

Now, you will remember from your lesson on the vacuum tube, that there is quite a large resistance in the tube between the plate and the filament. The plate current must flow over this path, and hence encounters this resistance in its path. This resistance is quite high, in ordinary practice being from about 6,000 to 15,000 ohms. It is called the *plate resistance* of the tube, and is represented by the symbol r_p. You will see it marked on the diagram A of Figure 12.

From these things, it is clear that the plate circuit of the tube may be represented according to the diagram B of Figure 12. The voltage of the plate circuit μe_g is considered as a generator G. In series with it is the plate resistance r_p, and also in series is the primary of the transformer. The load in the generator circuit is a resistance in series with a reactance. As we have seen, the reactance varies as the frequency varies, but the frequency has no effect on the resistance; it always remains the same. The total voltage μe_g is divided between the resistance and the reactance.

Read over these few lines carefully. When the frequency is low, the reactance is low. Naturally there is little voltage drop in the reactance as most of it is wasted in the plate resistance. As the frequency becomes higher, the reactance becomes greater; consequently the voltage across the transformer increases, and at the same time the current decreases, on account of this increased reactance. Since the voltage drop in the resistance is r_p times the current, and the current is less, the drop in the resistance must be less.

So you see that as the frequency becomes higher, and the input voltage e_g always remains the same, the voltage across the transformer will gradually increase and the voltage drop in the resistance will gradually decrease. The voltage that is in the resistance is useless to us—it is lost energy. The useful voltage is that at the terminals of the transformer. It is clear that at low frequencies the useful voltage at the transformer will be small and a great part of the voltage will be lost in the resistance. At higher frequencies, the useful voltage at the transformer is greater, and the loss in the resistance is smaller. (In order to simplify this discussion we have assumed the signal strength to be always the same, no matter what the frequency may be.)

Now you have learned how the voltage at the primary depends on the frequency. What happens *in* the transformer? We shall not study this very much in detail here, as it is unnecessary in this practical course. But, we may say that the voltage in the secondary is *very roughly* the voltage input to the primary multiplied by the ratio of the turns in the windings. For example, let us suppose that there are 1,000 turns

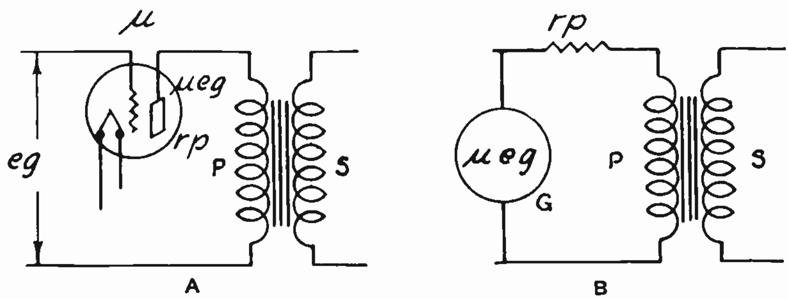

Fig. 12

of wire on the primary of the transformer, and that there are 3,000 turns of wire in the secondary winding. The turn ratio of the transformer is then 3:1 (spoken of as "3 to 1"), which is the same as saying that the voltage is multiplied approximately three times by the transformer. If we have a voltage of 1 millivolt at the primary terminals of the transformer, the voltage at the secondary terminals will be approximately 3 millivolts.

So you see that we have three important effects in an audio amplifier stage. First, amplification in the tube; second, the variation of voltage with frequency, at the primary of the transformer; third, the voltage "step-up" (as it called) in the transformer.

Now let us see what is the greatest amplification it is possible to obtain in an amplifier stage. At *very high* audio-frequencies, the reactance of the transformer is very great; therefore, nearly all the voltage in the plate circuit is available at the primary terminals as *useful* energy. This voltage is, very nearly equal to μe_g. Now, if we suppose that there are no losses in the transformer, and its turn-ratio is n_2/n_1, where n_2 is the number of turns in the secondary winding and n_1 the number in the primary, then the total voltage at the secondary terminals is

$$V_2 = \mu \times e_g \times \frac{n_2}{n_1}$$

The amplification is $\mu \times n_2/n_1$. For example, if the amplification in the tube is 7 and the turn-ratio of the transformer is 3, then the greatest amount of amplification that it is *theoretically* possible to obtain is 7x3 or 21. In other words, at very high frequencies, we can expect out of this stage an amplification of nearly 21 times. At low frequencies, as you have learned, the amplification is very much less.

In Figure 13 we have shown what is called an amplifier *characteristic curve*. It is a curve which represents how the amplification changes as the frequency changes. Take, for instance, a frequency of 500 cycles. The amplification at this frequency is about 8. At 1,000 cycles it is about 13; at 2,000 cycles it is about 17, at 5,000 cycles it is about 18. You see as the frequency gets higher and higher, the curve becomes more nearly horizontal, gradually approaching a certain *maximum* amplification at very great frequencies. This is about how the usual transformer curve looks, although it is not usually as smooth as the curve in Figure 13.

Now what does all this mean, as far as the reproduction is concerned? The answer is simple. Suppose the transformer causes the low notes to be weak. If we are listening to an artist playing the piano, for instance, it would seem as if the artist had a weak left hand and a strong right one, for he plays the high notes with the right hand and the low notes with the left hand. As another example, suppose we are listening to an orchestra. The bass-horn would not be heard very well from the loud-speaker, while the violin with its high tones would come in very strongly. In other words, the music would not sound just as it should sound.

In the same way, the harmonics of the sounds, which are of high frequency, would come in strong and the low fundamental frequencies would come in weak. The voice of a bass would then sound much higher than it really is, for the overtones (or harmonics) are amplified considerably while the low frequency fundamental is not amplified as much.

There is one other important defect in transformers. You are aware of the fact that whenever we have two surfaces of metal separated by air or any other insulator, we have a condenser. Now, in a transformer we have a lot of metal—it is the copper of which the wire is made. So the primary winding can act as one plate of a condenser and the secondary winding can act as the other. Furthermore, different parts of the same winding can act like condensers of small capacity. On the whole then, the transformer may at times have considerable capacity.

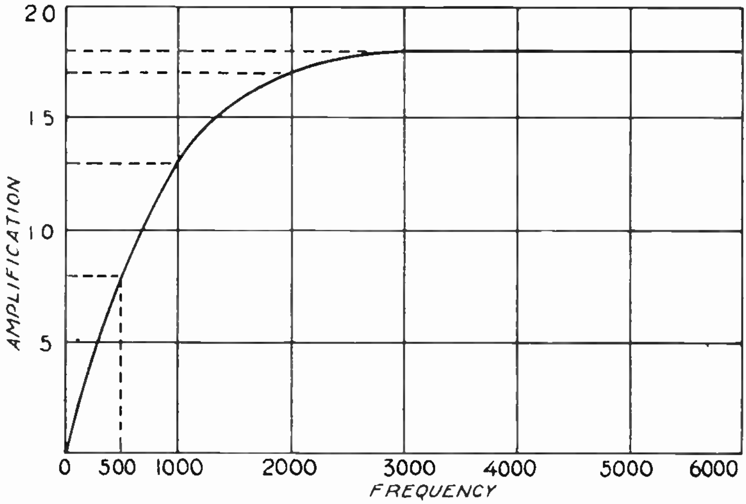

Fig. 13—An Amplifier Characteristic Curve.

Having the capacity between the windings, and the inductance of the windings, we have a *tuned circuit*, just as the capacity of the variable condenser and the inductance of the coil form a tuned circuit in a *radio*-frequency amplifier. So the transformer itself, having both inductance and capacity, is tuned to certain particular frequencies. These frequencies are generally rather high, mostly occurring at 5,000 cycles or higher. When such frequencies are being amplified, the transformer is *tuned* to them, or is *resonant* to them, and the current through the transformer becomes very great. The amplification at these particular *resonant frequencies* is very much greater than the amplification at other frequencies, and as a result we have *resonance peaks* or humps in the transformer curve.

Figure 14 shows such a curve. The particular transformer to which this curve applies is resonant to a frequency of about 5,000 cycles. The amplification at this frequency is very much greater than at say 4,000 or 6,000 cycles. The effect is, for example, that when we are listening to an orchestra, and an instrument happens to play a note having a frequency of 5,000 cycles, this particular note just "blares" out of the loudspeaker. It is much stronger than all the other notes played by the orchestra, and this effect spoils the reproduction. It is another cause of *distortion.*

Due to all these defects of audio transformers, experimenters have introduced other systems of coupling, in which

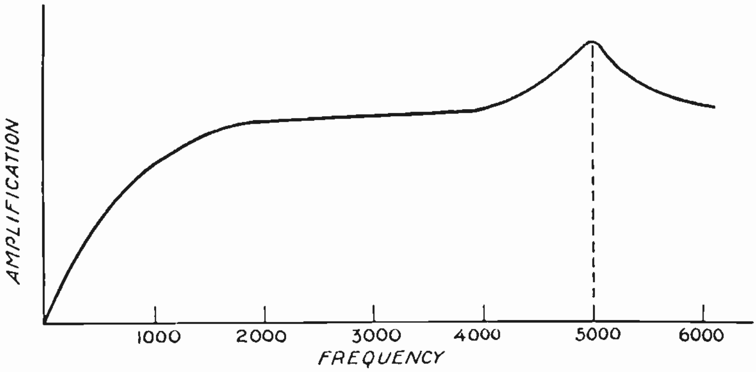

Fig. 14—Typical A. F. Transformer Curve.

they tried to avoid these defects, or at least reduce them. Although in some cases they have been successful in avoiding some of these defects, unfortunately, they have introduced other defects. The most prominent defect of the other systems is that the amplification is always less than that obtained with transformers.

The first system tried is known as "the resistance-capacity coupled amplifier." Let us study this system next.

In order to obtain energy from the plate circuit of an electron tube, we must have a "load" which can receive this energy. Now this load may just as well be an ordinary resistance. A resistance has an advantage over an inductance, in that it does not vary with the frequency. Figure 15-(A) shows what we mean. We have again left out the filament battery for simplicity. The audio voltage in the plate circuit (equal to μe_g) causes a current to flow in that circuit. This current flowing establishes a voltage across the terminals of the resistance. This voltage is equal to the value of the resistance "r" multiplied by the alternating current flowing through it "i", or

$$V = r \times i$$

If we wanted to add another tube to the amplifier, we might just as well connect it to the points a and b, as we have done in Figure 15-(B). But right here enters a difficulty.

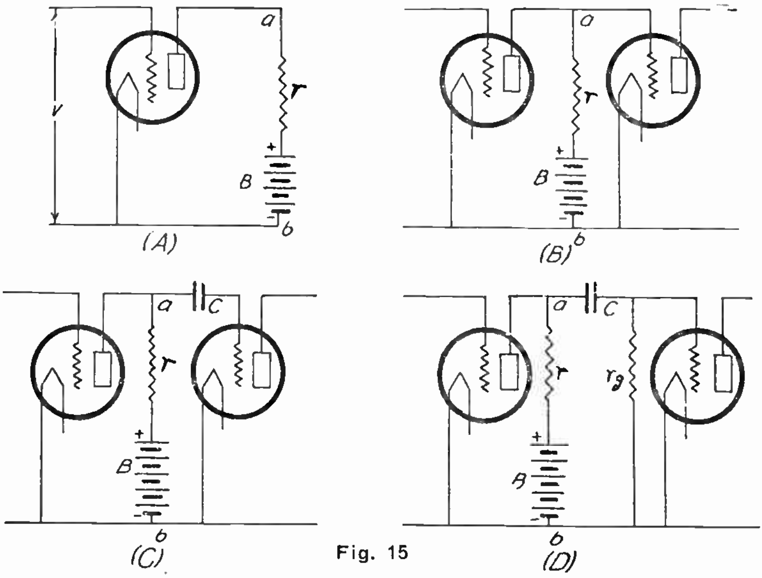

Fig. 15

Note:—These theoretical diagrams do not show all connections to the batteries.

You will notice that the positive terminal of the "B" battery is connected to the grid of the second tube through the resistance. If you remember your lesson on the electron tube, you will know that when the grid has a large positive bias, as it would have here, a large grid current will flow in the tube. A large grid current means a large power loss, and among other things, an additional cause of distortion.

In order to avoid this large positive bias we place a blocking condenser in series with the grid of the second tube, as shown in Figure 15-(C). This is marked C. Now we have introduced *two* more complications. In the first place the reactance of the condenser varies with the frequency. Its reactance at low frequencies is very high, and at high frequencies is much lower. It is clear, that we are getting right back to the trouble we tried to avoid. The condenser C will pass the high frequencies easily enough, but will offer considerable obstruction to the lower frequencies. We can make this effect (that is, unequal amplification) small by making the condenser C quite large. In practice, this condenser is never smaller than about 0.006 microfarad, and it is much better to use perhaps a capacity as large as 0.01 or 0.02 microfarad.

To come to the other difficutly which we mentioned. If you look carefully at Figure 15-(C), you will notice that the grid of the second tube is "free." That is to say, the condenser prevents the electrons, which the grid may collect, from leaking off the grid and passing on back to the filament from which they originally came. We will not repeat here the ill-effects of the "free" grid as we have taken this up earlier in this lesson.

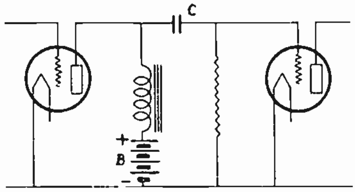

Fig. 16—Choke Coil or Impedance Coupling.

It will be sufficient to say that a leakage path must be furnished, and so we connect in the circuit the grid leak r_g, in Figure 15-(D). In this figure we have the complete circuit diagram of the resistance-capacity coupled amplifier, minus the "A" battery.

We have mentioned some of the troubles of this type of amplifier. There are several others that we must not pass over. The first of these is that quite a large voltage is required in the "B" battery in order to satisfactorily operate the system. We could use 90 volts very well when we use a transformer in the plate circuit of the tube, because there is not much resistance in the transformer, and therefore little loss of the "B" voltage in it. In the resistance coupled amplifier, the resistance r, in the plate circuit, is often about 100,000 ohms. On account of this, there is quite a loss of "B" voltage in the resistance, and in order to have enough voltage left over to operate the tube satisfactorily, it is necessary to use a "B" voltage of 135 volts or higher. This trouble is not serious because it is easy to simply add another 45-volt block to the "B" battery. As a matter of fact, nowadays with all electric A. C. sets higher voltages are being used in transformer coupled amplifiers.

The other difficulty which we mentioned is in connection with the grid leak. The greater the resistance of the grid leak, the greater the amplification will be. On the other hand, the greater the resistance, the more easily is the tube overloaded and the grid "blocked." When we say the word "blocked," we mean that the leakage path for the grid charge is of too high resistance, and the charge cannot leak off the grid easily or rapidly enough. This introduces distortion.

What is the greatest amount of amplification that can be obtained in each stage? If we make the condenser C *very*

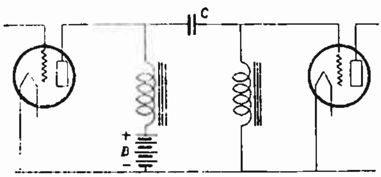

Fig. 17—Choke Coil or Impedance Coupling.

large, and make the grid leak resistance also *very* large, and if the tube were not overloaded or blocked, and we had a very large "B" voltage and a very large plate resistance r, then the greatest amplification we could obtain would be equal to the amplification constant of the tube. If the tube is the 201A, this would be 7.

We can never actually obtain an amplification equal to the μ of the tube, because if we would do all the things mentioned in the preceding paragraph the amplifier would not work anyhow. But this points out a serious limitation to the resistance-capacity coupled amplifier. Two stages of transformer coupling are generally used, but it is always necessary to use three stages of resistance coupling, in order to obtain satisfactory volume from the loud-speaker. It is claimed by many that the quality of reproduction is better with resistance coupling than with transformer coupling, and that the additional stage required is worth the trouble and expense. There are arguments for both sides, and the system you prefer is up to you.

Again, in order to avoid the difficulties of resistance coupled amplifiers, Radio Engineers have tried other methods. We will simply point them out in what follows, without going into a detailed description, for what you have already studied so far will enable you to understand them very easily. In order to avoid using a large "B" battery and also in order to obtain a much larger impedance in the plate circuit than the resistance offers, sometimes a *choke coil* is used. A choke coil is simply an impedance coil using a great number of turns of fine wire wound on an iron core. This is shown in the diagram of Figure 16. As in the previous case, a blocking condenser and a grid leak are required.

This system has the same disadvantage that the transformer system has; the reactance of the choke coil is low at low frequencies. There is the difference in that a choke coil of greater inductance can be wound in the same space as the transformer, reducing the drop at the low frequencies with

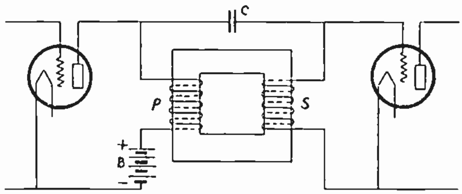

Fig. 18—Combination Transformer and Impedance Coupling System.

the transformer. As with the resistance coupled amplifier, the amplification can never be greater than the µ of the tube.

Next we have a method using another choke coil for the grid-resistance which is sometimes called dual impedance coupling. This choke coil has very large reactance to the audio-frequency currents, but has low resistance, so the grid charge can easily leak away, and the tube will not overload easily.

We have another circuit, as shown in Figure 18, in which the two choke coils of Figure 17 have been brought together onto an iron core. We have then a *combination of transformer and impedance coupling,* which is another name for choke coil coupling. In this system, the two windings are made exactly the same, having a turn ratio of 1:1. The claim is made that this system has all the advantages of the systems of Figures 16 and 17, and in addition has greater amplification.

We have now studied the most important types of audio-frequency amplifiers, as far as the coupling system is concerned.

CHARACTERISTICS CURVES

We must now study the electron tube itself—how it acts, and how it should be operated, in order to get the best results

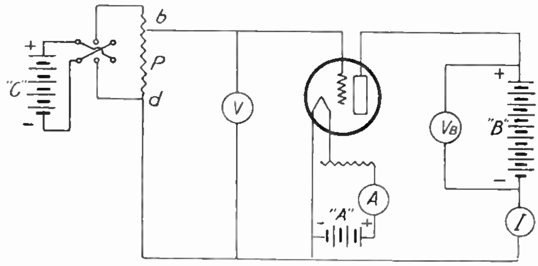

Fig. 19—Circuit Arrangement for Determining the Characteristic Curves of Vacuum Tubes.

out of such amplifiers. In order to study the tube itself, we shall make use of the circuit shown in Figure 19.

This is the circuit that is used to determine what are called the characteristic curves of the electron tubes. It consists of a vacuum tube, "A," and "B" batteries connected in

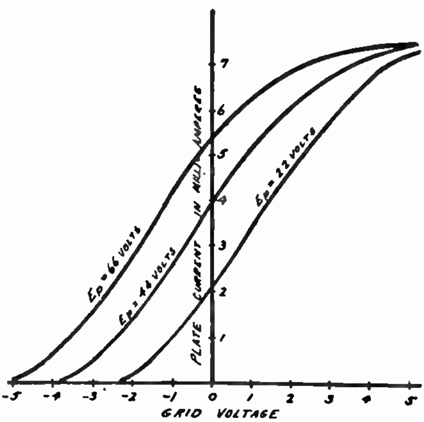

Fig. 20—Grid Voltage. Plate Current Characteristic Curve of a Vacuum Tube.

the usual way, a "C" battery with a reversing switch and a potentiometer connected in the grid circuit. There is a Voltmeter (V) in the grid circuit and an ammeter (A) in the filament circuit, also a voltmeter (VB) and a milli-ammeter (I) in the plate circuit. By throwing the switch to the right or left and moving the slider on the potentiometer, we can obtain any value of positive or negative bias we want. Now if we move the slider of the potentiometer b and take a reading of the various values of voltage and current applied to these circuits, we will have a number of values as in the table below:

Grid volts	Plate milliamperes
0	4.0
−1	2.8
−2	1.6
−3	0.7
−4	0.2
+1	5.0
+2	5.8
+3	6.5
+4	7.0

By plotting them on cross-section paper, we will obtain a curve like the curved marked Ep = 44 volts in Figure 20.

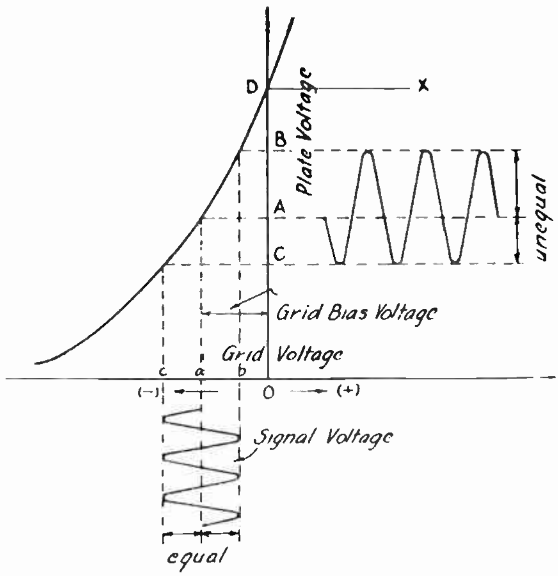

Fig. 21

Now remember while doing all of this, we keep the voltage of the "B" battery the same as 44 volts. Suppose we repeat the procedure and make our measurements with a plate voltage of 66, or 22 volts, then we will get similar curves but when plotted, they will be higher and lower than the curve for a plate voltage of 44 volts.

Now as we have learned what this is all about, why do we go to all this trouble and what do the curves tell us?

These curves furnish us with some very important information on how to operate tubes. They are called "characteristic curves."

Look at Figure 21; here we have a characteristic curve like those in Figure 20. Now suppose we have an audio-amplifying circuit and there is a "C" battery in the circuit which gives us a certain grid bias. Suppose we did not have any bias on the grid, in other words, the bias were zero. A large

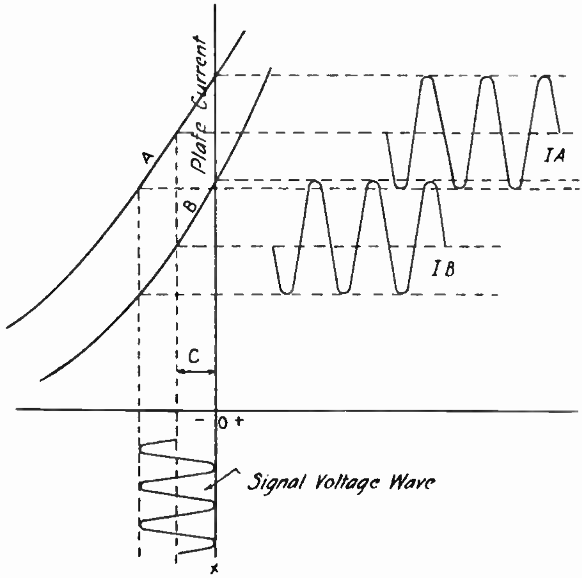

Fig. 22

plate current will then flow whose value is represented by the height of the line O-D in Figure 21.

When the "C" battery is connected in the circuit, giving us a certain negative grid bias, we can represent this negative voltage by the line O-a in Figure 21. This is called the operating voltage of the grid. When the signal voltage comes along and is impressed on the grid together with the C bias voltage, this signal voltage oscillates about the grid bias. Sometimes, making the grid voltage higher and at other times, lower.

Below the horizontal line of Figure 21, the signal voltage is shown. For simplicity, we have chosen a very simple wave form. When the signal voltage is at its maximum positive value, the voltage of the grid is O-b. When the signal voltage is at its maximum negative value, the grid voltage is O-c. When the signal voltage is zero, the grid voltage is O-a, which is the same as the bias voltage.

When there is no signal voltage on the grid, the plate current has a certain steady value O-A. This is the normal plate current. When there is an alternating signal voltage on the grid, the plate current oscillates higher and lower than this steady or normal value.

Now you will notice that although we have drawn the signal voltage wave so as to have both halves of it equal, the two halves of the plate current wave are not equal. This is because there is always a certain amount of curvature to the characteristic curve. The nearer we get to the bottom of the curve, the greater is its curvature. In other words, the plate current is not the same in wave form as the incoming signal voltage. This means that there is distortion introduced as the signal is amplified.

What must we do to reduce this distortion? Simply operate the tube at that portion where the curvature is least. In other words, we must get away from the low end of the curve.

In Figure 22, we have shown two characteristic curves for the same tube. Curve B is obtained for a certain plate voltage and curve A is for a higher plate voltage than curve B. At the bottom, we have a certain signal voltage wave. We have made the grid bias sufficiently negative that when the signal voltage comes along, the grid will never be positive. Then there can never be a grid current. You can readily understand that if the grid bias were less than negative C, the signal voltage wave would pass over the line O-X, and during part of the cycle, the grid voltage would be positive. It is necessary to make the "C" battery voltage or grid bias voltage not less, but preferably greater, than the strongest signal we expect to amplify.

Suppose with this value of grid bias, we operate the tube with a voltage on the plate corresponding to curve B of Figure 22. The plate current will then be as shown at I-B which has, as you can see, a great amount of distortion in it. As we learned before, we should not make the grid less negative, or we will have a grid current flowing. So the only other thing to do is to raise the plate voltage. When we do this, we no longer operate the tube on the curve B, but now operate it on curve A. This curve is higher than the curve B, so we are now operating our tube higher up on the characteristic curve. As a result, the distortion is much less as is shown by the appearance of the plate current wave I-A.

So you see what it means to use the proper voltages on the tube. You must use enough "C" battery voltage or grid bias as to prevent the grid from becoming positive. When you do this, you must have a sufficiently high plate voltage and see that the tube is operated far enough away from the lower bend of the characteristic curve.

We have learned in this lesson all the main things in connection with wiring and operation of audio-frequency amplifiers; also, the various coupling systems used between the tubes. We have by no means learned all about audio-frequency amplifiers. We have merely learned the most important facts—the facts that you will need all of the time in your practical Radio work. Therefore, if there are some things which you do not understand at the first reading, do not fail to go back and read the lesson again.

TEST QUESTIONS

Number Your Answers 12—1 and add Your **Student Number**

1. What is the purpose of an audio-frequency amplifier?
2. What is the frequency of sound waves?
3. What are the two main requirements of an amplifier?
4. Draw a diagram of a two-stage transformer coupled amplifier.
5. What is the main shortcoming of the transformer type of amplification?
6. What is the greatest amount of amplification that it is theoretically possible to obtain, using a 4 to 1 ratio transformer and a tube which has an amplification constant of 7?
7. Draw a diagram of a resistance capacity coupled amplifier.
8. Draw a diagram showing the choke coil type of amplifier.
9. Draw a diagram showing a combination of the transformer and impedance coupling systems.
10. What is the plate current for the Ep 44-volt plate curve when the grid voltage is zero (0) in Figure 20?

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Complete Course in Practical Radio

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RADIO FREQUENCY AMPLIFICATION

As you have learned at an earlier stage in this course in practical radio, there are several main parts to a radio receiver. These main parts are (1) **the radio frequency amplifier,** (2) **the detector,** (3) **the audio frequency amplifier,** and (4) **the reproducer.** In this lesson we are concerned with the radio frequency amplifier only. The general arrangement of these various parts in a radio receiver is shown in figure 1. The radio frequency amplifier strengthens the signals before they reach the detector, the latter changes them so that they are put into a condition to be heard.

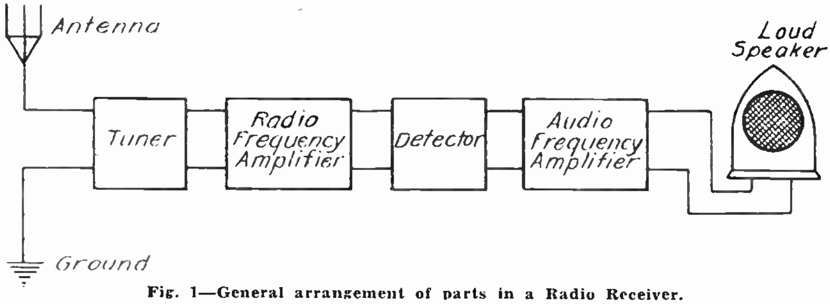


Fig. 1—General arrangement of parts in a Radio Receiver.

The radio frequency oscillations, as the term implies, have a frequency extremely high. They could by no means operate a loud-speaker, or, even if they could, the human ear could not respond to them. So it is the duty of the detector to modify them; we say the detector rectifies them; and in the output circuit of the detector we have such a kind of current flowing that can operate a loud-speaker.

Now, unfortunately the detector acts poorest when we need it most. The response of a detector to a signal is strong on a strong signal and weak on a weak signal. That is to say, the response of a detector varies as the square of the signal voltage applied to its input. For the sake of example, suppose we impress on the input of the detector a signal whose strength is 2. Then suppose we double the signal to 4. The response of the detector (that is, its alternating plate current) will then not be doubled but quadrupled, that is, increased four times. Suppose we double the signal again, or make it 8 times as strong as it originally was. The response will then be increased 64 times.

Or, if we look at the thing the other way, if the signal is cut in half, the response is cut in quarter; if the signal is cut to 1/8 its original strength then the response is cut to 1/64th of its original value. So you see, that in order to get as much as possible out of the detector, it is necessary to amplify the signals before they reach the detector; this places a much larger signal voltage at the input of the detector than would be there if we had no radio frequency amplifier.

The great advantage of using a radio frequency amplifier before the detector can be easily understood when we consider the output of the detector. The sensitivity of a radio receiver depends mainly upon the voltage which comes to the detector input, for there is a certain limit to the amount of audio frequency amplification which we can place after the detector. Suppose we add one stage of radio frequency amplification preceding the detector, and this stage amplifies the radio frequency signal voltage four times. Then on account of the square law of the detector, the over-all sensitivity of the receiver is increased 16 times! Or, if we add two stages, having an amplification of 4 each, then the total sensitivity of the receiver is increased (16x16) or 256 times! With such remarkable gains in sensitivity obtained when we add radio frequency amplification to a receiver, there is hardly any need of further explaining why it is used in all the up-to-date receivers.

Of course, as we hinted before, it might be possible to increase the amplification by using more stages of audio frequency amplification, but also as we have said before, it is not generally advisable to use more than two or three stages of transformer coupled A. F. amplification or three stages of impedance coupled amplification. The reason for this is that when such a great amount of A. F. amplification is used it is difficult to keep the system in a stable condition. Howling or audio frequency oscillations are generally set up, and is very difficult to control. It is much easier to add an extra stage of R. F. amplification, and when we do this we have the added advantage of increasing the selectivity of the receiver. Every stage of R. F. amplification added means another tuning circuit added to the receiver, and the more tuned circuits the more selective the receiver becomes. So, viewed from every angle the addition of R. F. stages to a receiver is a very good thing to do. There is one other feature which we must not omit, however, before we go further, and that is, with one exception, the addition of R. F. amplification to a receiver does not introduce additional distortion in the signals, as would the addition of more A. F. stages. The exception which we mentioned is where regeneration is used. Regeneration may spoil the quality of reproduction; we shall learn more about regeneration later on in this lesson.

Now we must begin discussing the radio frequency amplifier in detail. There are many different circuits for the radio frequency amplifier, but as you have learned before, all these circuits are based on the same fundamental circuit of the electron

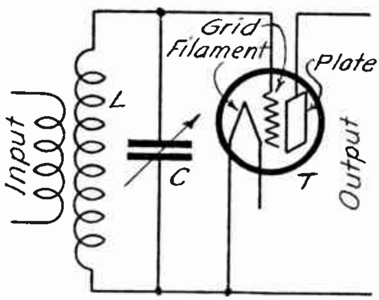


Fig. 2.

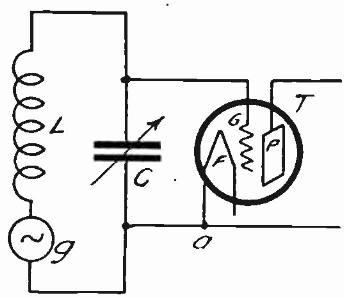


Fig. 2-A.

tube. There is a tuned input to the tube, and the output of the tube may be tuned or untuned, according to how and where in the circuit it is employed. Look at figure 1. This shows the location of the radio frequency amplifier in the receiver, and in figure 2 we have one stage of this amplifier shown in detail. For the purpose of simplicity we have omitted the various batteries, but you must remember that there is always a "B" battery supply connected to the plate of the tube, and there is always an "A" battery required to light up the filament of the tube. There are various ways of connecting these batteries, however, which we will discuss later on.

In figure 2 the signal voltage is impressed upon the R. F. stage at the left. It passes into the tuned circuit which includes the coil L and the condenser C; this tuning circuit allows us to tune the system to the frequency of the signal voltage, or to separate the particular signal we want to listen to from other signals which have different frequencies or different wavelengths.

Now, before we go any further, I want you to get into your head one thing—and be sure that you never forget it. This thing is a source of constant trouble to most students, and it is for that reason that we want you to be sure to get the idea right. It is—the secondary circuit, that is the tuned circuit, is **NOT A PARALLEL** circuit, it **IS A SERIES** circuit. You are, no doubt, surprised to hear this, for it is easy to see that the circuit looks as if the condenser C and the coil are connected in parallel across the grid and filament of the tube. But this is only the **looks** of the things. You must remember things are not always as they seem.

Let us see why it is a series circuit and not a parallel circuit. In the first place, you must realize that the voltage in the secondary coil is **induced** in it by the current in the primary input circuit. A magnetic field established by the current in the primary links the turns of the secondary winding and creates in the latter a similar alternating voltage. Now, whenever a voltage is **INDUCED** in a coil, it is always considered as in **series** with that coil. For this reason then the secondary circuit of figure 2 can be pictured as in figure 2A, where the voltage **induced** in the secondary is **represented** by the alternating current generator g. Then g, L and C are all in series, and we take the voltage across the terminals of the condenser, to operate the electron tube T.

The circuit shown in figure 2 is the one which is used in almost all radio frequency amplifiers. The way in which two tubes are joined together by means of this R. F. transformer, or **resonance transformer** as it is more properly called, is shown in figure 3; the batteries have again been omitted for simplicity. In studying the diagrams of radio frequency amplifiers, it must never be forgotten that the main circuits to consider are those which carry the radio frequency currents. For this reason it is more or less immaterial in what way the batteries are connected to the circuit, just so we keep the radio frequency circuits complete. Of course there are other things which we shall consider one by one as we come to them, but for the present the R. F. circuits are the main things.

It is on account of this that we have so far in this lesson omitted the batteries. We shall now consider the various ways in which the batteries are or may be connected to radio frequency amplifier circuits. Let us consider the "B" batteries first. In the first place what we require wherever we use an electron tube is that the plate be at a rather high positive potential compared with the filament, or rather, compared with the point of the filament to which the input circuit is connected. In figure 3 this point is "a." It is called the **grid return connection**, because, going over the input circuit starting at the grid, we leave the tube at the grid, pass around through the tuned circuit, and **return** to the tube at the point "a."

Now, we have said that what we require is that the plate be at a high positive potential compared with this point called the grid return point. How we obtain this condition of affairs is not so extremely important. You will see what we mean in a moment. Look at figure 4. In that illustration we have shown two radio frequency amplifier tubes, and these R. F. amplifiers are

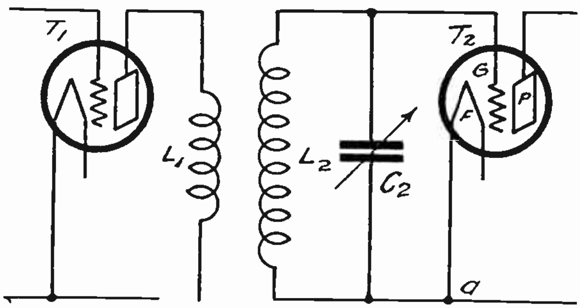


Fig. 3.

exactly the same in every respect as regards the circuits which carry the radio frequency currents. They differ only in the way in which we apply the potentials to the plates of the tubes; that is, in the way in which we connect the "B" batteries to the circuits.

In figure 4(A), for instance, we have connected the "B" batteries in series with the coil in the plate circuit, and we have connected a by-pass condenser across the battery. This by-pass condenser is fairly large, having a capacity of perhaps 0.006 microfarad or larger, so that the reactance or opposition it offers to the radio frequency currents in the plate circuit is very small. In fact, it is in most cases small enough to neglect. The radio frequency currents therefore pass around the plate circuit through the coil L and the condenser C, but do not pass through the "B" battery.

Now, in the circuit of figure 4(B) we have the "B" battery connected in series with a **radio frequency choke coil** marked Z, and the two connected directly to the plate and filament of the tube. The radio frequency choke coil offers very large reactance, or opposition, to the radio frequency currents which flow in the plate circuit of the tube, so that no radio frequency currents can flow through it or through the "B" battery. They travel through the coil L in the plate circuit.

So you see, as far as the radio frequency currents are concerned, the two circuits are exactly alike. In 4(A) the by-pass condenser C is connected across the "B" battery for by-passing the radio frequency currents, and in 4(B) the choke coil prevents the flow of radio frequency currents through the "B" battery. But in both cases the circuits of the R. F. currents are the same,

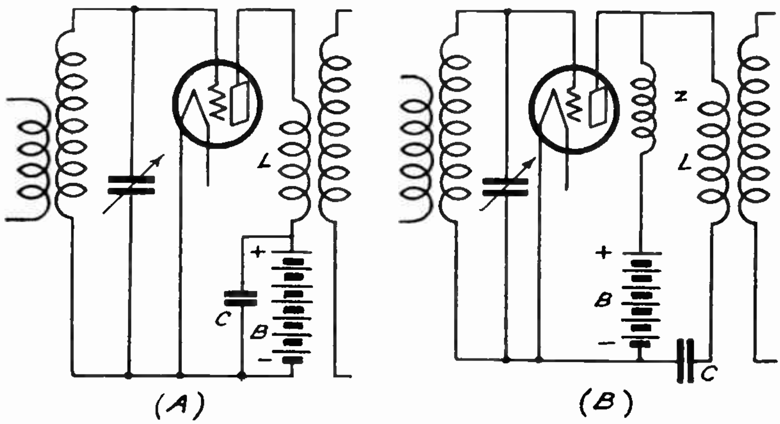


Fig. 4.

and also in both circuits we get the positive potential of the "B" battery on the plate of the tube, and the negative on the filament. You will note, however, that we have placed a condenser C in series with the coil L, in figure 4(B). If this condenser were not here, as far as the direct current coming from the "B" battery is concerned, the "B" battery would be short-circuited, and would be ruined. Therefore this **blocking condenser** C is required.

In order to show you how all this works out in a regular circuit, we have drawn the two circuits of a two-stage radio frequency amplifier in figure 5. Figure 5(A) uses the method employed in figure 4(A), and figure 5(B) uses that employed in figure 4(B). The first method is called the **series connection** and the second is called the **shunt connection.** It is clear why we use these names; in the first method we connect the "B" battery in series with the load (or coil) in the plate circuit, and in the second method we connect it in parallel with the load. Where it is in series figure 5(A) we must use a by-pass condenser. A by-pass condenser has been drawn in each stage; they are marked C1 and C2. But you must note that these two condensers, drawn

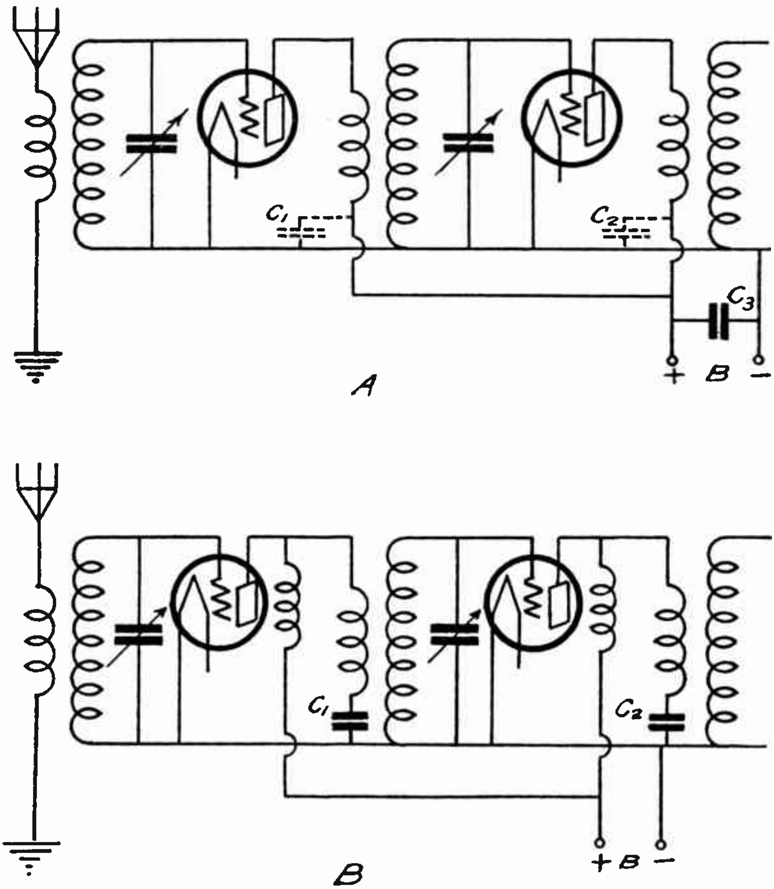


Fig. 5.

in broken lines, are in parallel with each other; they are both connected across the B+ and B— terminals. Therefore it is not necessary to use both; we can use one by-pass condenser, C3, making it a little larger than we would if we used two separate condensers.

In figure 5(B) we have the shunt connection of the "B" battery circuit. In each stage we have to use a blocking condenser and a radio frequency choke coil. Which of the two methods you use in designing a set depends on the conditions in the receiver, and the amount of money you want to spend. The shunt connection is probably more expensive than the series connection, but it has advantages which we will learn of later on. One of these advantages is that the blocking condensers need not be large, rarely being greater in capacity than about 0.0005 microfarad, whereas in the series connections the by-pass condenser must be rather large; in practice this condenser may range anywhere from about 0.006 to 1 microfarad.

Now, as regards the connections of the "A" battery, the way in which it is connected depends upon the receiver. Generally the negative terminal of the "A" battery is connected to the grid-return, and the resistance which controls the filament cur-

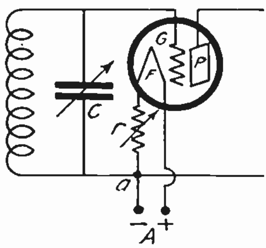


Fig. 6—Negative Bias.

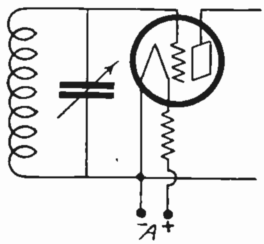
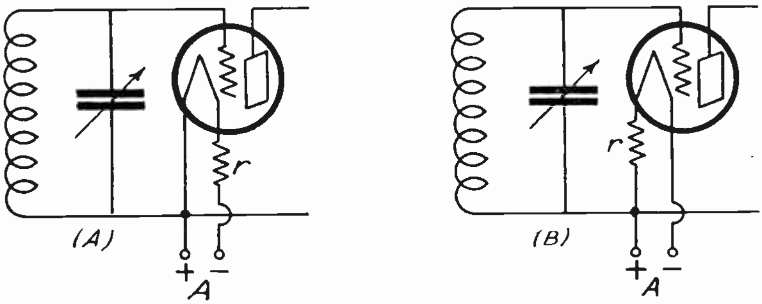


Fig. 7—Zero Bias.

rent is also placed in this line from the "A" battery. The idea is illustrated in figure 6. The resistance r is the filament control resistance, or rheostat, and the grid-return is connected to the point a. The negative pole of the "A" battery is connected to the grid-return at a. The reason for this is that when we do this we have the grid G at a negative potential with respect to the filament F. That is, considering only the direct voltage which we get from the "A" battery, you will notice that the grid is connected directly to the minus of the "A" battery. The filament, however, is not connected directly to it. There is a certain drop of voltage in the rheostat. If we are using 201A tubes, the drop in the rheostat will be about 1 volt when we have it adjusted properly. There will be a negative bias on the grid therefore of one volt. By making the connections in this manner, the bias on the grid will keep the plate current low, and will make the receiver more sensitive. It becomes more sensitive because the negative bias on the grid prevents grid currents from flowing so there will be no power loss due to this cause.

There are many ways of varying the bias on the tube as illustrated in Figures 6, 7, 8. A zero or positive bias is very seldom used on amplifying tubes because it has a tendency to cause the tube to oscillate, while a negative bias decreases the tendency of the tube to oscillate. The amount of bias necessary to prevent oscillation will vary depending upon the type of circuit and tubes used.

In the illustrations given so far we have always shown two tubes connected together by means of a **radio frequency transformer,** generally known as a **resonance transformer.** In nearly all cases at the present time the secondary winding of the resonance transformer is tuned by means of a variable con-



Positive Bias. Fig. 8. Positive Bias.

denser. But it is not necessary to confine ourselves to this type of coupling. There are other ways of coupling two tubes together, just as you learned there were many different ways of coupling together two tubes in an **audio frequency** amplifier. The three main types of audio amplifier couplings were **transformer, impedance and resistance** couplings. In radio frequency amplifiers we may have the following types of coupling systems:

(a) Resonance transformer, which at present is generally tuned in the secondary.

(b) Impedance coupling; this is a special type of resonance transformer coupling, in which the resonance transformer takes the form of an autotransformer. **Choke coil** coupling also falls in this class.

(c). Resistance coupling, which at present is generally limited to wavelengths above 1000 meters.

You must remember that tuning must take place in the radio frequency amplifier stages and in the detector stage.

We cannot tune the audio frequency amplifier. The detector stage must be considered as a part of the radio frequency amplifier, for in all cases of class (a) and in most cases of class (b) the input of the detector is tuned, while the output is not. We shall see what this means as we go on.

A resonance transformer consists, as we have seen, of two windings, a primary and a secondary winding. It does not, as a rule contain an iron core, but has simply air for the core. The general circuit of a resonance transformer is shown in figure 9. At the left we have the input to the transformer circuit, where a voltage v is marked on the diagram. In the tube circuit this voltage v is the signal voltage which is developed in the plate circuit of the tube to which the resonance transformer is connected. In other words, we have a signal voltage applied to the input of the tube T1. This voltage is amplified in the first tube, and we have a larger voltage v developed in the plate circuit of T1. This causes a current to flow in the primary circuit (L1) of the resonance transformer, and this current **induces** a current in the secondary circuit. As the current flows in the secondary it establishes voltage across the terminals a and b of the condenser C2, and it is this voltage which operates the second tube T2.

We want the current in the secondary to be as great as possible, for this will make the voltage input to the second tube (that is across ab) large, as we will then have quite a lot of amplification in the system. In order to do this the secondary circuit is tuned to resonance by adjusting the variable condenser C2.

As we have said before, generally, only the secondary circuit is tuned, but there are circuits used occasionally which also have a condenser C1 in the primary of the resonance transformer circuit. We shall see why later on. You must note that when a condenser is placed in the primary circuit it is necessary to use the **shunt feed** method of connecting the "B" batteries (see figure 4B) whereas when there is no condenser in the primary you must use the series method (see figure 4A).

Now, in the circuit of figure 9, the closer we get the primary and secondary coils, L1, L2, the greater will be the amount of energy transferred from the primary circuit to the secondary. Or, what amounts to the same thing, we should use as great a primary winding as we can. A fair example of a resonance transformer as generally used would be a single layer of wire on a tube 3 inches in diameter having about 60 turns; the primary may be wound on a tube which just slips into the other, and may have perhaps 10 turns of wire. The wire might be No. 20 B. & S. gauge. Actually these dimensions may not always be used in any receiver; the number of turns and diameters of the coils differ considerable from one receiver to another. We only give these figures to give you an idea of their size.

If we want to increase the coupling between the primary and the secondary circuits, we may use more turns on the primary coil or place the primary coil L1 closer to the secondary coil L2. But there is something which will not permit us to use any number of turns we choose, but must use a certain number of turns in each receiver, and this something is called **regeneration.** We will learn about this before we finish this lesson.

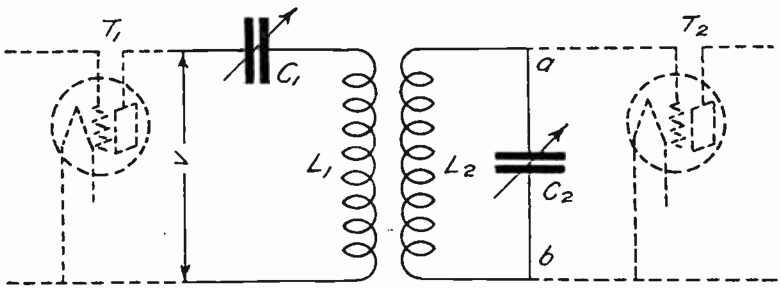


Fig. 9.

In the ordinary circuit, such as we see in figure 10, L1 is the primary coil of the resonance transformer coupling the two tubes. As this coil is made larger and larger by increasing the number of turns of wire, the **inductance** of the coil increases. At the same time, as we increase the inductance, the amplification increases and increases, until finally we reach a point where we hear a whistle when we try to receive a signal. When this happens the receiver is no longer acting as a receiver, but is acting as a low-power transmitter. The electron tube circuits of the receiver have begun to **oscillate.**

The oscillations thus established in the receiver interfere with the incoming signals, which you are trying to receive, and as a result, instead of hearing the incoming signals, all you hear is a loud whistle. This is called a **heterodyne** whistle, and is a **beat note** caused by the interference of the oscillations in the receiver and the oscillations of the incoming signal.

It is clear that the receiver must not be allowed to oscillate. For that reason we must keep the number of turns of wire in the primary so small that oscillations will not occur. This is what limits the design of the resonance transformer in the ordinary radio frequency amplifier.

The next question to answer, for we know you will ask it, is "What causes this increase of amplification, and why do the circuits oscillate?" The reason for these things is that the electrodes in the tube form little condensers. As you know, a condenser is formed by any two pieces of metal near each other. In the tube, for instance, we have the grid and the plate; these two are separated by a small distance. They form a small condenser. Likewise the grid and filament form a small condenser,

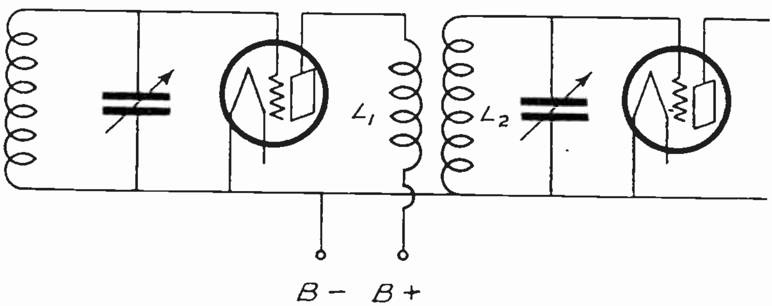


Fig. 10.

and again, the filament and plate form a small condenser. In other words, looking at figure 11, we have the effect in the tube, indicated by the condensers drawn with broken lines.

The most important of these small condensers formed by the electrodes of the tube is the capacity between the grid and the plate, for this capacity forms a connecting link between the output circuit and the input circuit of the tube. In the ideal tube there would be no such connecting link between the input and the output circuits. The alternating signal voltage impressed on the grid or input of the tube would **control** the alternating voltage of the plate circuit, but there would be no path by which power from the plate circuit could get back to the grid circuit.

On account of the amplification in the tube there is much more power in the plate circuit, so that some of this power can be **fed back** to the input circuit through the small condenser formed by the grid and the plate. Now, you remember that the input circuit, consisting of a coil and tuning condenser, has a certain amount of resistance, and therefore loses some of the power of the signal. The energy **fed back** from the plate circuit to the input makes up for part of this loss, so that the input circuit acts as if it were receiving more power from the signal. Consequently the amplification goes up.

Under some conditions the power fed back from the plate circuit to the input circuit may actually be greater than the power due to the signal. When this happens the receiver oscillates and becomes a transmitter instead of a receiver. The **greatest amount of amplification** occurs when the power fed back just about, but not quite, equals the power input to the tube.

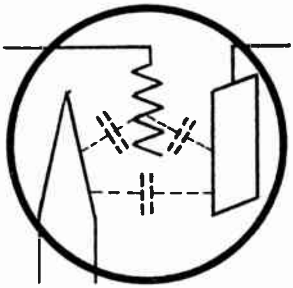


Fig. 11—Illustration showing the capacity effect between the elements in a vacuum tube.

This is called the **critical point** in the amplification. The whole process is called **regeneration,** up to the point where oscillation begins.

Now it happens that the more inductance we have in the plate circuit of the tube the greater is the regeneration, or the tendency to oscillate. When the inductance (that is, of the primary coil of the resonance transformer) becomes great enough it is impossible to stop the tube from oscillating except by special means which we will learn in a little while. Also it is found that the circuits oscillate more easily when tuned to the lower wavelengths (higher frequencies) than when tuned to the longer wavelengths (lower frequencies). As a result, receivers which employ regeneration to make them sensitive, generally are more sensitive when tuned to the short wavelengths than when tuned to the long wavelengths.

These effects occur naturally in all tube circuits unless special means are employed to counteract them or to control them. If it were not for these things all radio frequency amplifiers would be built alike, but in order to control these things a great many different arrangements have been tried, and it is on account of this that we have the great number of so-called radio receiver circuits. We are going to study some of these circuits in this lesson before we finish it.

The simplest way in which to prevent self-oscillation of the circuits is to increase the power losses in the input circuit. By doing this it makes it necessary to have more power fed back from the plate circuit than it can feed back, so that although we can have a regenerative effect and an increase of amplification, the circuits cannot start oscillating. And the simplest way of increasing the power losses in the input circuit is to introduce resistance in this circuit. Thus, in figure 10 we could so design the coil L2 that it had quite a lot of resistance; then the power loss in the input circuit of the second tube would be more than the power fed back from the plate circuit of that tube through the tube capacity. But this is a poor way of doing it; when the tuning circuits have a lot of resistance the tuning becomes broad and the receiver becomes less sensitive.

Another way of accomplishing the same result is to build the primary coil L1 in figure 10 so as to have little inductance. This also is not a good way of doing it, for it limits the amount of energy that can be transferred from the primary circuit of the resonance transformer to the secondary circuit. Although it is not a very good method it is widely used, for it is the simplest and cheapest method. The same effect can be obtained by keeping the primary and secondary coils sufficiently far apart, that is, by keeping the coupling loose.

Another means of doing the same thing is to place a resistance, not in the tuning circuit, but connected directly to the grid of the tube. This is indicated in figure 12 where the resistance is marked r. This is a little better than placing resistance in the tuned circuits, for the resistance r, does not decrease the sensitivity quite as much or make the receiver tune quite as broadly. The idea of this resistance r, is that as the power is fed back from the plate circuit it encounters the difficulty of passing through the resistance, so that only a little power can go back as far as the tuned circuit. At the same time, since there is very little current due to the signal, which flows from the grid to the filament of the tube, the loss of signal power in the resistance is not very great. In this way the resistance r decreases the feed-back and the tendency to oscillate but does not cause as much loss of signal power as occurs when there is resistance in the tuned circuits.

Resistance may be introduced in the tuned circuits in other ways. For instance, any way of absorbing power from the tuning circuit will have the same effect. If the coil is placed close to any large metallic surface, as the tuning condenser, the metal may absorb some of the power. Or, if another circuit is coupled to the tuned circuit it may absorb power from it, especially if it is tuned to the same wavelength. This idea is illustrated in figure 13, where an **absorption circuit** (A) is **coupled** to the secondary of the resonance transformer. This absorption circuit consists merely of a small coil and a variable condenser connected together as shown.

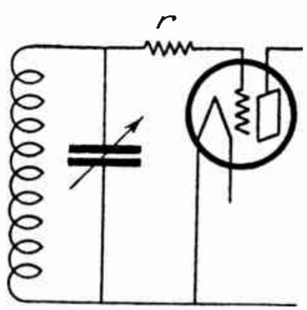


Fig. 12.

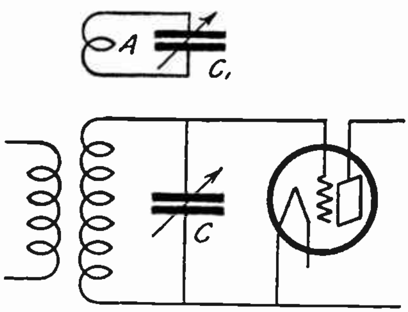


Fig. 13.

When methods of controlling the tendency to oscillate like that shown in figure 13, are used, where we are able to make the adjustments while we operate the receiver, it is clear that we can make it oscillate or not, as we please. For instance, as we tune the condenser C, bringing the receiver into resonance with the signal we wish to listen to, we can adjust the condenser C1 so that it absorbs a little power or a lot of power. When we adjust it to absorb little power the receiver may oscillate, which makes it useless as a receiver. Then we can change the adjustment a little, so that the oscillations just stop. This is the condition under which the receiver is most sensitive. Then, we can adjust the condenser C1 so that the receiver is considerably "below" the point of oscillation.

When such adjustments as these are on a receiver, there is a tendency for the operator to make the adjustment so that the receiver will oscillate, for this enables him to find the station he is trying to tune to very easily, by means of the whistle which it causes in the loud-speaker. This is not a very good way of "hunting" for stations, as these whistles are **radiated** by the receiver and may cause whistling and howling in other receivers in the neighborhood. So when you operate such receivers keep this in mind, and do not join the army of "bloopers" as they are called. Always keep the receiver "below" the oscillation point when you are tuning.

The next way of causing a power loss in the input circuit which we will consider is the **potentiometer** method. This is illustrated in figure 14(A)(B).

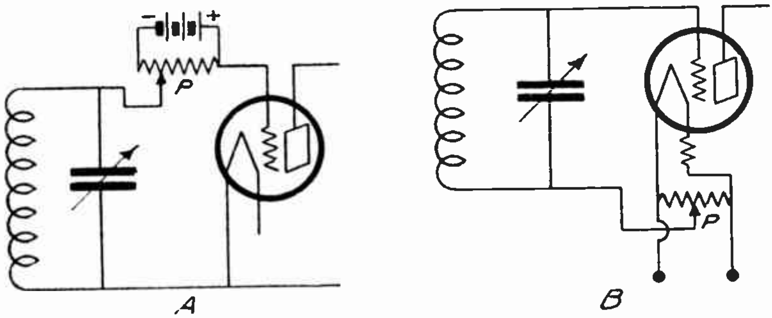


Fig. 14.

The reason why a potentiometer is used is to enable us to control the tendency to oscillate at will. In order to obtain the greatest amount of amplification, different values of bias are required at different wavelengths (or frequencies), so it is to our advantage to be able to make the necessary adjustments. You will note that in figure 14(B), instead of adding another battery to the circuit, we are making the "A" battery do the double duty of lighting the tube and at the same time supply the bias for the grid of the tube.

As we have said before, it is possible to control the tendency to oscillate by keeping the inductance in the plate circuit of the tube below a certain critical value. A little while back, when we were discussing the resonance transformer, we stated that the closer the coupling between the primary and secondary coils, the greater would be the amount of energy transferred from the one circuit to the other. Now, when any amount of energy is transferred from the primary to the secondary, it is clear that the secondary must exert a certain influence upon the primary.

But we must go a little further and explain that the higher the frequency of the current being carried by the transformer windings, the greater is the effect of the secondary on the primary. And we also must remember that the higher the frequency becomes the smaller becomes the critical amount of inductance that we can have in the plate circuit of the tube before oscillations set in.

In other words, as the frequency becomes higher (or the wavelength shorter) we have the critical amount of inductance

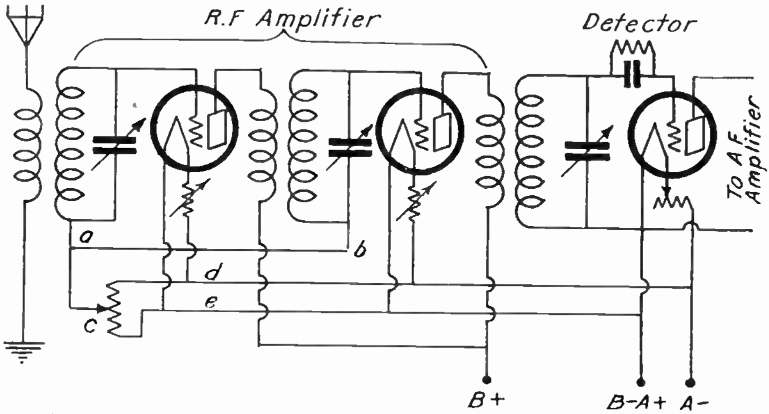


Fig. 15—Circuit diagram of two stages of tuned radio frequency and detector.

decreasing and the apparent primary inductance of the transformer decreasing also, so that if they decreased at the same rate everything would be fine and the circuits could be adjusted easily so that they would not oscillate. Unfortunately, the primary inductance does not decrease rapidly enough as the frequency becomes greater and greater, and although we might adjust the circuits so that they would not oscillate when tuned to the longer wavelengths (lower frequencies) they generally oscillate easily when tuned to the shorter wavelengths (or higher frequencies). On the other hand, if we adjust the circuits so that they do not oscillate at the higher frequencies, we shall find, in many cases, that the receiver is "dead," or relatively insensitive at the lower frequencies. This is a general failing of receivers of the **tuned radio frequency** (abbreviated T.R.F.) type which do not have adjustable means of controlling the regeneration, such as potentiometers, or absorption circuits.

On account of this difficulty there have appeared on the market receivers which vary **the coupling** between the primary and secondary as the tuning condenser is rotated in order to tune to the various wavelengths. They all operate on the same principles, so that when we describe one we describe all. First we have the secondary coil wound in a single layer, in the form of a solenoid. Then we have the primary coil, which is wound on another piece of tubing which can be rotated either inside the secondary coil, or at its end.

The idea of the contraption is to make the primary coil move away from the secondary coil just the proper amount as the condenser is tuned to the shorter wavelengths. A cam attached to the condenser moves the primary coil, so that as the condenser

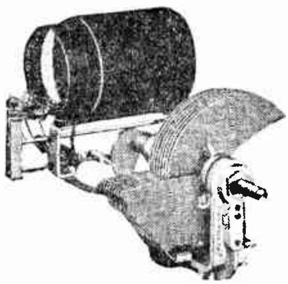


Fig. 15-A—Typical Radio frequency transformer attached to a variable condenser.

is turned the primary coil turns also, always keeping the proper distance from the secondary coil so that the circuit always operates just below the critical point, where the greatest amount of amplification is obtained.

Of course the shape of the cam is a peculiar one; there is no way of determining the shape by calculation; it must be determined by actual trial. There are various mechanical arrangements which permit this to be done, but the one shown in figure 15-A will illustrate the principle.

There are still other ways in which regeneration may be controlled in a tuned radio frequency amplifier; another simple way is to place a resistance in the plate circuits of the amplifiers. Figure 16 shows how this is done. In figure 16(A) we have the plate resistor applied to a circuit where the "B" battery is connected by the series feed method. The resistance R is connected right in the B+ line, so that when we introduce resistance in the circuit we are merely lowering the plate voltage of the r. f. tubes. This will effectually control the tendency to oscillate.

In figure 16(B) we have the plate resistor connected in a circuit which employs the **shunt feed** method of connecting the "B" batteries. In this circuit the plate voltage remains constant, and the resistor R introduces resistance into the primary circuit of the resonance transformer, which carries high frequency current. The effect of the resistance in this circuit is to introduce

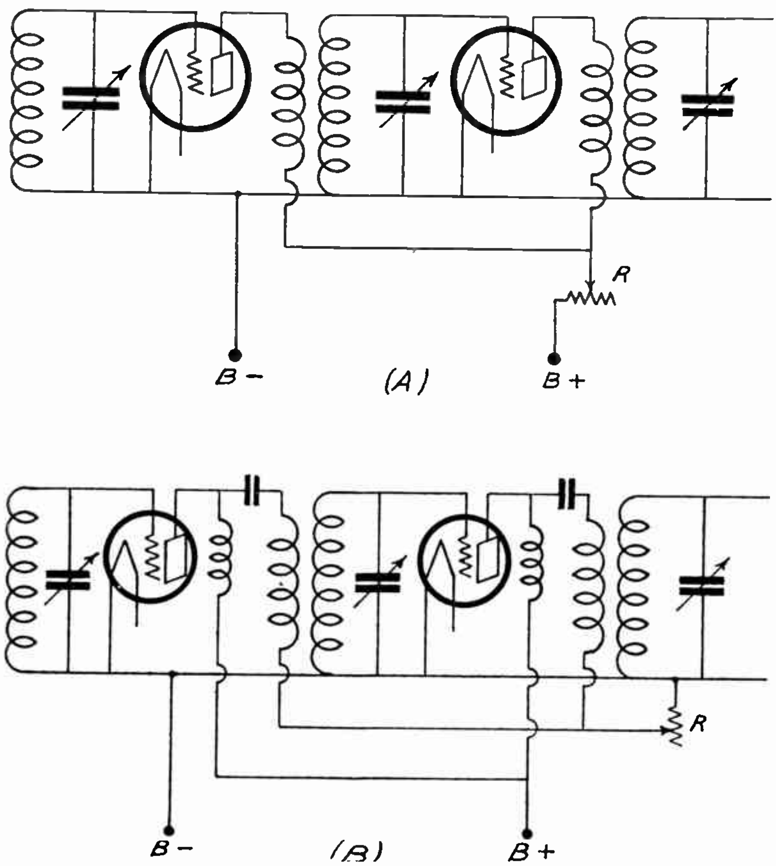


Fig. 16.

power losses in the plate circuit, which will prevent the circuits from oscillating. The same thing is true of these circuits as is true of other regenerative circuits. The greatest amount of amplification is obtained by making the adjustments so that the set is operated just slightly below the critical point at which oscillations occur. In the circuit of figure 16(A) the resistor R may have a maximum value of several hundred thousand ohms and in the circuit of figure 16B, R must have a maximum value of something like 100,000 ohms.

There are many other ways in which such receivers can be controlled, but it is not possible at the present time to study all of them. They all work in the same way; they introduce power losses into the circuit in some way or another, so that the effect of the feed-back can be reduced so the circuits will not oscillate.

Next we come to a type of receiver in which the regenerative effect is **balanced** out. You will remember that in the T.R.F. type of circuit the feed-back is accomplished through the capacity between the grid and plate of the electron tube. If this capacity were not present in the tube there would be no feed-back. So, since we cannot remove this capacity, if we could find a way of counteracting its effect, there would be no feed-back in the circuits. This is what is done in the **bridge type** of receivers.

All of these receivers are based on the Wheatstone bridge. We will briefly review the operation of a Wheatstone bridge, so that you will have it fresh in mind. Look at figure 17. Suppose at G, in figure 17, we have an alternating current generator. The rest of the circuit contains four resistances, r1, r2, r3 and r4, arranged in a square or bridge form. The alternating current generator is connected to two opposite corners of the square, and a pair of phones is connected across the other two corners of the square.

Now, there will be a certain current flowing through the various branches of this network. At the corner marked (a) the current coming from the generator will divide. Part of it will flow through the branch r1 to the point (b). The rest of it will flow through the branch r2 to the point (c). At the point (b) part of the current may go through the phones or through the branch r3 to the point (d). Then at the point (c) the current coming down through the phones will join the current coming through r2 and the total will flow through the branch r4 to the point (d) and thence back to the generator.

In other words, there will, in the general case, be a current flowing through all the branches of the network, and upon placing the phones to the ears a sound will be heard corresponding in pitch to the frequency of the generator. But supposing, instead of making it a general case, we make it a special case; suppose we take special precautions to adjust the resistances of the various branches in a certain special manner. Or, suppose we adjust the resistances so that the current flowing through r1 when multiplied by r1 will be equal to the current through r2 multiplied by r2. By this we mean that we are going to make

$$r_1I_1 = r_2I_2$$

Now, since the resistance multiplied by the current gives us the voltage drop in the resistance, it is clear that the voltage drop across r1 must be the same as the voltage drop across r2. It is then clear that there can be no difference of potential (or voltage drop) from the point (b) to the point (c).

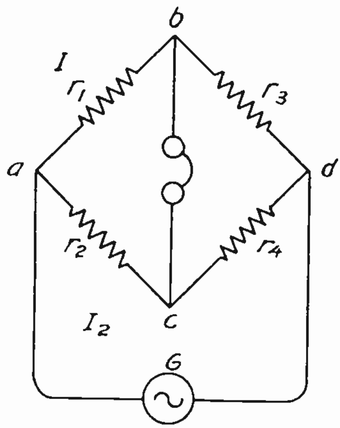


Fig. 17—A Wheatstone Bridge for measuring unknown resistances.

This might be explained in a simpler manner. Suppose the potential of the point (a) is 10. Then suppose we so adjust the resistances that the voltage drop in the branch r1 is 4. Suppose we also adjust the branch r2 so that the voltage drop in it is 4. It is plain then that the potential at the point (b) is 10—4 or 6, and likewise the potential at the point (c) is also 6. In other words, the potential at (b) being the same as the potential at (c), there is evidently no difference of potential between (b) and (c). This is the same thing as saying that there is no voltage across the phones, and consequently, when we have made this adjustment, we will hear no sound in the phones, and there will be no current flowing through them. The bridge is then said to be **balanced.**

This is the principle of the Wheatstone bridge. Although, in order to simplify the explanation we have supposed that there were only resistances in the various branches of the network, it is possible to connect various combinations of capacities, inductances and resistances instead of simply resistances, and the bridge can still be made to **balance.**

Now, you will remember that the feed-back in a T. R. F. amplifier is the current flowing from the plate to the grid within the tube. What we do in the bridge systems is to furnish another path for current to flow in the opposite direction so that this other current neutralizes the effect of the feed-back current. Let us see how this can be done.

First we start out by having the input, or tuned circuit, connected to the points (a) and (d), just as in figure 17. You can see this in figure 18. It is clear then that the points (a) and (d) must be the grid and filament of the tube, for the tuned circuit is connected to these, as shown in the upper corner of figure 18. Now, across the other two corners of the bridge (b) and (c), we must have the output of the tube, and therefore one of these points must be the plate of the tube. Let us say it is the point (b). Now we have the plate, grid and filament assigned to three corners of the bridge, so we have two arms of the bridge already furnished for us. These are the capacities within the tube itself; they are marked Cgp (meaning capacity between the grid and plate) and Cfp (meaning capacity between the filament and plate). In order to complete the bridge we must furnish two other arms, viz., the arm between (a) and (c), and the arm between (c) and (d). These may just as well be fixed condensers, as shown at C1 and C2 in the bridge. They may be about the same size, since Cgp and Cfp are about the same size.

The complete circuit is shown alongside the bridge arrangement. The two differ only in the way they are drawn. The capacity between the grid and filament does not enter into the bridge circuit for it is across the points (a) and (d), and therefore can be considered as merely in shunt with the tuning condenser. In the circuit diagram the capacities within the tube have been drawn in broken lines so that you can see their location in the circuit. This is one form of bridge circuit in use today. So far as known no particular name has been given it.

The neutralizing effect can easily be seen in the bridge circuit of figure 18. Suppose we have in the output circuit (between b and d) some energy or power which is trying to get back to the grid at the point (a). It flows in one direction from the plate to the grid (that is, from b to a) and flows in the opposite direction to the grid through C1 (that is, from c to a). The two currents coming to the point a (the grid) from opposite directions, neutralize each other, or cancel out, so that none of the feed-back current can enter the tuning or input circuit. The diagrams show only one stage of the r. f. amplifier. Several of these may be connected in cascade in the usual manner. On studying the circuit you will notice that there is no continuous path from the plate to the filament. This path is broken by the condenser C2. It is clear therefore that the "B" batteries cannot be connected by the series feed method, but must be connected by the shunt feed method. In connecting up this circuit the two condensers C1 and C2 may be of small capacity, say about .0001 mfd. or 100 mmf. One of these may be fixed and the

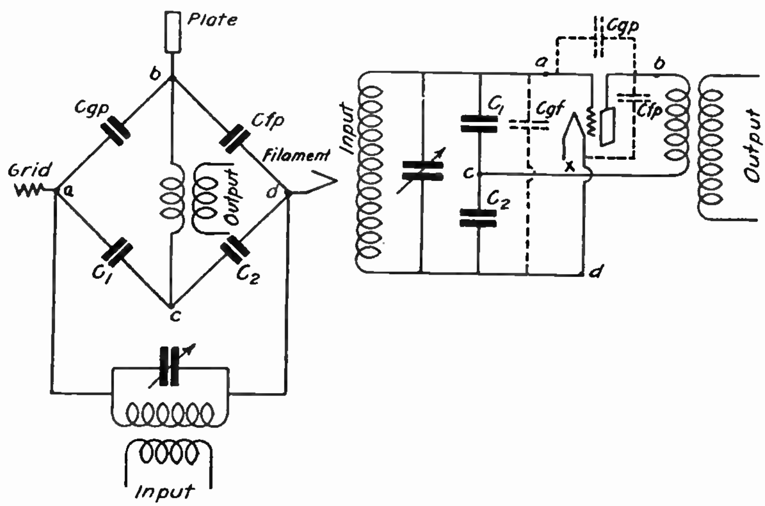


Fig. 18—Capacity bridge alongside a vacuum tube circuit.

other may be variable. The adjustment of the circuit is made as follows:

A very strong local broadcasting station is tuned in very accurately. Then the tube in one of the R. F. stages is taken out of the socket, and a piece of paper is fastened to the filament prong of the tube which is not in the bridge circuit. This is the side of the filament marked x in the circuit diagram of figure 18. Then the tube is put back into the socket, and the filament will not light up since the piece of paper breaks the circuit. Then the variable condenser C2 is adjusted until the sounds **completely disappear** in the loud-speaker. Then this particular stage is exactly neutralized. The same procedure is followed in neutralizing the other radio frequency stages.

A neutralized receiver of this type will not generally oscillate. There have been discussions as to whether or not there is regeneration present, although there is little doubt that there is some regeneration when the amplifier is not neutralized accurately. There are also some types of bridge circuits which can be accurately balanced or neutralized when tuned to other frequencies or wavelengths. Bridge circuits which have condensers in all four arms of the bridge will generally stay neutralized at all frequencies no matter at what frequency they are neutralized, but bridges which have coils in some of the arms may not stay as well balanced at all frequencies. The reason for this seems to be that the inductances of the coils vary somewhat as the frequency changes and this variation is not the same in all the

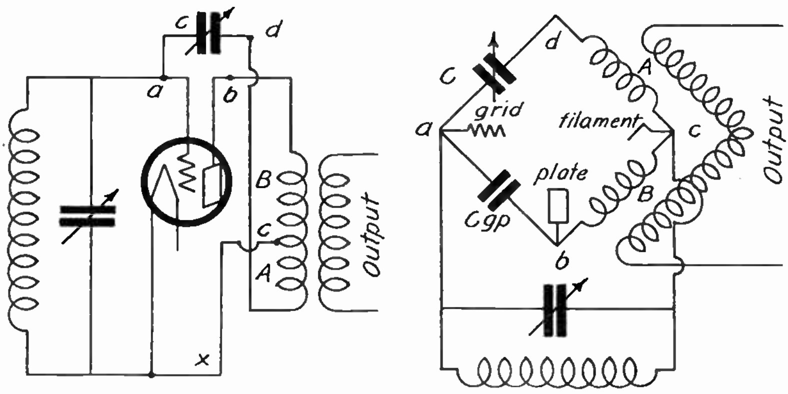


Fig. 19—Neutrodyne Bridge Circuit.

coils in the bridge. Consequently the inductance in a certain arm of the bridge which contains a coil will not be the same at one frequency that it is at another frequency. On the other hand, the capacity of condensers does not change with the frequency, so that it is easier to keep a good balance in a bridge circuit which has condensers in all of its arms.

Of course, a little regeneration due to a slight unbalance of the bridge may not do any harm; in fact, it may do some good by increasing the sensitivity of the receiver. But it is always good to have the balance as close as possible, for the gain due to the regeneration may not be worth the loss of good quality of reproduction which it may cause.

Another bridge circuit is shown in figure 19. This circuit is widely used at the present day. This circuit is a simple form of the **neutrodyne** circuit. The primary coil has a tap at a certain distance from one end. This is the point c in the diagrams. A neutralizing condenser of very small capacity, marked C, forms one arm of the bridge. The two parts of the primary coil, A and B, form two other arms of the bridge, and the grid-plate capacity in the tube forms the fourth arm of the bridge. The bridge is balanced as described above, by adjusting the neutralizing condenser C when the filament is not lighted. The secondary coil is coupled to both parts of the primary coil. Since there is a direct unbroken path from the plate to the filament, it is possible to use the series connection for the "B" batteries, which may be connected at x in the diagram.

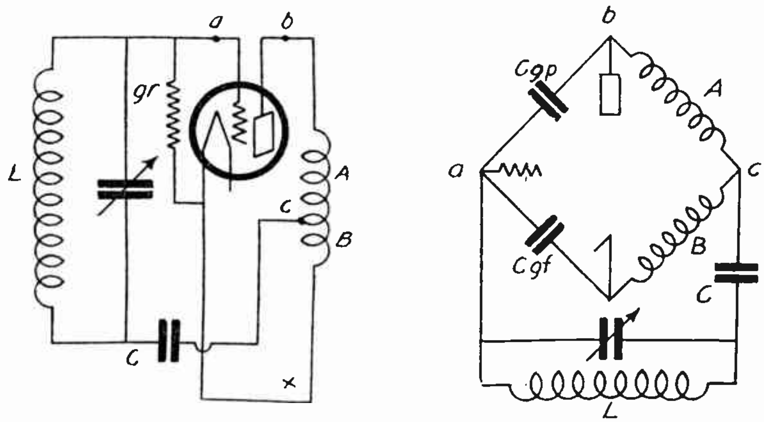


Fig. 20.

In figure 20 we have still another form of the bridge circuit. The plate coil is tapped as in the previous case, and this time the capacities Cgp and Cgf form two arms of the bridge. The two parts of the coil form the other two arms. The "B" batteries can be connected by the series method at the point marked x. It will be noted that a large blocking condenser is connected at C in the diagram. This condenser is required in order to keep the high positive voltage from the "B" batteries off the grid of the tube.

This brings up another point in connection with many bridge circuits. You will note that by placing the blocking condenser in the circuit, we have broken the path from the grid to the filament, which passes around through the coil L. As a consequence the grid is left "free" and is quite likely to become highly charged negatively. In order to let this charge leak off the grid we have to furnish a "leakage" path. In the present circuit it is difficult to do this, as any leakage path we might connect in the circuit might allow a high positive or negative voltage from the "B" battery to be placed on the grid of the tube. In either case this is bad. What might be done, however, is to place a grid-leak resistance as shown at gr. This may have a resistance of about 3 megohms. This particular bridge circuit is not adjustable. The balance or neutralization is only approximate, and is made by adjusting the tap (c) on the coil to the point of balance with the tube not lit, when building the receiver. When tubes are changed the adjustment will change slightly, but although there may be some regeneration, there is not much likelihood of oscillations being started.

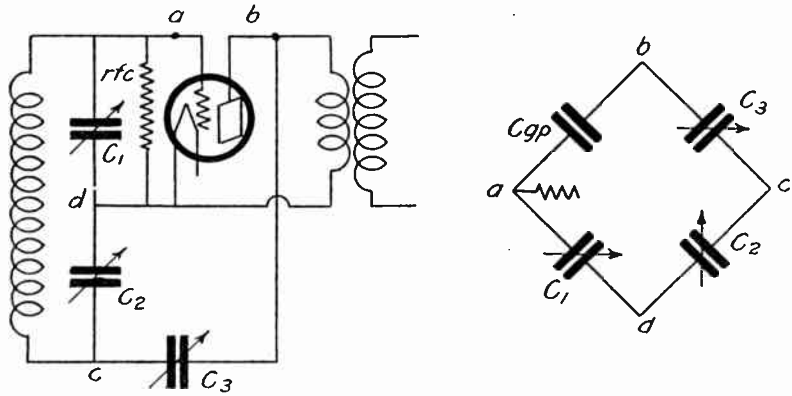


Fig. 21—Isofarad Bridge Circuit.

In figure 21 we have still another form of bridge circuit. This is known as the Isofarad circuit. The two condensers C1 and C2, forming two arms of the bridge, are rotated together, so that the capacity of one always bears the same relation to the capacity of the other. The grid-plate capacity forms another arm, and the fourth arm is formed by the neutralizing condenser C3. On account of the fact that the connection shown would leave the grid of the tube "free," a radio frequency choke coil rfc is connected between the grid and filament.

You, no doubt, have noticed that up to this time we have illustrated many drawings showing the connections from vacuum tubes to batteries. Therefore, it is advisable at this time to know the difference between circuits using D.C. tubes and A.C. tubes.

In Figures 22 and 23, we have shown a standard 2-stage

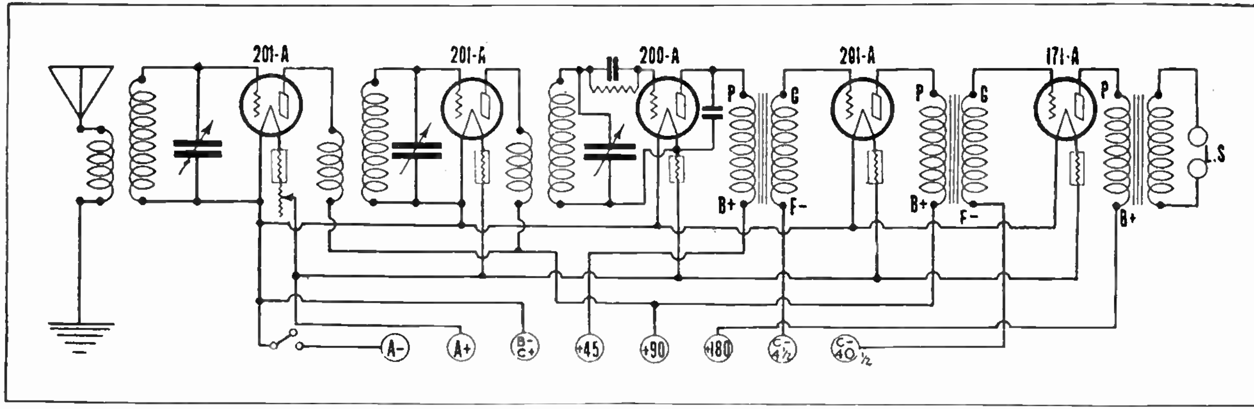


Fig. 22—The circuit diagram of a 5-tube Receiver using two stages of T.R.F., detector and two stages of A.F. amplification for battery operation is shown above.

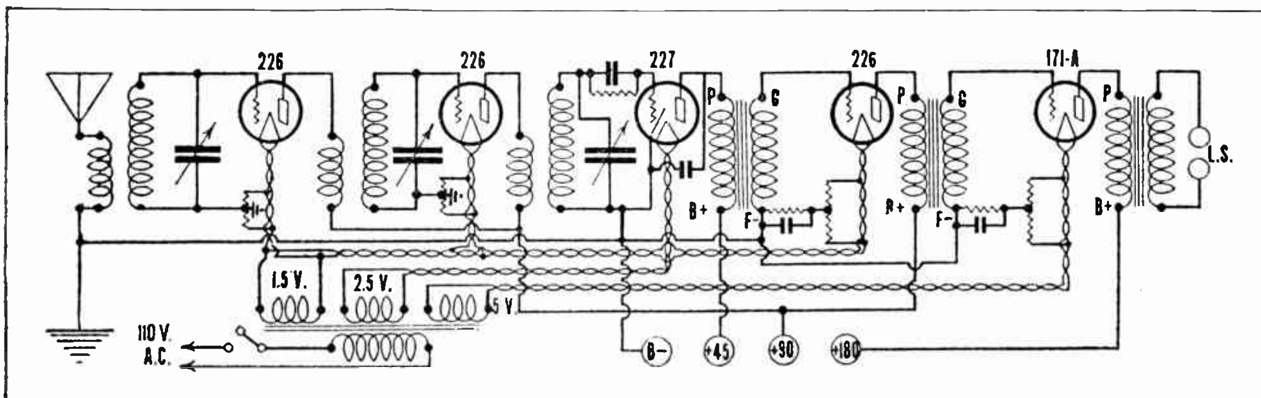


Fig. 23—Circuit similar to Fig. 22, using A.C. tubes operated from filament transformer and B power supply.

tuned radio frequency amplifier, detector, and 2-stage audio frequency amplifier for both D.C. and A.C. operation. In the D.C. operated set, the filament power is obtained from a storage battery, while in the A.C. operated set, the power for the filament is obtained from the 110-volt light source, through a step-down transformer. To furnish the correct operating voltage to the various types of A.C. tubes and the power amplifier tube, the step-down transformer must have besides its 110-volt primary winding, three other windings, namely, a 1.5-volt supply for the 226's, 2.5-volt supply for the 227 and a 5-volt supply for the 112-A or 171-A type of power tube.

In battery operated receivers, the return side of the secondary coil, whether it be in the tuner or amplifier, ultimately returns to one side of the filament; the same is true with A.C. tubes with the exception of the heater or 227 type of tube, where this connection can be made direct to the oxide coated element (cathode). However, it is not practical to make direct connection to either side of the filament when using 226 A.C. tubes or power tubes operated from a transformer for the reason that a disagreeable hum would be produced. To eliminate this hum, it is necessary that the midpoint of the tube be connected to the return side of the secondary coil. Mechanically, this is impractical in tubes now available because it would necessitate the actual connection to the center point of the filament.

The problem can be solved in a more simple and direct manner. Merely by shunting the filament terminals of the 226 A.C. tube and power tube sockets with a center tapped resistor, a satisfactory return connection is obtained when connection is made to the midpoint of the resistor unit. Where it is desired to obtain the proper C bias without the aid of external C batteries, it is simply necessary to insert in the return connection a resistance unit of the value which has been predetermined to give the correct C bias to the tube.

The A.C. amplifying tubes, the 226's, are of the standard 4-prong base. The 227 or detector tube, however, has 5 connections or 5 prongs at its base and, therefore, requires a 5 terminal socket. These sockets usually have terminals marked as follows: G for grid, P for plate, H-H for the heater terminals to which is supplied the filament voltage, and C (cathode) to which is attached the return side of the secondary circuit of the tuner coil. Figure 23 shows how this tube socket is connected in the circuit.

You will notice in Figure 23 that the filament leads are twisted together This is done so as to prevent the alternating current flowing through the filament leads from acting magnetically on the coils or grid leads which may cause a hum. This effect may be prevented also by keeping the filament leads as far away as possible from the other wires and also by shielding the filament leads.

The plate voltages applied to both D.C. and A.C. tubes may be obtained from standard B batteries or a regular B eliminator, the latter being preferable.

As the student has probably guessed by this time, the study of radio frequency amplifiers is an enormous one. We can hope in these lessons to give you only a fair idea of what it is all about, and can introduce you to only a limited number of circuits. By learning carefully what has gone before you will have a very good knowledge of the subject we will take up in detail in advanced text books A.C. receivers. Having learned this lesson it will be easy for you to read what is written on the various circuits in the radio magazines and future text books; as a matter of fact, you will not be in a fair position to understand what you read about them until you have thoroughly digested this lesson.

TEST QUESTIONS

Number Your Answer Sheet 13-2 and add your **Student Number.**

1. What is the purpose of using a radio frequency amplifier ahead of the detector circuit?
2. Draw a diagram of a two stage radio frequency amplifier.
3. Show by diagram how an "A" battery can be connected in the filament circuit so we can obtain a negative bias on the grid of the tube.
4. State the advantage of placing a negative bias on the grid of an amplifying tube.
5. Name the various coupling systems used in radio frequency amplifiers.
6. How is the secondary circuit of a tuned radio frequency transformer tuned to resonance?
7. How can we increase the coupling between the primary and secondary circuits using radio frequency transformers?
8. What causes a receiver to oscillate and become a small transmitter?
9. Explain what is meant by a critical point in the amplification of a tube.
10. Draw a simple form of Neutrodyne Bridge circuit.

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SOME GOOD STUDY HABITS

A Personal Message from J. E. Smith

Despatch. There is no habit more detrimental to good mental work than procrastination. Procrastination is not a "disease," as someone has said, but it is a habit. Putting it off until tomorrow merely encourages putting it off another day. "Some people," says Swift, "again, are always making resolutions—always promising themselves to begin work vigorously, tomorrow, always waiting for a great and perhaps conspicuous opportunity to do social service, always preparing to break a bad habit; and then, as the habit postponement becomes fixed, moments of anguish come, followed by periods of elation, as emotional virtue again soothes the mind. These people are rich in purposes, resolutions, and plans, but they never cross the Rubicon and burn the bridges."

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RADIO SOUND REPRODUCERS

Radio's success has largely depended upon the quality and faithfulness of reproduction from the sound producing device, whether it came from the first headsets, or our latest dynamic loud speakers of today. Radio reception today is quality recep-

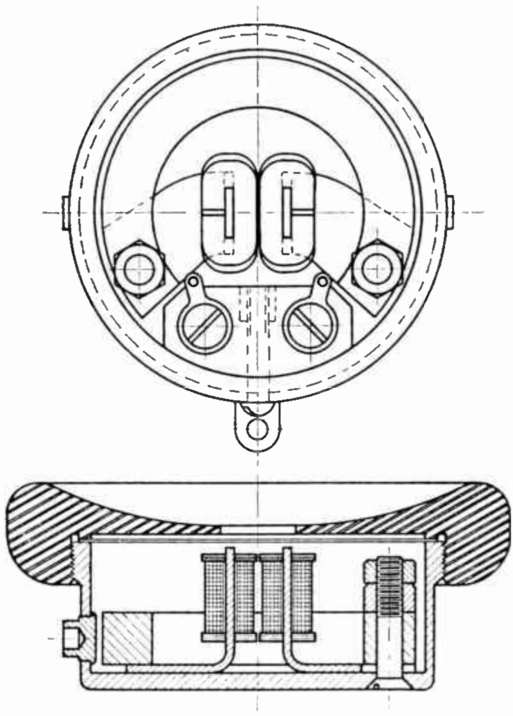


Fig. 1—Illustration showing details of the bi-polar type headphone unit.

tion and this faithfulness of reproduction is the result of intensive and exhaustive studies and development on Acoustical (sound producing) Devices.

The types of Acoustical Devices illustrated and described in this text are those used for listening to the speech and music of a radio broadcast receiver. The first acoustical device used in radio was the headset, and for years the principle employed in headset units was used in loud speaker devices. Even today, the principle used in one of the old standard headsets is still used.

Acoustical devices for radio broadcast reception should be distinctly classified into two groups: Telephone Headsets and Loud speakers or Reproducers. The loud speaker of today is the result of careful study and development of the ordinary headset, and, for this reason, due and careful consideration must be given to the types, theory and performance of the telephone headset.

TELEPHONE HEADSET

The telephone headset is known to us as headphones, earphones, or headsets, or those devices used over the ears for

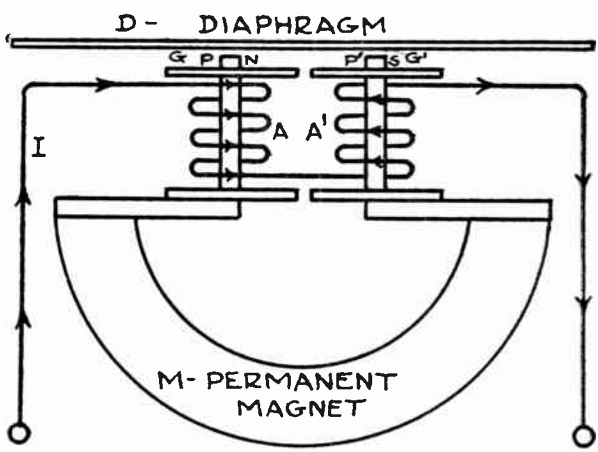


Fig. 2—Bi-polar type headphone unit.

listening in during the old days of first broadcasting of music. Before the era of broadcasting, these devices were used by radio operators on ships and land stations. Few realize today that these same units formed the foundation of the first important loud speaker devices.

There are two important types of telephone headsets, **bi-polar and balanced armature.** The bi-polar type is illustrated in Figs. 1 and 2, and the balanced armature in Figs. 3 and 4.

Referring to Fig. 2: A and A' represent the pole pieces which consist of bobbins with many thousands of turns of wire and the iron pole pieces P and P'; D the diaphragm; G and G' the air gaps between pole pieces and diaphragm; and M the permanent magnet. Permanent magnets are used because they produce a greater response for a given current than obtained with soft iron magnets. As current I passes through the winding as indicated, the pole pieces P and P^1 become north and south respectively, setting up a magnetic field around the pole pieces. This magnetic field passes through the diaphragm. The diaphragm attracted to the pole pieces depends upon **two factors,** the **strength of the magnetic field** and the **strength of the magnets.** The current which passes through the bobbins, being a pulsating current, that is always in the same direction, but varying in strength from a minimum to a maximum, the diaphragm is attracted to the pole pieces when the current is maximum and returns to its neutral position when the current is zero.

The strength of the magnetic field around the pole pieces is directly proportional to the amount of current passing through the bobbins, the number of turns in the bobbins, and the quality

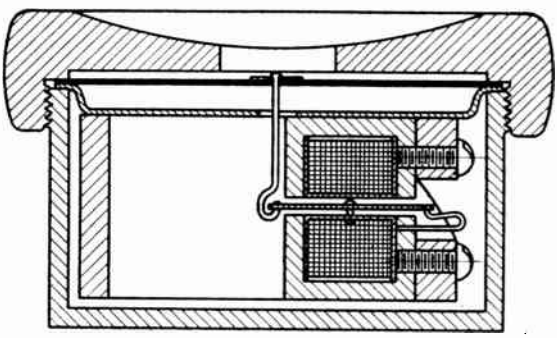


Fig. 3—Constructional details of balanced armature type headphone unit.

of steel in the pole pieces. The product of the number of turns and the current in the bobbin is known as the ampere turns of the bobbin, that is current times number of turns, and this should be a maximum. In telephone headsets, three to five thousand turns of very small enamel wire, generally No. 40 to No. 42 B. & S. gauge, are used in bobbins. Since the quality of iron in the pole pieces plays a very important part, only the best grades of iron are used, such as high grade Swedish iron, very carefully treated pure soft iron free from impurities, or the good grades of silicon steels having 3 to 5% silicon content.

The magnetic field above the pole pieces passes through the diaphragm D, and the quality of this diaphragm metal is of the best, such as soft iron or silicon steel. In headsets, where the ear piece comes in contact with the air and ear, the diaphragm is lacquered or japanned to prevent rusting.

The length of the air gaps G and G^1 is dependent only upon the amount of maximum vibration of the diaphragm, the gaps being so adjusted that the diaphragm will not touch the pole pieces.

The permanent magnet M is of sufficient size and strength to initially magnetize the pole pieces P and P^1. This magnet is so designed that it will not lose its magnetism in time. Chrome and Tungsten magnets are generally employed. In the high grade units Tungsten magnets are used because they hold their magnetism for a much longer time than Chrome magnets.

The theory of a telephone headset unit is best understood perhaps by analyzing the changes occurring in the magnetic circuit which, of course, is the important factor to take into consideration when transforming electric current into sound waves.

The attraction or pull of the diaphragm to the pole pieces is approximately proportional to the square of the magnetic field passing from pole to pole through the metal of the diaphragm.

From the above paragraph, it can be seen that the greater the permanent magnetic field, or flux, as it is sometimes called, the greater will be the efficiency of a good telephone headset unit. The magnetic field is increased by strengthening the magnet or by using thicker diaphragms, also by reducing the air gaps between the diaphragm and the pole pieces, but the magnetic saturation of the diaphragm sets the limit to useful increase of strength of the magnet as readily becomes evident. If, with a certain thickness of diaphragm, we unnecessarily increase the strength of the magnet in the unit, the superfluous magnetic field will cause a magnetic leakage which will be wasted as it cannot be crowded through the diaphragm.

With diaphragms of a given diameter, a thicker one carries more magnetic lines, is stiffer and can, therefore, be brought nearer to the pole pieces, but a limit to the thickness of the diaphragm is soon imposed by the increase of thickness and inertia, and also by the decrease in the natural period of vibration of the diaphragm, which should also be in the neighborhood of the periodicity of the current sent through the unit. As the diaphragm is a stretched elastic body it tends to vibrate most easily and perfectly at a frequency depending upon its construction and elastic properties, which is known as its natural frequency, hence it is found that if the input current to the unit is kept constant in amplitude, but if its frequency is varied, then the greatest response or motion of the diaphragm occurs when the impressed frequency is identical to the natural frequency of the diaphragm.

Figures 3 and 4 represent the balanced armature type of headset unit:

In the balanced armature type of unit, a soft iron armature is placed in the center of a coil, mechanically supported at the middle, and the diaphragm is connected to one end of the armature by a connecting link. Tips of two sets of pole pieces are located at both ends of the armature, and these pole pieces are magnetized by the permanent magnet M. As the current passes through the single winding as indicated (Fig. 4), the respective ends of the armature become north and south and the armature is

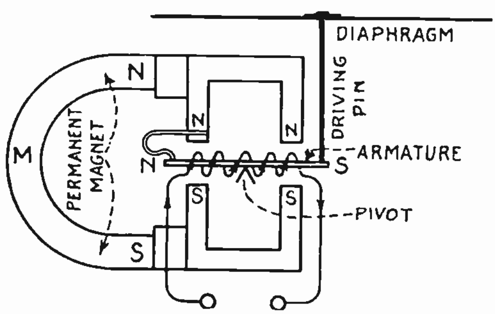


Fig. 4—Balanced armature type headphone unit.

thus caused to pivot at the fulcrum. The attraction or repulsion of the armature to the pole pieces is governed by the same laws as in the bi-polar unit, the pivoted movement of the armature depending upon the amount of current passing through the coil, the number of turns in the coil, the quality of the iron of the armature and pole pieces and the strength of the magnetic field at the pole pieces.

With the proper design of pole pieces, diaphragm, magnets, etc., very efficient telephone headsets were developed and manufactured in great quantities, especially during the first years of radio broadcasting. During the years of 1922, 1923 and 1924 manufacturers were producing great quantities of these headsets and one manufacturer produced as high as seven to eight thousand headsets a day.

Soon after broadcasting seriously gripped the country many headsets were used in a single home, several persons sitting around a single radio receiver, each with a headphone clamped on his or her head, listening intensively to the broadcasting received. It was not long before everyone realized the necessity of an acoustical device such that everyone could hear the reception of music or speech from the radio receiver without the inconvenience and uncomfortableness of a telephone headset on one's head. This was seriously appreciated as early as 1923 and all important engineering departments began on this most important development—the **"Loud Speaker"** or **"Reproducer."**

HORN TYPE LOUD SPEAKER OR REPRODUCER

The first loud speaker was nothing more than a horn placed on a telephone receiver unit, as shown in Fig. 5.

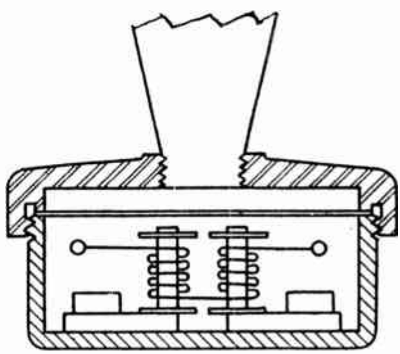


Fig. 5—Illustration showing how a horn can be attached to a headphone unit.

These first loud speakers served the purpose for a time, because they eliminated the use of headsets, but the quality of reproduction from these loud speakers was not as good as from the headset unit. During those days, it was often remarked, "Yes, I like your loud speaker, but for good quality reception, I still use my headset." The public demanded loud speakers and the quickest developed loud speaker was a simple horn on a simple unit. Engineers soon found that pole pieces and component parts designed for telephone headset units were not correct for a loud speaker device.

Referring again to Fig. 2, it was brought out that there were two kinds of magnetic fields in the magnetic circuit, the permanent magnetic field produced by the permanent magnet and the varying or fluctuating magnetic field produced by the pulsating current passing through the bobbin coils. In following both of these fields through the magnetic circuit, they both have the same path, that is, from one pole piece through air gap G, through diaphragm D, across air gap G^1 to the other pole piece and through the permanent magnet back to the first pole piece. Due to the high reluctance or magnetic resistivity of the permanent magnet to this varying magnetic flux, if some other path could be provided besides going through the permanent magnet the varying magnetic flux would be stronger at the pole piece tips P and P^1. Such a path was made available in the improved horn speakers.

Figure 6 shows the redesign of pole pieces of a telephone unit for a horn type loud speaker. R is a very small reluctance (magnetic equivalent of electrical resistance) gap between five to ten

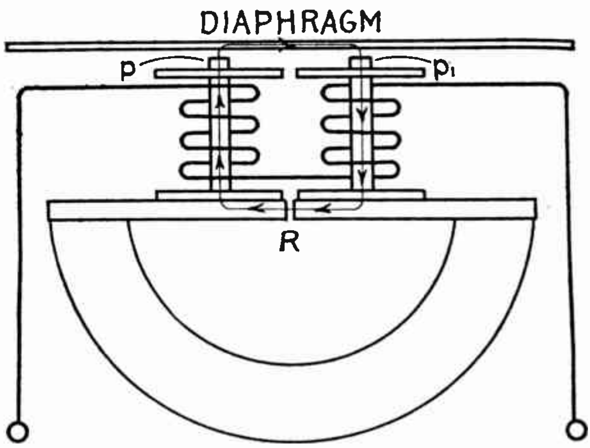


Fig. 6—The segregation of the current in a horn type loud speaker.

thousandths of an inch, to prevent magnetic short circuit of the permanent flux from the permanent magnet, but which allows a very good path for the varying magnetic flux as shown by arrows. This not only increased the magnetic force upon the diaphragm, but increased the efficiency of the loud speaker unit at the lower frequencies.

In ordinary telephone headsets the energy passing through the unit was so small that laminating the pole pieces did not appreciably help its efficiency, but in loud speaker units, the energy coming from first and second stage audio amplifiers, it was found that laminating the pole pieces increased its efficiency tremendously. As is appreciated, laminating iron decreases the iron losses, such as eddy currents (stray currents set up in the core of electro-magnets) and hysteresis (slowness or lagging behind when a change of condition is taking place), and, in laminating the pole pieces in loud speaker units, the principal iron losses are the eddy currents induced in the solid pole pieces.

Larger and thicker diaphragms of silicon steel, bigger and better magnets, redesign and introduction of a reluctance gap in the pole pieces, replaced those of the ordinary telephone improved horn type loud speaker.

HORNS AND THEIR DESIGNS

Two types of horns were first used on loud speaker devices, **conical** and **exponential.** In the conical horn, the area varies directly per unit length as shown in Fig. 7 while in the exponential horn the area varies exponentially per unit length as shown in Fig. 8.

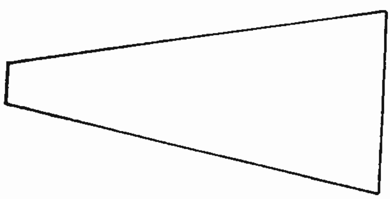


Fig. 7—The conical horn.

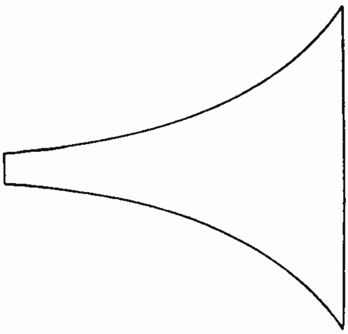


Fig. 8—The exponential horn.

The correct type of horn for a loud speaker is one which places a sufficient air pressure upon the diaphragm, and this air pressure to be gradually released through the horn. The taper of the horn controls the air pressure in the horn, and it is important that this air pressure is not suddenly released until towards the free end of the horn. It is for this reason that the exponential horn is far superior to the conical horn, as, by examining the illustrations, Figs. 7 and 8, the rate of change of areas at the beginning in the respective horns is very much greater in the conical horn than in the exponential. The exponential horn is used now almost entirely.

The length of the horn determines the range of response from the loud speaker. The longer the air column in the horn, the better will be the response of the lower frequencies. As in the case of organ pipes, the longer the air column in an organ tube, the lower will be the note produced. It is, therefore, to be expected that a horn-type speaker with a short horn will sound thin and high pitched, lacking in low notes, whereas a speaker with a very long horn will be rich and full in its response, due to the reproduction of the low notes. Horns vary in length from 18 inches to 120 inches, depending upon how they are used. It is not important what material the horn is made of, providing its walls are strong and thick enough to prevent vibrations setting up a natural period of their own.

UNITS FOR HORN-TYPE SPEAKERS

Besides the bi-polar type of unit for horn-type speakers, the balanced armature and moving coil type of units can be em-

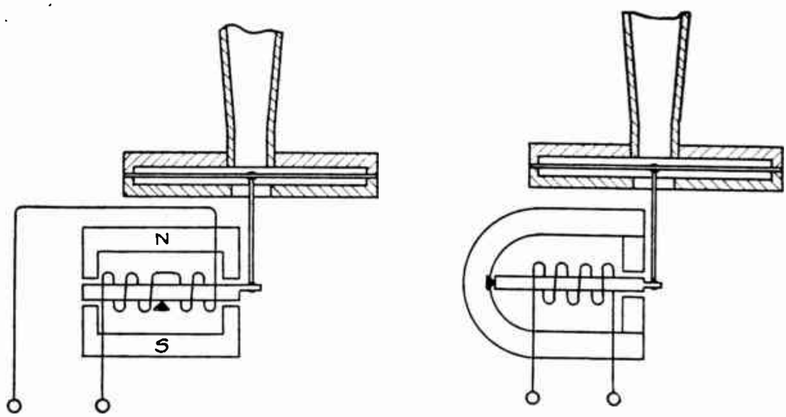


Fig. 9. Fig. 10.
Illustrations showing the balanced armature type coil units.

ployed. Two important types of balanced armature horn-type units are shown in Figs. 9 and 10 and the moving coil type is shown in Fig. 11.

The importance of steels, windings, air gaps and magnets in balanced armature type of units hold the same as bi-polar type of units, and the same efficiency and performance can be obtained from both. The bi-polar type of unit has its advantages in its simplicity of design for mass production whereas the balanced armature has the advantages of slightly better performance by its adaptability to employing special diaphragms which will be taken up later.

The moving-coil type of unit for horn-type speakers was introduced early in 1924. It was first invented by Sir Oliver

Lodge in 1898, in which he employed large thin pieces of wood for diaphragms.

The theory and operation of this very important moving coil system is as follows:

Figure 12 shows the principle of the moving coil unit. Around the center core of the shell type casting A is a large magnetizing coil B. When this type of unit came out for a horn-type speaker, this winding, which is called the "energizing field," was designed for 6 volts, drawing one to three amperes in order that it could be used with a standard 6-volt battery. This winding magnetizes the shell iron casting A, so that the center core B is

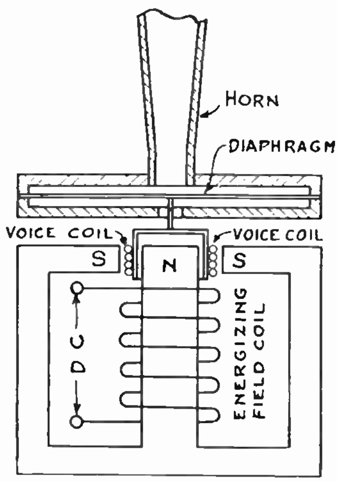


Fig. 11—The original moving coil type loud speaker unit.

"North" and the outer ring "South" as indicated. Centrally located in the gap between the center core and outer ring is a small coil "V.C.," known as the "Voice Coil." This voice coil is in a gap of a very strong magnetic field, set up by the energizing field "B." The current which is passed through this voice coil is an alternating current from the last tube of an audio amplifier. The coil is shown cross-sectionally. Now let us assume that the current in the left winding is coming towards us, as represented by the "arrow," and the current in the right winding is going away from us, as represented by the other "arrow." It is the law of a motor that when a current is passed through a coil of wire in a magnetic field the wire will be forced to move, and by the left-hand rule for a motor, the movement of the voice coil is "down." When the current in the voice coil is reversed, the movement of the coil is "up." By the movement of the voice coil the diaphragm is caused to vibrate.

This type of unit for a horn-type loud speaker was not very popular, because the field coil was too much of a drain upon the six-volt storage battery, running down the battery too quickly which meant that the battery had to be recharged often. The response of this type of speaker was very little better than the other existing bi-polar and balanced armature types, and yet this moving coil principle was soon to become the outstanding development of the "Cone Dynamic Speakers."

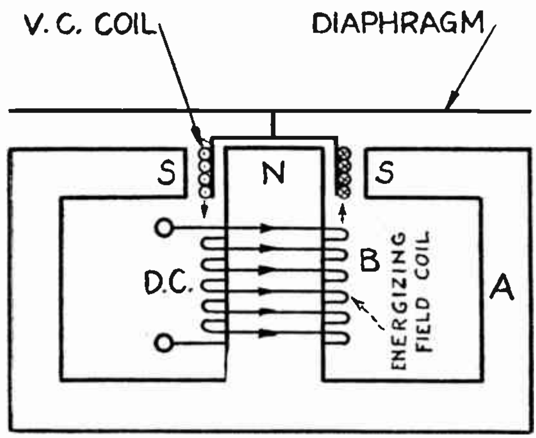


Fig. 12—Illustration showing the principle of the moving coil speaker with shell type casting. This unit was the forerunner of the dynamic speaker of today.

DIAPHRAGMS FOR HORN-TYPE SPEAKERS

Diaphragms in horn-type speakers vary in diameter from 1½ inches to 4 and 5 inches, and in thickness from .006″ to .032″. Larger diaphragms are used in loud speakers than headsets in order to obtain greater frequency response.

Diaphragms employed in bi-polar type of units are perfectly flat and made of a good grade of magnetic material, generally silicon steel.

In the balanced armature type of unit, great varieties of diaphragms are used, several of which are illustrated in Figs. 13 and 14.

Figure 13 shows at the left a flat corrugated type of diaphragm commonly used, the material of which is generally light pressed aluminum, the corrugations running concentrically. The corrugations not only add stiffness and rigidity to the diaphragm, but break up the tendency of a diaphragm to have local vibrations of its own. This figure also shows two types of conical diaphragms, one being plain and the other corrugated. Light pressed aluminum is very often used in these types of diaphragms. By making the diaphragm in the form of a cone, greater rigidity is obtained, and slightly better performance results. Figure 14 illustrates one type of diaphragm made of a

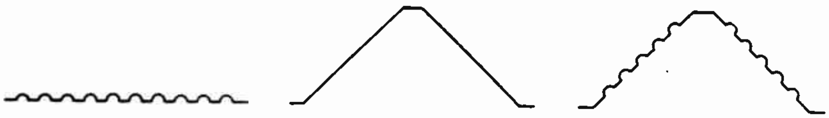


Fig. 13—Different types of diaphragms.

non-magnetic material, a moulded composition, its thickness at the center being greater than at its edges. A magnetic metal button is fastened at the center.

Most of the diaphragms are clamped at the edges, but not clamped rigidly, two methods of which are shown in Figs. 15 and 16.

Figure 15 shows where two rubber tubings are used on each side of the diaphragm, the pressure of the clamping depending upon the compression of the rubber tubing against the diaphragm. Fig. 16 shows a similar method whereas rubber gaskets are used in place of the rubber tubing. By clamping the diaphragm between rubber tubings or gaskets, the diaphragm is not

Fig. 14—A type of diaphragm made of a non-magnetic material, the thickness at the center being greater than at its edges.

rigidly held at its edges and it has a greater freedom of vibration, particularly helpful for the response of the lower frequencies.

LIMITATIONS OF A HORN-TYPE SPEAKER

It has been brought out in this text that the first horn-type speaker was nothing more than a horn on an ordinary headset unit, but great improvements were made by proper detail consideration of unit design, larger and thicker diaphragms and longer and better horns. However, after all of these improvements were made it was still noticed that speech and music was not distinct and clear, lacking in good articulation, and reproduction of music at times unnatural with an overexaggeration of the low notes.

The lower frequencies of a horn-type speaker can be controlled by the following factors:

(1) Low reluctance magnetic circuits.

(2) Large diaphragms.

(3) Long air column horns.

(4) Strong magnetic fields.

The higher frequencies can be controlled by—

(1) Laminated magnetic pole pieces, to reduce the magnetic losses.

(2) Small or thick diaphragms.

(3) Short horns.

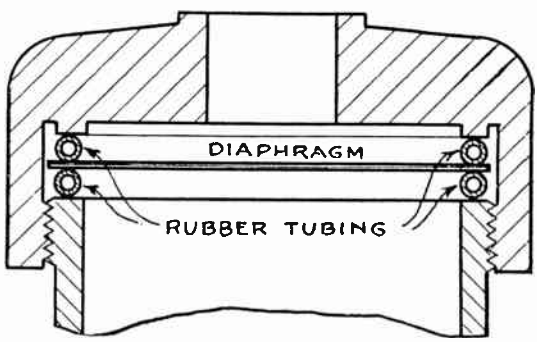


Fig. 15—Illustration showing how two rubber tubings are placed on each side of the diaphragm.

For good reproduction of speech and music a loud speaker should reproduce frequencies from 100 cycles to 5000 cycles per second, that is, the diaphragm should be able to respond faithfully from 100 vibrations to 5000 vibrations per second.

Because a diaphragm is clamped at its edges, it is very difficult for it to vibrate at a very high frequency, the best horn-type speaker being only capable of vibration as high as 2500 to 3000 cycles per second. Also to obtain the fundamental notes at 100 to 200 cycles, the diaphragms would necessarily have to be very large, and if too large to get the lower frequencies, the higher frequencies would suffer. The use of very long horns to obtain these low notes is an economical difficulty both in development and manufacture. At its best, the choice of parts in the design of a horn-type speaker is a compromise. Satisfactory high frequencies could not be obtained and lower frequencies were obtained with difficulty. This was the problem in horn-type speakers when the cone type was introduced.

HISTORY OF THE CONE-TYPE SPEAKER

The first cone type of speaker known to be used as a real sound producing device was in 1908 when two English scientists, Starling and Cole, used a cone to reproduce music from a phonograph record, as shown in Fig. 17.

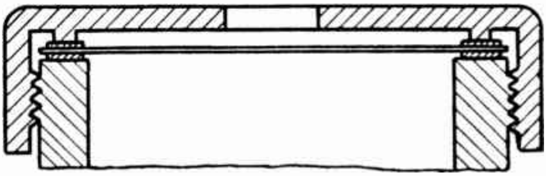


Fig. 16—Illustration showing how rubber gaskets are used in place of the rubber tubing, as shown in Figure 15.

A is an ordinary 2″ mailing tube, with a cone 6″ in diameter made of manila paper, glued at its apex to one end of the mailing tube. As the mailing tube rides over the tubular reproducing record, the mechanical vibrations from the record are transferred to the mailing tube, and thus to the cone, giving a feeble response of sound. This device was only used where loud response

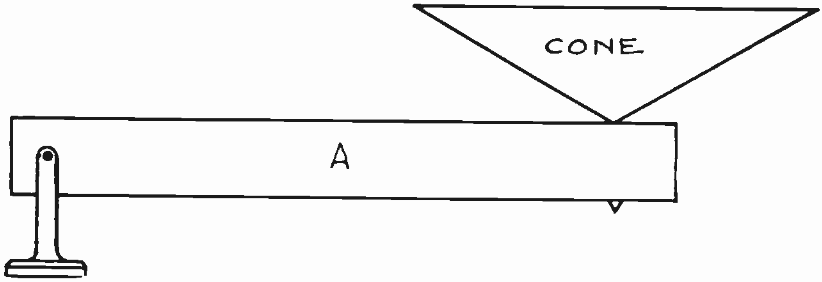


Fig. 17—Diagram showing how the first cone type of loud speaker was used. It consisted of a mailing tube with a cone attached at one end.

was not required, for if this cone vibrated too much, its edges would whip and vibrate in a local vibration causing rattles.

Of course cone-type diaphragms were used in horn-type speakers but their diameters rarely exceeded 4″ and were not used as a direct acting radiator of sound.

In 1918 the first important patent on a cone-type invention was allowed to Marcus L. Hopkins in his letters patent No. 1271529, granted July 2, 1918, but it was some time after 1918 before this was used commercially. The patent relates to a cone diaphragm of the direct acting type, to reproduce sound from a phonograph record. Details of this cone is shown in Fig. 18.

Hopkins calls the portion within the huge bulky rings AA, a tympanum, the other part of the unit consists of a conical central portion C and a plane peripheral portion DD. The edge of the conical portion C is not held rigidly at its edges, and thus the conical portion is free to move in accordance with the vibrations given to it at its apex B. This diaphragm was intended to be used for the reproduction of sound from a phonograph record, but complicated and elaborate mechanical devices were necessary to transfer the mechanical vibrations from the record to the apex of the cone, and, on account of the mechanical parts involved, serious difficulties were encountered and the cone-type

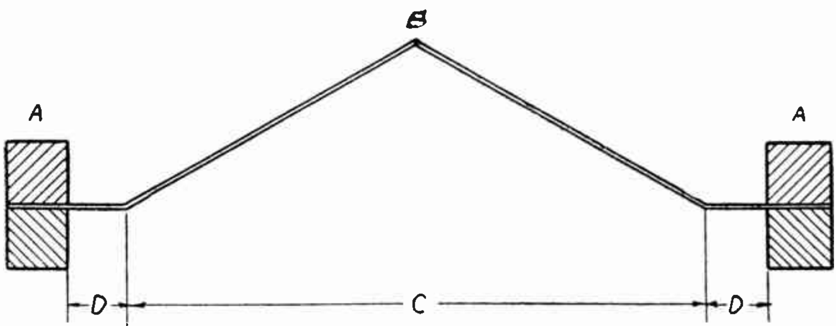


Fig. 18—Details of the original Hopkins cone.

speaker was not very successful in the reproduction of sound from a phonograph record. However, in the cone-type speakers, the construction of the majority of the cones came within the claims of the Hopkins patent, so today a number of manufacturers of cone-type speakers are paying tribute to the Hopkins patent of 1918.

CONE-TYPE SPEAKERS

The introduction of a cone on a unit is a great improvement over the flat and other diaphragms of horn-type speakers. It had been realized for some time that large diaphragms were desirable, but in most cases flat diaphragms made of a variety of materials were used, which proved unsatisfactory because the flat surfaces would break up into local vibrations of their own, introducing harmonics into the original vibrations given to the diaphragm, resulting in distortion. By shaping the diaphragm in the form of a cone the diaphragm became stiff and rigid and vibrates in accordance with the vibrations given to it at its apex.

Constructional details of several types of Cone Speakers are shown in Figs. 19, 20, 20(a) and 24.

Figure 19 shows the constructional details of one early form of interesting cone speaker employing the bi-polar principle, two of these units were used in "Push-Pull." As the current of the windings of one of the units sets up a magnetic field about the pole pieces to attract the armature, the current in the windings of the other unit is in such a direction as to give a magnetic field to repel the armature. The cone is connected to the armature at

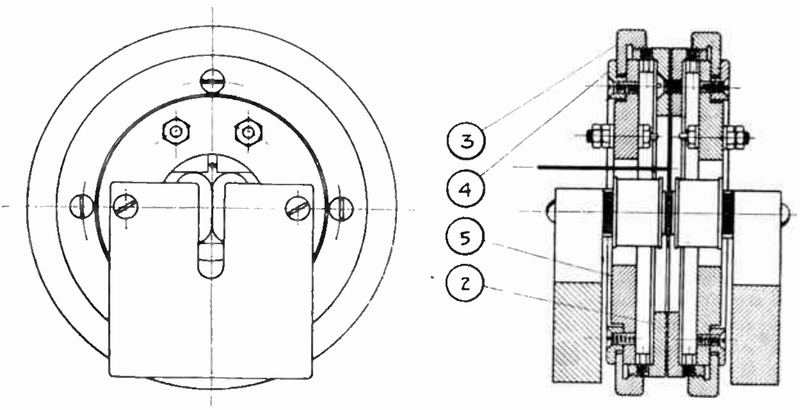


Fig. 19—Drawing showing details of construction of one of the early forms of cone speakers employing the bi-polar principle.

the center by a connecting link. Although this unit was popular for some time, the limitation of a heavy thick armature clamped at its edges prevented satisfactory response of the high frequencies.

In Figures 20 and 20(a) we see again two forms of the balanced armature type units. The balanced armature principle has always been desirable because the mechanical system of the unit itself, consisting of a small armature free to pivot inside an exciting coil, was flexible to satisfactory slow vibrations and capable of extremely high vibrations. These high vibrations were limited to the diaphragms in the horn-type speakers, not to the mechanical system of the unit, and so when cones were employed for diaphragms improvement in results was immediately noticed.

CONES, THEIR STRUCTURE AND THEORY—THE BAFFLE BOARD

The cone when used as a diaphragm is so designed that it is free to vibrate without distortion, in accordance with the mechanical vibration actuated at its apex. By the vibration of the cone, it sets up an air displacement about it and reproduction of sound results.

By referring to Fig. 18, the conical portion C is generally made out of a good grade of paper, ranging in thickness from .005″ to .025″ and from 6″ to 36″ in diameter. A "Waterfalls Ledger" (trade name), Alhambra low frequency and high grade manila are some of the best papers used. The plane peripheral

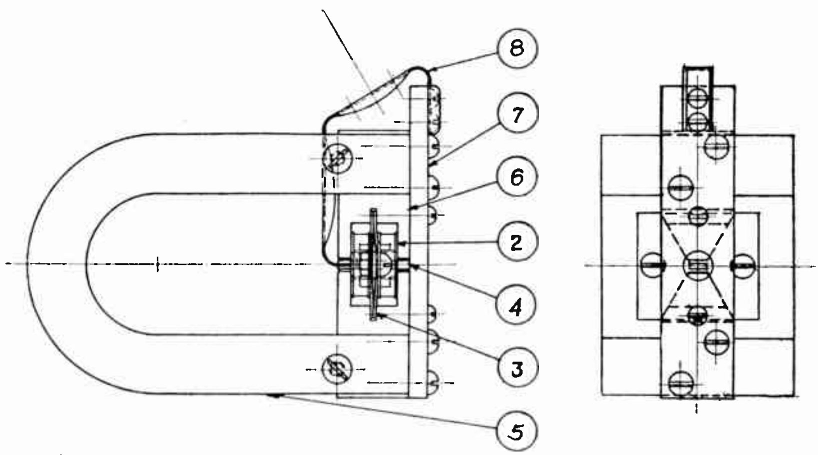


Fig. 20—Constructional details of a balanced armature type of loud speaker unit.

portion D may be paper, rubber, leather or even strings, supported at the ponderous rings AA.

As the apex B is actuated from a mechanical source the cone is set into vibration, as shown in Fig. 21.

In Figure 21 an actual wave vibration is set up from the apex to the edge of the cone, and nodes "N" appearing, depending upon the frequency and the length of the cone from the apex to the edge; the longer this length the greater will be the response from the lower frequencies, as the cone will have a lower natural period.

Cones are generally circular but some cones are made eliptical or egg-shape. There is very little advantage gained in using cones of peculiar design as the cost and difficulty of manufacture do not warrant the little, if any, acoustic gain obtained.

As the cone is made to vibrate, a rarefication of air occurs in front of the cone and a condensation of air in back of the cone setting up sound waves in front and back of the cone opposite in phase relation. If the sound waves emitted from the back of the cone are allowed to come around to the front of the cone, these waves, being in opposite phase to the sound waves emitted from the front of the cone, will neutralize the sound wave from the front. This is particularly noticeable on the lower frequencies or longer waves, since the length of the sound wave at these

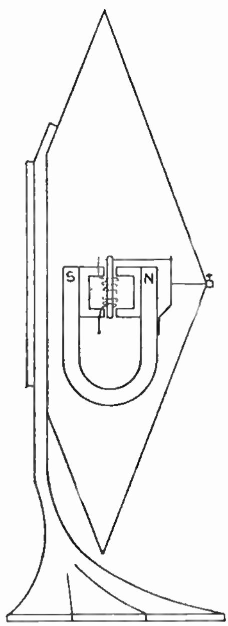


Fig. 20(a)—A transparent view of an early type of cone speaker showing how the loud speaker unit is attached to the large cone.

lower frequencies is sufficient to extend around to the front of the cone.

It is for this reason that the "Baffle Board" plays such an important part in the reproduction of the lower frequencies of a cone speaker.

Figure 22 shows how a baffle board is used with a cone. It can be seen that the baffle board is of such proportions to prevent the sound waves from the back of the cone to interfere with the waves emitted from the front of the cone.

A good baffle board should be made of wood or wall board not less than 3/8" to 1½" of an inch thick. This baffle board should be of non-resonant material so that it will not vibrate or rattle and radiate sound when the unit is being operated. The opening in the baffle board must be of the proper diameter determined by the size of the cone being used. The unit should be mounted behind the baffle board with a felt ring on the front of the cone housing pressed evenly and tightly against the board. The unit should be held in this position by screwing down the base to a shelf provided for that purpose. It is not necessary or desirable to screw the cone housing itself to the baffle board. When a speaker is mounted in a console cabinet care must be taken to insure that it is properly baffled. When the grill opening is larger than the cone a baffle board the size of the cone should be placed behind the grill and the speaker unit mounted tightly against it.

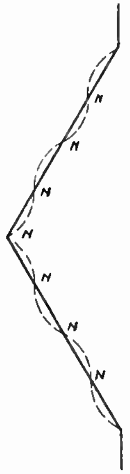


Fig. 21—Illustration showing how the actual wave vibration is set up from the apex to the edge of the cone.

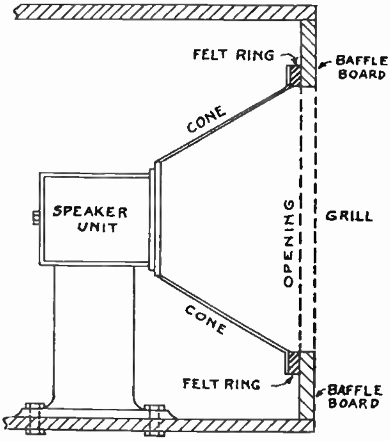


Fig. 22—Illustration showing how a suitable baffle board is used with a cone.

You probably have noticed that when a cone speaker is placed in a cabinet a difference in response is noticed, particularly in the lower frequencies. This is due to the "baffle effect" of the cabinet, the partitions around and behind the cone serving as a good baffle. Very small cones with large baffles can produce practically the same results as large cones with small or no baffles. A cone of large diameter not only reproduces lower frequencies on account of its lower natural frequency, but on account of its large size it acts in itself as a baffle.

Several types of cones are used as illustrated in Fig. 23.

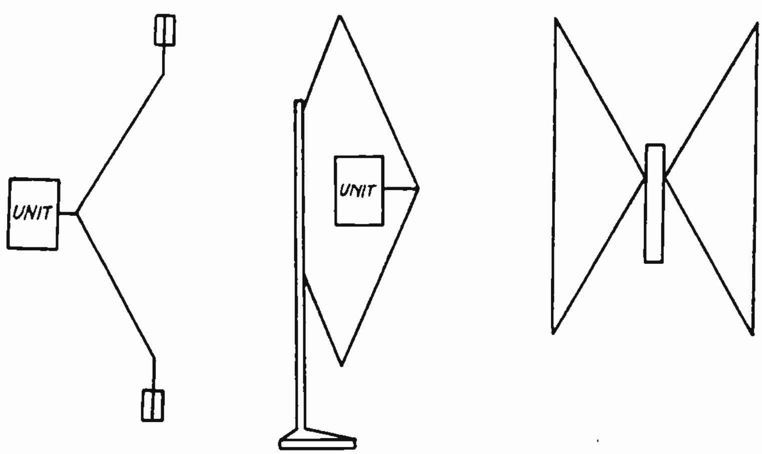
In Figure 23, "A" is the simple type of cone commonly used;

"B" is a popular cone structure, having a back membrane forming a partially enclosed air chamber behind the cone proper; and "C" shows a double cone structure operating from a single unit.

THE DYNAMIC SPEAKER—POWER CONE

The types of cone speakers described so far excell by far the horn-type speakers because they are able to reproduce the higher frequencies much better, going readily as high as 4000 cycles per second, and the reproduction of the lower frequencies is more pleasing and natural.

For a loud speaker to reproduce lower frequencies satisfactorily, the cone and armature must vibrate at large amplitudes. Also for a speaker to give out large volumes, the amplitudes become so great as to cause rattles by the armature hitting



A B C

Fig. 23—Several types of cone loud speakers.

against the pole pieces, and distortion by the whipping and movement of the paper cone.

Power from audio amplifying tube circuits is necessary for the proper reproduction of the low notes and volume. Ordinary speakers cannot use this power to full advantage. To obtain better quality of reproduction with large volumes, the "dynamic" or "moving coil" principle of cone speaker was developed.

The reason that they are called "dynamic" speakers is because the moving or voice coil principle is the principle of the motor or dynamo and the reason that they are called "Power Cones" is because this moving coil takes its power from a power tube such as the UX-171A, UX-210, UX-245 and UX-250 to operate it satisfactorily.

The theory of the moving coil principle as explained in reference to Fig. 12 and Figs. 24, 24(a), 25 and 26 show types of important dynamic speakers of today.

The first important commercial dynamic or power cone speaker was developed by C. W. Rice and E. W. Kellogg, two General Electric research engineers of Schenectady, New York. This power cone speaker was put on the market the latter part of 1925. The principle of this speaker is shown in Figs. 24 and 24(a). The field winding is different than that shown in Fig. 12 for a horn-type speaker, inasmuch as it is designed for 100 volts,

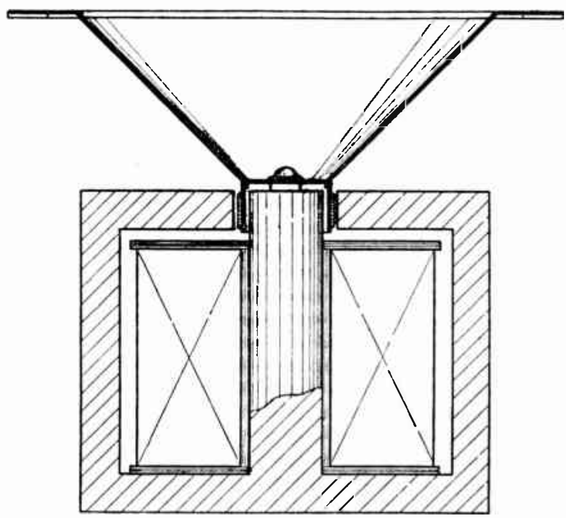


Fig. 24—The first commercial type of dynamic cone speaker.

50 milliamperes, instead of 6 volts, 2 amperes. The voice current coil is wound on a circular tubing and connected to a frustrum of a cone. Glued at the frustrum of the cone is a spider membrane, held to the center core by a screw, to centralize and hold the voice current coil in the magnetic gap, the spider, however, being so designed as not to impede the motion of the cone. The diameter of this cone is six inches, made of manila paper, and placed behind a suitable baffle board. The current in the voice coil is obtained from an output transformer, the primary of which is connected to the plate circuit of a power tube.

Figure 25 shows another type of successful power cone. In this case the voice coil is wound on a circular moulded bobbin which is glued near the apex of the cone and centralized in the magnetic gap by a small leather diaphragm which is stretched between two rings. The small stretched leather diaphragm also aids in the performance of the cone. The cone is a full cone having a diameter of 10" or 12" with an apex angle of 120°. The center core of the magnetic circuit is cupped to allow room for the apex of the cone. In this type of dynamic speaker a 350-volt, 50-milliampere field winding is employed, consisting of 50,000 turns of No. 33 B. & S. enamel wire.

Dynamic speakers differ principally in the method of centralizing the voice coil in the magnetic gap. A great many of

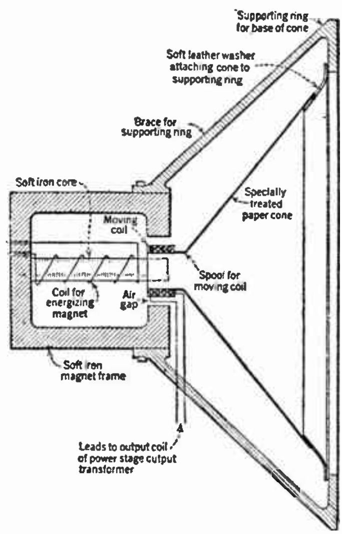


Fig. 24(a)—Construction of the moving coil type of Dynamic Speaker.

these speakers use the three-point suspension for positioning the voice coil, as shown in Fig. 27. Some of the suspensions are non-metallic such as bakelite; others are made of aluminum or phosphorus bronze.

FIELD EXCITATION FOR POWER CONES

When dynamic speakers are used as power cones, to work from the output of power tubes the field excitation consists of a rectified voltage obtained from one of the sections of an electrical filter circuit.

Figure 28 shows a standard electrical rectified filter circuit with the field coil of a dynamic speaker shown as the second reactance or choke coil in the second section of the filter. The field coil, besides being efficiently used for field excitation, serves as a fine choke coil for the filter circuit. By the proper design of the rectifying and filter circuit, any field coil voltages and currents can be readily obtained.

Dynamic speakers which are to be operated from a small power tube, such as the UX-171A, with rectified circuits, do not adapt themselves to such high voltages and currents for field excitation. In these cases separate field excitation must be employed. Two methods are used for this purpose, a vacuum tube rectifier or a dry rectifier. In the vacuum tube rectifier some rectifying tube such as the UX-280 or Raytheon must be used,

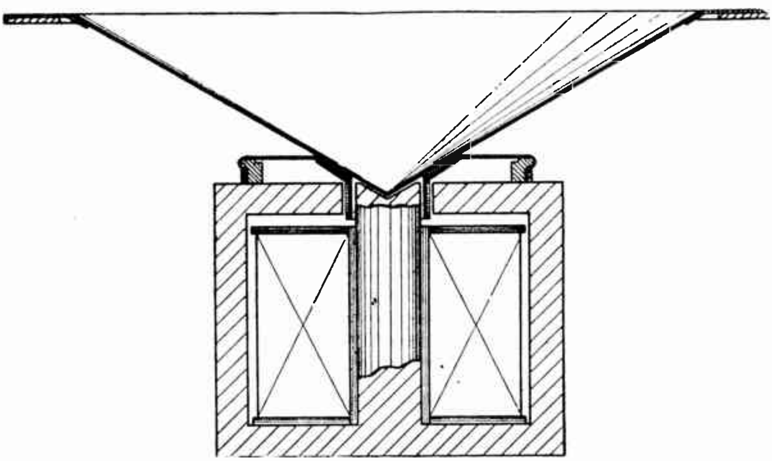


Fig. 25—Another type of power cone.

and the field coil is connected directly across the rectified output. A condenser of 2 or 4 microfarads can be used across the field coil to filter the ripple. Absolute rectification is not necessary in a field coil winding, as quite a large A. C. ripple can be tolerated before it is noticed as a hum in the voice coil. Satisfactory dry metallic plate rectifiers such as the Westinghouse, Kuprox or Elkon dry rectifiers are designed for 6 to 7½ volts one ampere output for dynamic speaker field excitation. Some of these dry rectifiers are designed for much higher voltages, such as 60-100 volts, with 50 to 100 milliamperes output.

ELECTRICAL DATA AND ACOUSTIC MEASUREMENTS

In designing loud speakers it is important that the characteristics of the speaker will fit the condition of the vacuum tubes with which it is to be worked.

The resistance or impedance between the filament and plate elements of vacuum tube power tubes vary from 1800 to 4000 ohms. In order to obtain the maximum power in a loud speaker device, the speaker must be designed to have an impedance to match that of the power tube.

The reason for this is due entirely to a standard electrical rule, such as used when dealing with direct current circuits to get maximum power (watts) output.

The current which will flow in the circuit can be obtained by dividing the voltage of the battery or generator by the resistance of the whole circuit (internal and external added together).

The power in the external circuit will be given by multiplying the voltage drop (the fall of potential caused by the resistance through which the current is flowing) across the external resistance by the current that flows.

The voltage drop across the external resistance is given by multiplying its resistance by the current that flows through it. For example: If we have a 12-volt battery with a **constant internal resistance** of 1 ohm, and a variable resistance, forming an outside circuit, suppose this resistance in the outside circuit is .5 ohm

$$I = \frac{E}{R} = \frac{12}{1 + .5} = \frac{12}{1.5} = 8 \text{ Amperes}$$

Voltage drop $= 8 \times .5 = 4$
Power Output $= 4 \times 8 = 32$ watts

If the external resistance is changed to 1 ohm then we have:

$$I = \frac{E}{R} = \frac{12}{1 + 1} = \frac{12}{2} = 6 \text{ Amperes}$$

Voltage drop $= 6 \times 1 = 6$
Power Output $= 6 \times 6 = 36$ watts

Again if the external resistance is changed to 2 ohms, then we have:

$$I = \frac{E}{R} = \frac{12}{1 + 2} = \frac{12}{3} = 4 \text{ Amperes}$$

Voltage drop $= 4 \times 2 = 8$
Power Output $= 8 \times 4 = 32$ watts

From this it can be seen that a battery gives the most output in watts when the load resistance has the same value as the internal resistance because when the load resistance is lower the current rises and the voltage drops off, and when the external resistance is higher than the internal resistance the current drops

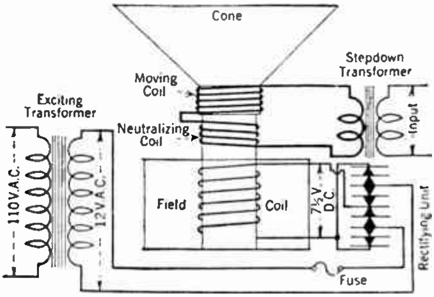


Fig. 26—Circuit diagram of Dynamic Speaker showing connections to moving coil and output transformer, also to field coil from rectifier unit.

off and the voltage rises, therefore the power output is maximum when internal and external resistances are equal or matched.

This same rule applies to a vacuum tube circuit. The difference in impedance between tubes and loud speakers can be taken care of by means of a coupling device (output trans-

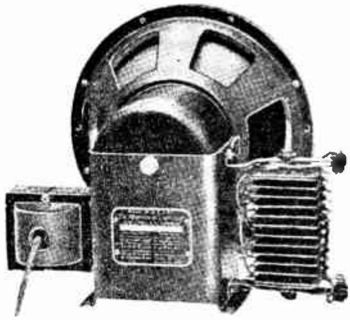


Fig. 26(a)—Rear view of dynamic speaker showing output transformer. and rectifier unit.

former). When this plan is resorted to, it is necessary for the impedance of the transformer primary to approximately match that of the tube. The secondary of this output transformer should have an impedance similar to that of the loud speaker. In this way, it becomes possible to use a low impedance speaker with a high impedance tube, although it is not particularly advisable since the high impedance tubes are not capable of handling any great amount of power and will very likely overload, if they are used to supply certain loud speakers.

Since the plate resistances of various tubes differ especially under different conditions of operation, it is important that the plate resistance characteristics of the tube under the conditions with which it is operated be known, before it is possible to recommend a loud speaker or coupling system that will give best results with a given output tube.

The A. C. plate resistance of the various popular power output tubes under different conditions of operation, are given in Table No. 1.

The figures in the plate resistance column show that the

TABLE NO. 1

Tube Type	Plate Voltage	Grid Bias Voltage	A. C. Plate Resistance
—01A	90	4.5	11,000
	135	9.0	10,000
—12A	135	9.0	5,000
	157.5	10.5	4,700
—71A	90	16.5	2,500
	135	27.0	2,200
	180	40.5	2,000
—10	250	18.0	6,000
	350	27.0	5,150
	425	35.0	5,000
—45	180	33.0	1,950
	250	50.0	1,900
—50	250	46.0	2,100
	350	63.0	1,900
	450	84.0	1,800

characteristics of the —71A tube, when operated at 180 volts plate voltage and 40.5 volts grid bias are very similar to those of the —45 and the —50 tubes. Practically the same loud speaker and coupling means can therefore be used for all three of these tubes, provided that the loud speaker and coupling means are capable of handling the power output and the plate current of the tube with which they are used. The —12A and the —10 tubes, however, would require a loud speaker and coupling combination of different characteristics while the speaker and coupling required by the —01A tube would be still different.

The usual type of magnetic speaker has a coil winding having a D. C. resistance of from 1,000 to 2,000 ohms with an impedance which varies from that value at zero frequency (D. C. current flowing through the winding) up to 30,000 to 40,000 ohms at the higher frequencies up to 5,000 cycles per second. These

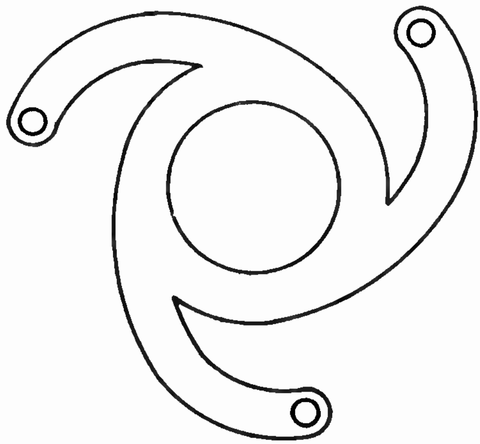


Fig. 27—A 3-point suspension for positioning the voice coil on a power cone unit.

high values of impedance for this type of loud speaker unit are due to the comparatively high inductance of the winding which is made up of a large number of turns.

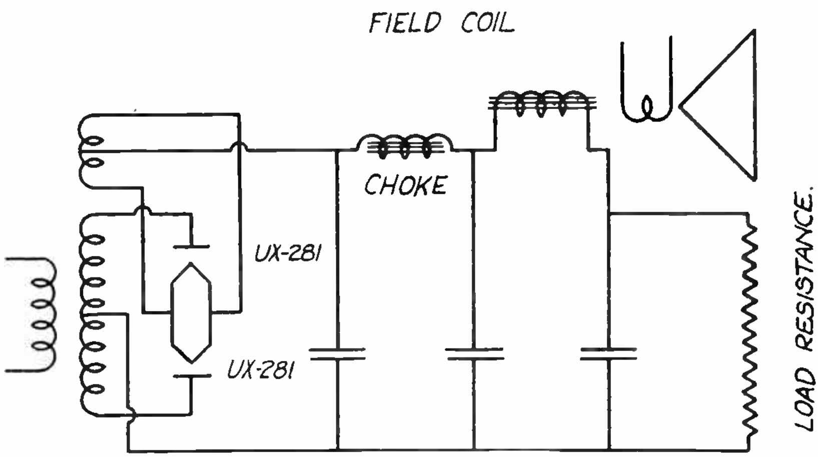


Fig. 28—A standard electrical rectifying filter circuit with the field coil of a dynamic speaker shown as the second reactance coil in the second section of the filter.

In the dynamic speaker, however, the voice coil is wound with as few turns as possible to keep the weight of the moving coil very low and to prevent excessive inertia of the moving system. The small number of turns results in a practically constant load impedance over a wide range of frequencies.

In the usual types of dynamic speakers, the impedance of the moving coil may vary from approximately 6 ohms at 100 cycles to not higher than 30 ohms at 5,000 cycles.

In some dynamic speakers, the impedance of the voice coil is much less.

These facts should be kept in mind since they have an important bearing when matching the characteristics of loud speakers to the characteristics of the output tubes.

When a loud speaker is properly designed and its characteristics match the tube it is going to be used with, it is not difficult to measure its performance. The procedure is to hang a

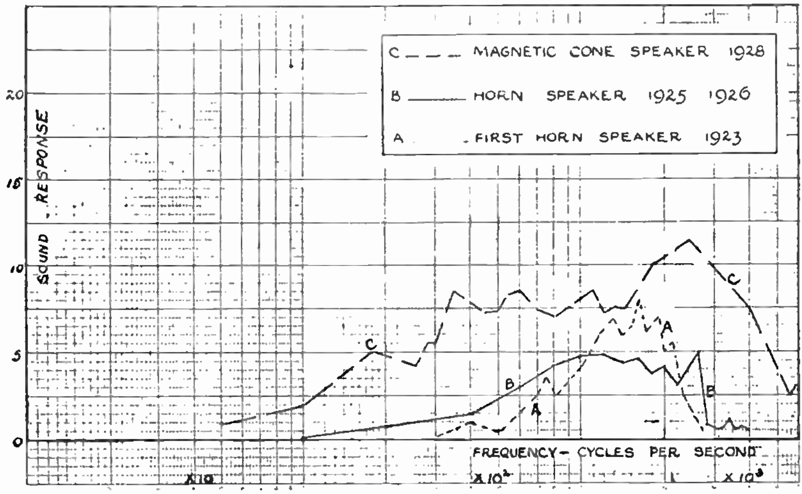


Fig. 29—Graph showing some actual sound curves taken using different types of loud speaker units.

calibrated microphone in front of the speaker which is actuated by various tones of known amplitudes from an oscillator. The output of the microphone is amplified and measured, and thus curves of output versus frequency may be obtained.

Fig. 29 shows some actual sound curves taken. A is the range of one of the first horn-type units; B is one of the latest horn-type speakers and C a cone-type speaker. Note how the range of speaker B is improved over speaker A and how speaker C is greatly superior to speaker B, indicating particularly the increase at the higher frequencies, due to the limitation of the diaphragm in B.

Loud speaker sound curves show the sound output of speakers over a complete frequency range and they always have bad peaks and valleys due to electrical and mechanical resonances, acoustic reflections and other irregularities. By sound measurements, these irregularities can be readily studied, improved and the range of the speaker extended.

TEST QUESTIONS

Number your Answer Sheet No. 14-3 and add your
Student Number

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What two types of telephone units were employed in radio telephone headsets?

2. What two factors governed the movement of the armature or diaphragm in a telephone headset?

3. How was the first horn-type loud speaker constructed?

4. Name three important types of units used with horn-type speakers.

5. How were cone diaphragms first employed?

6. What is the importance of the Baffle Board?

7. What type of speaker is generally used today to obtain quality with large volume?

8. How many ways can the voltage for the field excitation of a dynamic speaker be obtained?

9. Draw a diagram showing connections to the moving coil, also field coil of a dynamic speaker.

10. What are "sound curves"?

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RECEIVING ANTENNAS AND THEIR INSTALLATION

Originators of Radio Home Study Courses
··· Established 1914 ···
Washington, D. C.

"To the intelligent mind there is no such thing as fatality or luck; such puerile beliefs are the refuge of weak and ignorant souls."

SOME GOOD STUDY HABITS

A Personal Message from J. E. Smith

Decision. Some students are continually deciding to work but never get around to it; others do not even get as far as making a decision. "There is no more miserable human being," says James, "than one in whom nothing is habitual but indecision, and for whom the lighting of every cigar, the drinking of every cup, the time of rising and going to bed every day, and the beginning of every bit of work, are subjects of express volitional deliberation. Full half the time of such a man goes to the deciding or regretting of matters which ought to be so ingrained in him as practically not to exist for his consciousness at all. If there be such daily duties not yet ingrained in any one of my students, let him begin this very hour to set the matter right."

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RECEIVING ANTENNAS AND THEIR INSTALLATION

The results obtained from a Radio receiver depend to a very large extent on the antenna and ground of the receiving set. Without the proper antenna and ground, the receiving set cannot function properly. A good many people give little or no thought to the antenna. They construct or purchase an expensive receiving set and provide a poor antenna.

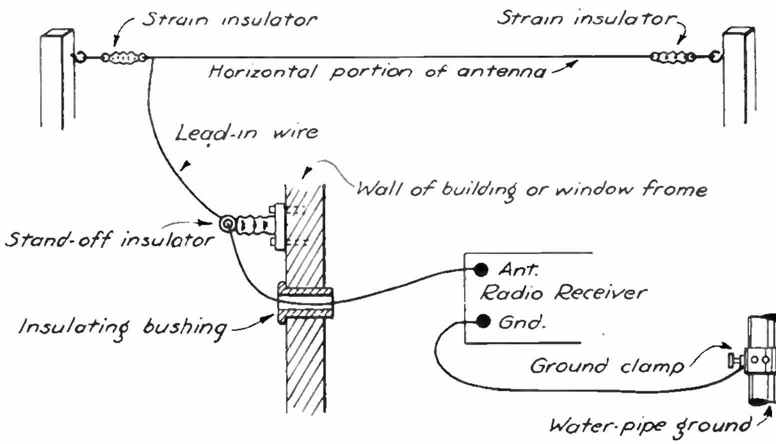


Fig. 1—Inverted L type antenna.

FUNCTION OF THE ANTENNA

It should be understood that the function of the antenna is to intercept and absorb energy from passing electromagnetic waves and to deliver this energy through the antenna lead-in wire to the receiving set.

Any reinforced steel buildings, smoke stacks, metal roofs, gutters, rain pipes, telephone and power lines, etc., in close proximity to the antenna tend to shield it from the Radio waves. It is, therefore, advisable that the site selected for the erection of the antenna be free from these obstructions.

From a general observation of the large net-work of wires strung high in the air on steel towers employed by the numerous

Broadcasting Stations, many persons gain the idea that it is necessary for a receiving set to have an elaborate antenna of several wires.

This is an error since a single wire of the proper length is far more efficient and better adapted to the reception of broadcast programs. Many of the best long-distance receiving sets use but a single wire antenna.

Antennas may be divided into two general classes, according to whether they are located outside the building or indoors. The former are unquestionably better from a technical point of view, but modern living conditions in the cities do not always permit outdoor installation, and a large percentage of Radio set owners will soon lose interest unless they can regard their set as a musical instrument to be moved about at will or capable of being used on different premises without further preparation.

Fig. 2—Two-wire T type antenna.

The tendency of manufacturers, therefore, is to produce self-contained sets that will fulfill these conditions, if necessary, making up for inefficient aerials by additional amplification. Some very excellent results are being obtained in this manner, especially in big cities. In the country at greater distances from the Broadcasting Stations, the objections to outdoor aerials are not so apt to prevail.

TYPES OF ANTENNAS

Receiving antennas may be subdivided into three groups—outside, inside, and coil or loop antennas.

While the past years have seen many styles of receiving antennas grow in favor, the old style outside antenna still holds its own. The inverted L and the T are the most common forms of outside antennas.

The inverted L aerial or antenna gets its name from its shape. See Figure 1. This type of aerial is widely used and gives very good results, though it has one defect, its directional properties. This defect is sometimes used to advantage. It receives strongest signals when its closed end, the end to which the lead-in is connected, is pointing towards the transmitting station.

The T type aerial is the same in construction as the inverted L, except that the lead-in wire is taken from the center instead of from one end. The T aerial, as its name implies, is T shaped. See Figure 2. This type of aerial is free from the directional properties of the inverted L type. It receives signals from any direction with equal ease.

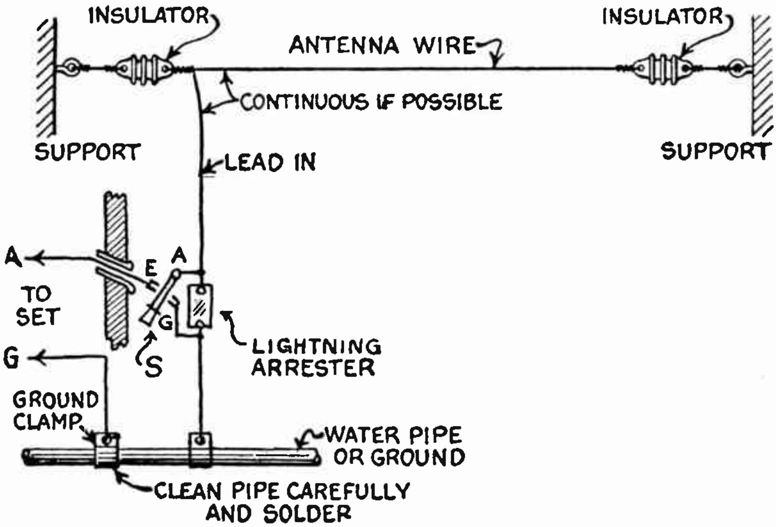


Fig. 3—Showing aerial insulation, location of lightning arrester, switch (S) for direct grounding during a storm and method of ground connections.

The two main important points in connection with the erection of an aerial are that it be properly insulated, and that it should not be surrounded by objects such as buildings, trees, and other aerials. An insulator should be placed at every point where the aerial wire touches a support. There is no exception to this rule.

A good aerial for broadcast reception may be made by stringing a copper wire about 100 ft. long between two points as illustrated in Figure 3. The lead-in wire should not be over 25 ft. in length. A good inverted L or a T type aerial may consist of three or four wires fastened three or four feet apart to a spreader. It may be from 25 to 60 ft. high and 50 to 75 ft. long. The lead-in wires may taper to a point where the lead-in enters the building.

No matter what type of antenna is used, certain precautions must be taken. If you don't insulate properly, you are bound to fail. Figure 3 illustrates the proper method of insulating an aerial, attaching the lightning arrester and bringing the lead-in through the wall.

Figures 5 and 6 illustrate the installation of a Ball Antenna. The Ball is made of a non-corroding aluminum alloy, approximately 10″ in diameter. It has a conductive surface of approxi-

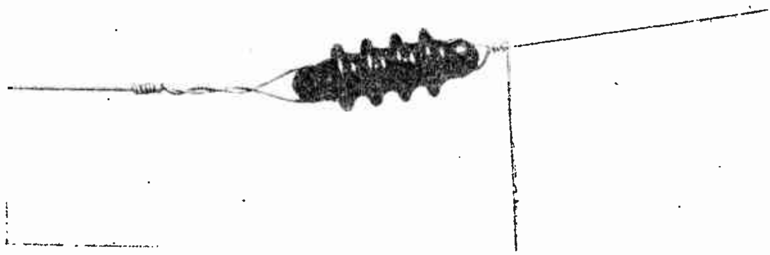


Fig. 4—Illustrates how to fasten one end of the aerial to the supporting insulator and bring off the lead-in wire without cutting it. This prevents a loose or soldered joint.

mately 346 square inches, equal to that of a 75 ft. wire aerial. Its capacity is (bunched) centered in one spot. Three 12 ft. guy wires are connected directly to the Ball and insulated from the roof of the house. The Ball rests on a condenser consisting of two plates, parallel to each other and separated by a ¼″ of non-conductive material (renolite). The upper plate is connected

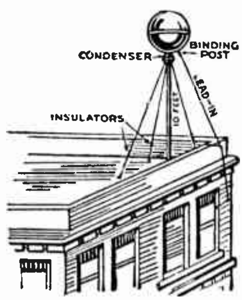


Fig. 5—Ball antenna installed on apartment house or office building.

Fig. 6—Ball antenna installed on suburban home.

directly to the Ball and also to the guy wires, these wires being effectively insulated from the roof at the lower end. The guy wires act as a supplementary energy collector, feeding Radio energy to the Ball, where it is conveyed through the lead-in wire to the receiver. The lower condenser plate, being connected directly to the steel pole on which the Ball is mounted, acts as a ground for the entire antenna system.

Ball antennas may be placed as close as 10 ft. apart and still give good reception. This means, for instance, that a considerable number of Ball antennas can be placed on an apartment building without interfering with each other, or on your own premises without reaching out to your neighbors. This type of antenna is easily installed and having the same amount of conductive surface exposed in all directions, the same amount of energy is delivered from all directions. It also rejects a large part of the interference which long aerial wires collect.

UNDERGROUND AERIALS

Dr. James Harris Rogers, whose laboratory at Hyattsville, Md., was the scene of much Radio Engineering research during the World War, is the inventor of the underground and under-

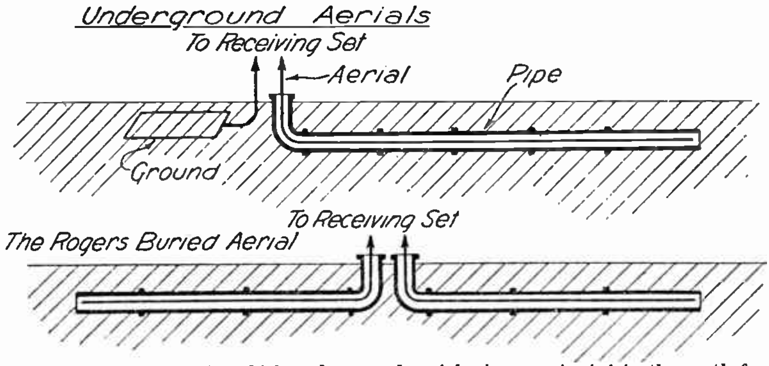


Fig. 7—Showing method by which underground aerial wires are buried in the earth for receiving Radio signals.

water antenna. Some of the trenches which Dr. Rogers had arranged to receive his underground antenna ran for several thousand feet in certain geographical directions. In some cases, these trenches crossed streets, and other people's property. Speaking of the geographical direction of an underground aerial with respect to the maximum response from a given station, it should be noted that when a lead sheathed insulated copper wire, for instance, is buried in a straight line in a trench 2 ft. deep and perhaps 100 ft. long, the maximum reception is in the direction in which the aerial points. If the aerial used in a given instance runs east and west, then the direction of the maximum Radio reception lies in this line.

In Figure 8 we have illustrated how an underground antenna can be arranged with minimum of labor, by simply winding the lead sheathed insulated antenna in several spirals, each spiral being covered with a layer of soil, and the whole finally filled up with soil, and kept moistened if necessary. Figure 7 shows the most desirable form of underground antenna, where the sheathed insulated wire runs in a straight line in a trench. The spiral antenna, sometimes called sub-antenna, may be used under water as well as under ground. See Figure 9.

The advantage of using an underground aerial is that it enables a transmitted signal to be received without interference and reduces to a considerable extent the interference caused by static.

One of the most important points to be remembered, if you are going to install one of these underground aerials, is that you will not reap the full benefits of static reduction unless you

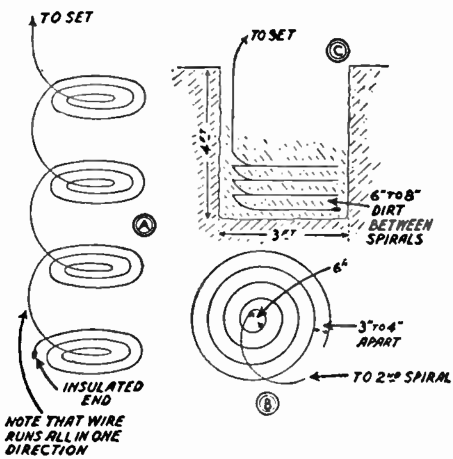


Fig. 8—The illustration above shows how an underground antenna can be made with a minimum of labor.—Illustration Courtesy Cloverleaf Mfg. Co.

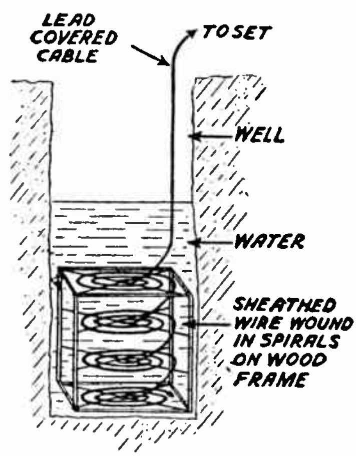


Fig. 9—The spiral antenna may be used under water as well as under ground. Above we see an antenna installed in an old well.

use a shielded set. If your receiving set does not already have shielded condensers and coils, the set can be shielded by placing aluminum or copper shielding all around the inside cabinet and then grounding this metal lining of the cabinet. It is also important to remember that the lead sheathed cable must extend up to the set, and that the ground wire must be a piece of lead sheathed cable.

INSIDE ANTENNAS

An inside antenna using a wire running up to and around the picture molding is shown in Figure 10. Small pins or staples can be used to hold this wire concealed in the grooves in the picture molding. This type of antenna can be carried along the picture molding to the diagonal opposite corner of the room, or carried completely around the four sides of the room. Never allow excess length of antenna or other external wiring to be stored inside the receiving cabinet. Always have these wires run straight from the binding posts to the holes in the rear of the cabinet. Avoid running the antenna wire close to other electric wires or close to metal electric lighting fixtures as losses in signal strength or the introduction of interfering noises may result. The type of wire for connecting the ground binding

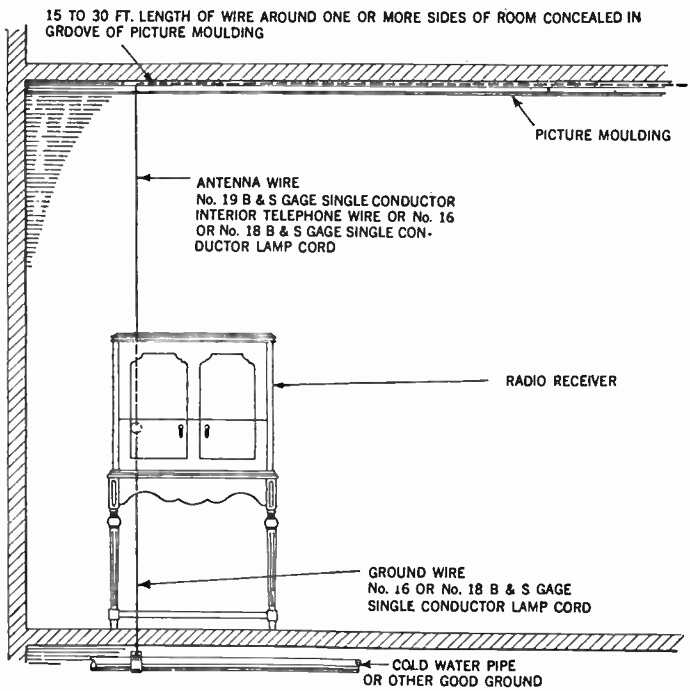


Fig. 10—Picture moulding antenna. Used when the room is not shielded by metal framework or metal lathing.

post of the receiver to the nearest cold water pipe can be the same as that used for the picture molding antenna. Use a good ground clamp for attaching this ground wire to the water pipe, and be sure to scrape all zinc, enamel or rust from the pipe before attaching the clamp. Any joints in the antenna or ground wires should be soldered if possible, thus insuring a permanent job.

Where the roof of a building is not covered with metal work, an antenna can be installed in the attic, using two parallel horizontal wires, between 25 and 40 ft. long, spaced about 2 ft. apart, as illustrated in Figure 11. Porcelain knobs can be used at each end of these horizontal antenna wires for support, care being taken that these wires do not come close to metal pipes or electric light wires. The ends of these two horizontal wires, directly above the place where the Radio receiver is to be installed, should be connected together with a piece of No. 18 B & S gauge interior telephone wire, or other rubber covered and braided wire, and this wire carried directly down to the receiving set. All joints in the wire should be soldered for permanency. A neat installation of this type of antenna can be made by carrying the wire down through the walls and thus be completely concealed. In no case should the wire be run through a metal pipe or metal conduit; a wall receptacle and an attachment plug can be used where this antenna connecting wire comes through the wall to the room in which the receiver is located. The Radio receiver should be placed as close to the point where this antenna connecting wire enters the room as convenient. The ground connection from the ground binding post to the receiver should be made to the nearest cold water pipe or other grounded metal part of the building.

USING THE ELECTRIC LIGHT WIRE AS AN AERIAL

There are several plugs on the market which may be screwed into electric light sockets using the house wiring for an aerial. These plugs are made of an ordinary condenser with mica dielectric and are in series with the house wiring. In this case we use only one wire of the line, the other line remaining idle as far as Radio reception is concerned.

The object of the condenser is to prevent the grounding of the current flowing in the line without opposing the passage of the high-frequency Radio current through the condenser to the receiving set.

Desirable qualities in a metal to be used for antenna wire are that it should not be brittle, that it should be durable when exposed to weather and other conditions, that its weight should not be excessive, that its cost should be reasonable, and that its ohmic resistance should be low. It is important that a metal used for antenna wire should possess high tensile strength; this is obviously more important for large antennas of long span.

Radio impulses in the antenna travel almost wholly on the surface of the wire and the inside of the wire might just as well be hollow. A great majority of antennas are found covered with corrosion. This corrosion is formed by the combination of oxygen in the air with the copper wire and, unlike a covering of enamel or other properly applied insulation, the corrosion becomes part of the wire itself; in other words, the outside of the antenna is no longer copper but is copper oxide. Copper is the best of all conductors for radio impulses but copper oxide is very poor. Since radio impulses travel on the surface of the wire, if this surface is composed of high resistance copper oxide, such an antenna has lost much of its effectiveness as a conductor of energy.

Bare uninsulated wires are in general use. In some cases the antenna wire is covered with a thin coating of enamel; this

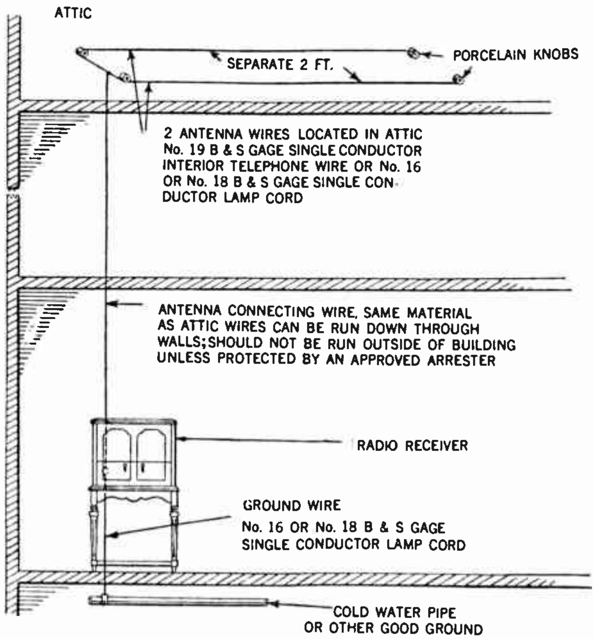


Fig. 11—Attic antenna. Used where the roof of the building is not covered with metal work.

helps to eliminate corrosion of the wire which is exposed to the weather, smoke, or acids and other fumes.

Solid copper or other conductors, of a size such as No. 14, are often used. Stranded conductors, however, have advantages, including flexibility, and lower resistance at higher frequencies than solid conductors, because of the skin effect. In the stranded conductor, for a given weight of copper, there is much more cross-section area available for carrying the current than there is in the solid conductor. The individual strands, however, should always be enameled in stranded wire used for Radio-frequency currents, or the stranded conductor may have a higher resistance than a solid conductor of the same size.

An antenna conductor composed of seven or more strands of carefully enameled No. 22 copper wire is usually found to give good satisfaction. Antennas of unenameled solid conductors which are very satisfactory on the day they are installed, often show a very considerable increase of resistance after exposure to the weather for even a week.

INDOOR AERIAL

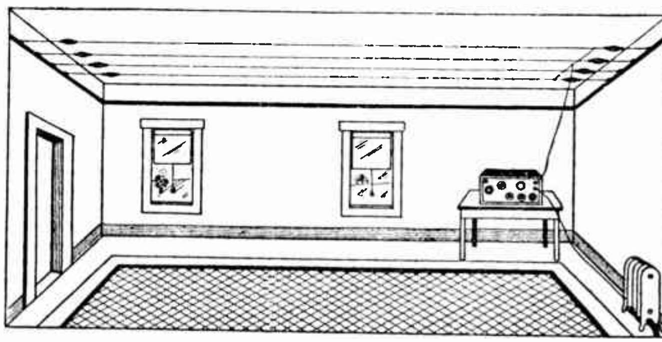


Fig. 12—Method of installing an inside aerial. This illustrates a four-wire inverted L type, although a single wire run around the molding will give satisfactory results for local reception.

Phosphor bronze stranded wire of 7 or more strands is sometimes used. It has a high tensile strength, but is open to the objection that it is relatively very expensive. Phosphor bronze wire corrodes easily when exposed to weather, and when corroded is very likely to have a high resistance. A silicon bronze wire is now being used to some extent, which does not corrode easily, has comparatively low ohmic resistance, high tensile strength,

Fig. 13—Types of aerial plugs which fit into electric light sockets for Radio reception.

and has been found very satisfactory. For many ordinary antennas, hard-drawn solid copper wire, carefully enameled, will be found most convenient and will give satisfaction.

THE GROUND CONNECTION

The necessity for a ground has been discussed in the earlier part of this text-book. The efficiency of the set as a whole is greatly dependent upon the efficiency of the ground connection. Sometimes it is possible to increase the volume of a receiver by improving the ground connection.

There are various ways of making a ground connection and the method employed will depend on the location of the receiving apparatus. In general, it is best to have the ground

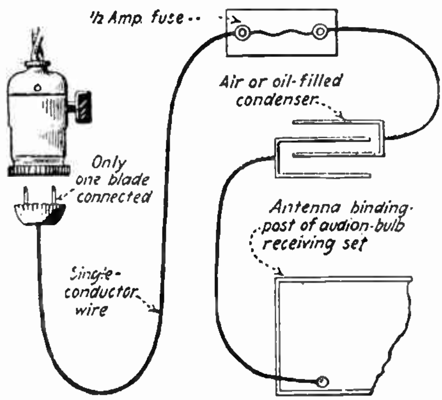


Fig. 14—Method of using house wiring for aerial.

leads as short as possible. Avoid long bended wires leading from the receiver to the ground connection. If in the city, the best ground connection is made by connecting directly to the water pipes. A special ground clamp which can be purchased at

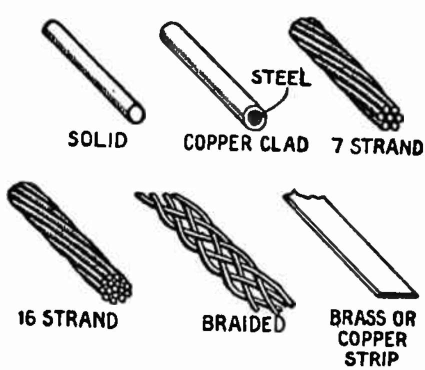


Fig. 15—Various types of wire which can be used for aerial construction.

any Electrical or Radio Supply Store should be used. The water pipe should be carefully cleaned with sandpaper, making sure that all rust and other dirt are removed so that the clamp can make a good connection. The wire leading to the receiver should be soldered to the ground clamp to insure good contact. If no water pipe is available, the gas or radiator piping system can be used. In the country, where no water pipe is available, a good ground connection may be made by burying about 100 square feet of chicken fence wire about 10 feet in the earth and soldering the lead wire to it. In making this sort of ground, moist ground should be chosen. Dry or rocky soil will not serve the purpose.

It is sometimes the practice to fill in the hole which has been dug for the ground with charcoal to aid in keeping the particular piece of ground moist, and to improve the connection between the fence wire and the earth. If fence wire is not available, any kind of sheet metal will serve the purpose.

COUNTERPOISE

In sections where it is not possible to make a ground as described previously, a counterpoise may be used instead. A counterpoise takes the place of a ground and consists of a network of wires laid out similar to the aerial but insulated from the ground. The wires of the counterpoise may be stretched out

Fig. 16—Picture of typical ground clamp.

radially from the center where the receiver is located. In area, the counterpoise should cover about 50% more ground than the aerial system.

Theoretically, the counterpoise is one plate of a huge condenser of which the aerial is the other plate. This huge condenser constitutes the distributed capacitance of the open oscillatory system. A counterpoise is used where the ground itself is rocky in nature and where the earth is especially dry and sandy. In Figure 17, we have illustrated a simple counterpoise. It is best to build it 8 or 10 feet above the ground, so as to clear any obstruction that might damage it or be damaged by it. Many times when an antenna is placed over a tin roof, the tin roof is used as a counterpoise, provided it is not grounded.

ANTENNA SWITCH

A lightning switch is not always sufficient protection because when a receiving set is connected to an antenna through a switch, lightning has free access to the inside of the house. Therefore, a lightning arrester is necessary to give double protection. The lightning arrester is automatic so at no time can one forget to turn off the lightning switch and thus lose protection, as the lightning arrester substitutes for the switch at all times. See Figure 3 which illustrates the installation of an Antenna Switch and Lightning Arrester.

Lightning arresters are divided into three groups—the air-gap, non-air-gap and vacuum.

In the air-gap type, the lightning arrester consists of two brass electrodes separated a distance of approximately .004 of an inch; at a pressure of 500 volts, this air-gap breaks down and permits the discharge to leak to the ground. The non-air-gap type consists of a block of carborundum held between two pieces of carbon of a high resistance.

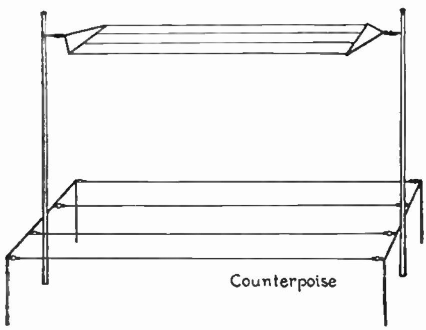


Fig. 17—Simple type of counterpoise.

The vacuum type of lightning arrester has two fine wires sealed in a glass tube and separated so that the gap will break down at a potential of 500 volts. A sectional view of a vacuum type of lightning arrester is shown in Figure 18. The outside appearance and how it is connected to an antenna is shown in Figure 19.

LEAD-IN WIRE

Bringing the lead-in wire from outdoors to the set is often a problem to the set owner. A specially designed lead-in connector is sold which is a piece of copper strip heavily insulated, fitted with connectors on both ends, which fits on the window sill and makes the drilling of a hole unnecessary. This type of lead-in connector is not approved by the Underwriters and is used at the owner's risk. A lead-in to comply with the regulations may come through an insulated tube inserted in a hole which has been drilled in the window sill. This tube should be preferably of porcelain and the wire passing through it must fit loosely and not be tight or binding in any way.

SPREADERS

A spreader is used when more than one wire goes to make up the aerial. A spreader may be made of bamboo or strong wood. The length of the spreader depends upon the number of wires and the length of the aerial.

GUY WIRES

When guy wires are used to support a mast or to prevent spreaders from swaying, they should be broken up by means of insulators into short electrical lengths of not more than 25 ft. This prevents the guys from absorbing too much of the radio waves surrounding the aerial. For small equipment, it is best to

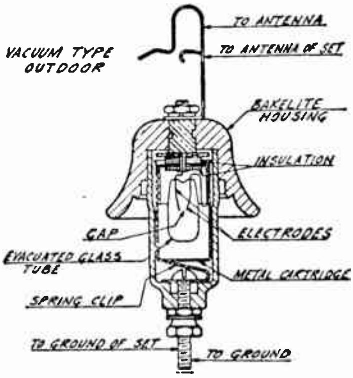


Fig. 18—A sectional view of a vacuum type of lightning arrester.

use a strong tarred rope instead of wire for guying purposes. Rope, being a non-conductor, absorbs no energy from the aerial. When a rope is employed, it is well to use insulators as carbon will gather on the surface of the rope and in wet weather may provide a leakage path to the ground.

The sketches shown in Figures 20 to 24 illustrate different methods of installing various types of aerials on different buildings, and give suggestions which you may individually adapt to your own requirements. In Figure 20, we have a frame dwelling of the average size, but without facilities about the house for fastening the antenna either to a tree, clothes pole, or garage, etc. A short, stout mast is erected at the front and back of the ridge extending perhaps 6 or 8 feet above the roof. If of sufficient diameter, these will not require guys, and are supported instead by metal clamps fastened to the edge of the roof, as illustrated. To keep the lead-in wire away from the wall, a stick is fastened beneath an upstairs window or under the edge of the roof as a prop. An insulator is fastened on the end of this prop to hold the lead-in wire firm and keep it away from the wood prop.

In Figure 21, we show a house with a good high tree close by. The problem of installing an antenna in this case is perhaps more simple, although some ingenuity will be called for in fastening the pole to the tree. Plenty of room is allowed between the insulator and the tree, however, a weight is used to keep the aerial tight under all wind conditions.

In Figure 22, we have a house and a garage. Such locations are usually in the suburbs, where an outside antenna functions well when it is lower down than would suffice for the city. If

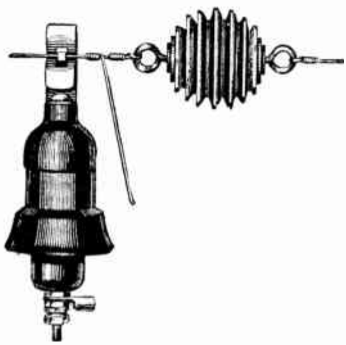


Fig. 19—Vacuum type of lightning arrester connected to antenna. (Note sectional view of Fig. 18.)

there is no room behind the garage for guying, the pole may be placed in the center of the roof and guyed in three directions as illustrated. On the city apartment house, where a good clothes pole is available, a short topmast may be attached as shown in Figure 23. It is well to fasten this extra mast to the pole with a couple of heavy clamps, having nuts and bolts. The topmast may be 8 or 10 ft. long, if it is strong enough to withstand considerable pull from the aerial without bending.

The installation shown in Figure 24 is a very fine arrangement, but unfortunately one which cannot always be obtained. Here two iron pipes are used as already outlined, guyed securely, and the lead-in wire kept away from the wall by an extra prop at the edge of the roof. The dimensions given in these figures are merely suggestions. The illustrations shown in Figures 25, 26 and 27 show how antennas can be placed on house-boats or cabin cruisers. The problem of an antenna on crafts of this nature is easily solved. There is always a tall mast on these boats and this may be well used as the high point of the installation. From the mast-head, a flat top or cage aerial may extend both forward and aft to the jack and flagstaff, respectively, with the lead-in coming from the end nearest to the location of the apparatus. Figure 25 shows the typical aerial installation on a popular make of cabin cruiser; two other methods of installing antennas on different types of boats are shown in Figure 26. It is very difficult to install an aerial on the yawl, because of the limited space, therefore, a cage type of antenna is best.

Fig. 20—How to install an aerial for the suburban home which will not be considered detrimental in point of appearance.

The greatest care should be taken in insulating the shipboard aerial. No part of it must touch the vessel. No part of it should be left free to swing or sag against any of the standing or running rigging. This rule of perfect installation is inflexible where antennas are concerned, but it must be remembered that when the yacht is wet either from heavy seas or rain, it is practically grounded. A ground connection is provided by running a wire from the set to a beam or plate in the vessel, providing that this beam or plate is of metal and connects to the hull, also of metal. If all these should be of wood, a ground connection may be made by screwing an unpainted strip of copper sheeting on either side of the outer hull just above the keel. This strip should be about 1 ft. wide and 4 or 5 ft. long. Copper is recommended because of its non-corrosive properties. Some vessels are copper sheathed just below the water line. This sheathing is an ideal Radio ground. The antenna ground installation on

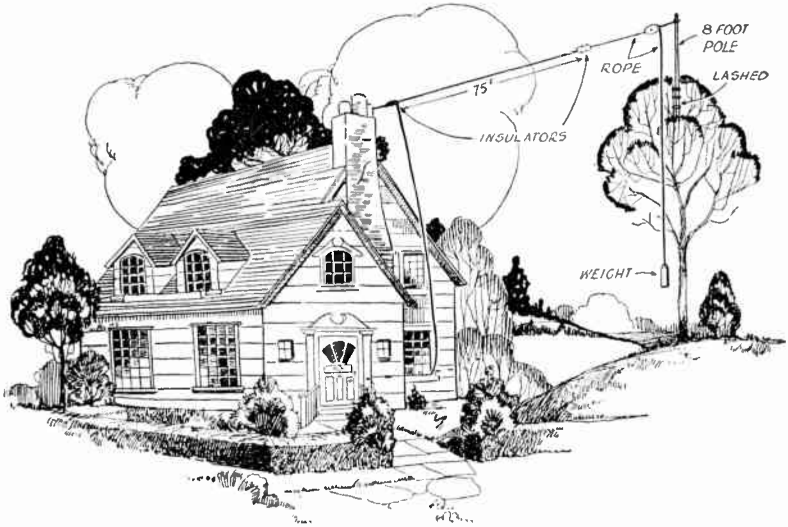


Fig. 21—Method of attaching an aerial to a tree. The weight at the end of rope allows the tree to sway without any danger of breaking the aerial wire.

a small boat is not complete without a lightning arrester shunted across the aerial and ground terminals of the set. If a switch is

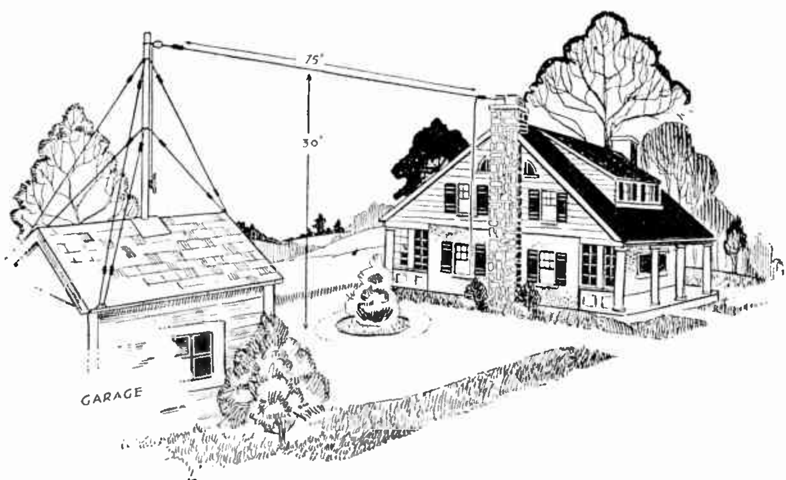


Fig. 22—Showing how to install an aerial pole on the garage or barn and method of guying firmly.

used, the one employed should be of a single pole single throw type and should be connected as shown in Figure 27. In this diagram, the switch may be replaced by an arrester gap, the only difference being that the gap is automatic. It will be noticed in this figure that the same ground is used both for the gap and the receiver. This is contrary to house practice, but on a boat there are neither legal nor technical objections to such an arrangement.

THE COIL OR LOOP AERIAL

Where it is difficult to erect an outdoor aerial or where a portable aerial is desirable, the loop aerial serves the purpose. It is, however, necessary that several stages of amplification be provided. The loop works best on such a set as a Super-heterodyne. The loop aerial has marked directional characteristics. By this is meant that the intensity of the received signals will depend upon the position of the loop and for this reason the loop is valuable in reducing interference. The fundamental wave-length of a loop depends on the size and number of turns of wire mounted on the frame.

Generally, the signal intensity delivered to a Radio set by a coil antenna is much lower than that delivered by an outside antenna even though the dimensions of the coil antenna may be relatively high. For instance, a single wire outside antenna approximately 30 feet high and 50 or 60 feet long will deliver to a receiving set more than 6 times the voltage that a coil antenna will.

Two forms of loops are in common use—the box or single layer square type, Figure 29 (A) and the spiral or flat square type, Figure 29(B). The spiral loop is the simplest and cheapest to construct, but is less desirable since the inner turns rapidly become less useful as the area diminishes. In simple language, the theory underlying the design and action of such a loop or coil antenna is as follows:

In the first place, the ordinary antenna, whether indoors or outdoors, acts primarily as a condenser. The earth or ground connection constitutes one plate and the wire or wires of the antenna the other plate. On the other hand, the loop must be considered principally an inductance, consisting usually of one or more turns of wire, spiral or box form, and tuned by the aid of a variable condenser connected across its terminals.

Experimenters have, perhaps, noted in many cases, the ability to pick up local and sometimes distant stations with an outside antenna or ground entirely disconnected. The coils and wiring of the receiving set in this case act similarly to a coil antenna or loop.

Perhaps the best method of explaining the theory of the loop would be to picture two vertical wires of the same length

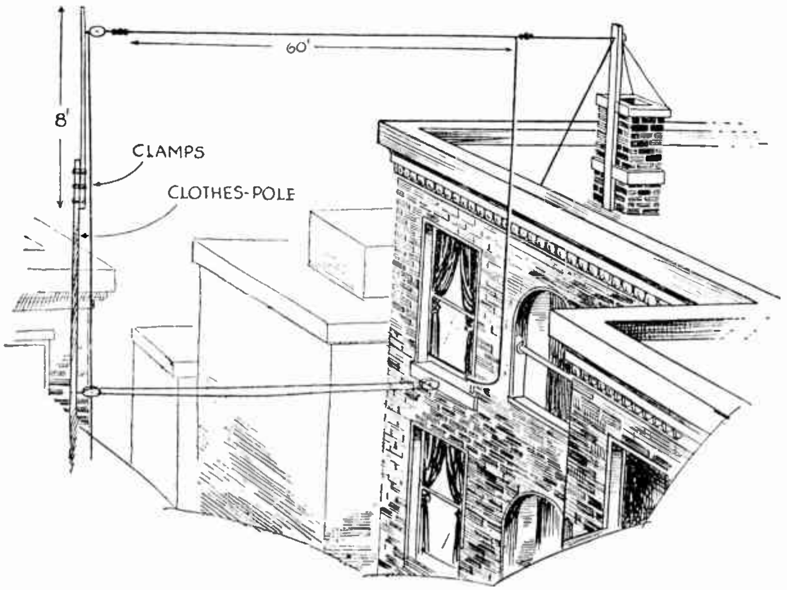


Fig. 23—Method of bringing your aerial up on an even keel by using a topmast clamped to the clothes pole.

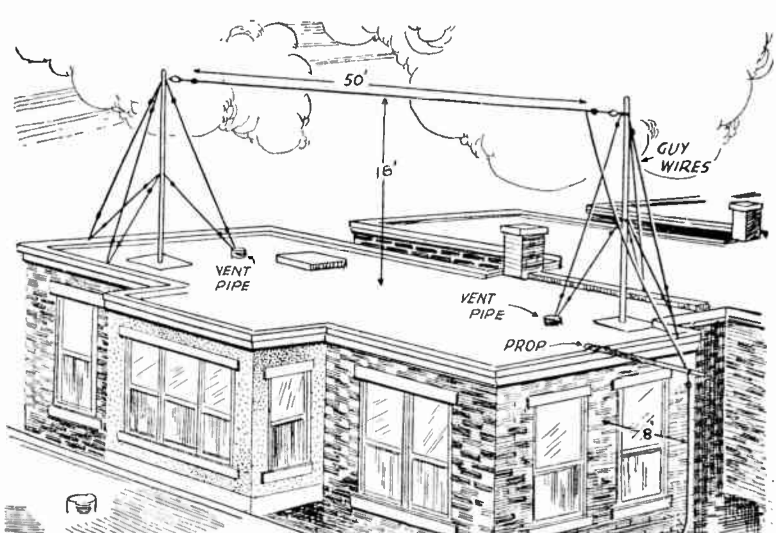


Fig. 24—How to install an aerial on an apartment house, showing two strong iron pipes secured with two sets of guy wires and a special prop for bringing the lead-in wire to set so it does not touch the roof or wall.

entirely insulated and placed 200 meters apart. Radio waves approaching at right angles and in the same plane to the wires will first cut one wire and then the other. A 400-meter wave will induce an E. M. F. and current flows in the second vertical wire just 180 degrees out of phase with that set up in the first, for the crest of one wave will cut wire 1/750,000th of a second before it will cut the other. The 400-meter wave would require one and one-half millionths of a second to travel the distance from 200 meters between the wires, or one-half the time required for the wave to pass a given point. Assuming the two vertical wires connected at the top and the lower ends connected to a receiving set, the voltage thus produced will actuate the vacuum tube and

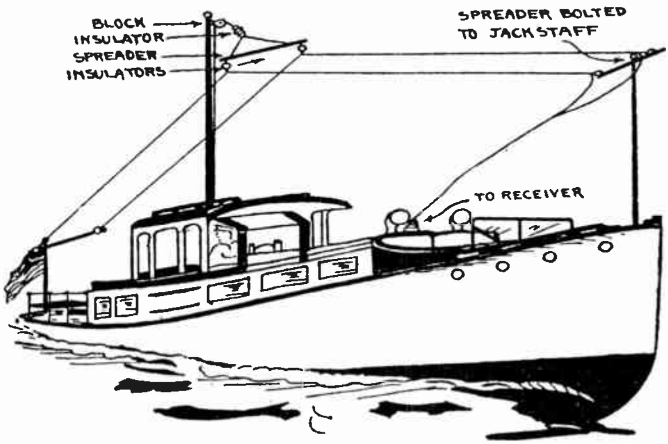


Fig. 25—The antenna installation on a typical cabin cruiser. This not only serves as an antenna, but gives the cruiser a sub-chaser aspect.

it can be detected in the usual manner. The horizontal wires, therefore, add nothing to the effective current induced in the coil.

In direct contrast, a wave approaching vertically or perpendicularly to the plane of the coil will strike both wires at the same instant and no phase difference or induced voltage will be heard and, therefore, no action of the detecting device will result.

The above explanation will, of course, hold for a wave other than being in length just twice the distance between the vertical wires. Any given wave-length will cause a maximum instantaneous voltage difference between the lower ends of the two wires when a wave approaches in the direction of the plane of the wires, but no change will occur when a wave approaches perpendicularly to this direction. It is obvious, then, that if such a coil is mounted on a frame and caused to rotate about a vertical axis, the coil can be usually adjusted for maximum and minimum signal intensity of strength for any given wave, thus resulting in directional characteristics and interference minimization as stated previously.

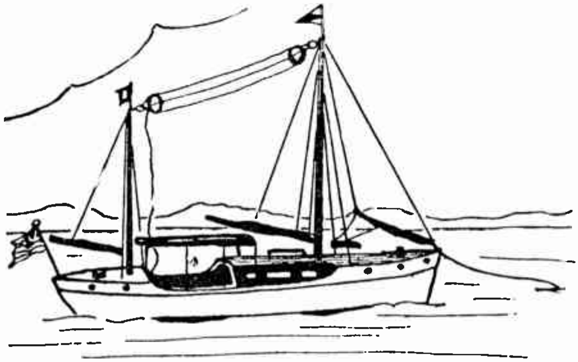


Fig. 26—Method of installing antenna on a yawl. Because of the limited space available on this type of vessel, a cage type of antenna is suggested.

Stronger signals are heard when the narrow side of the coil (plane) points towards the transmitting station.

The turns of wire in such a coil antenna have distributed

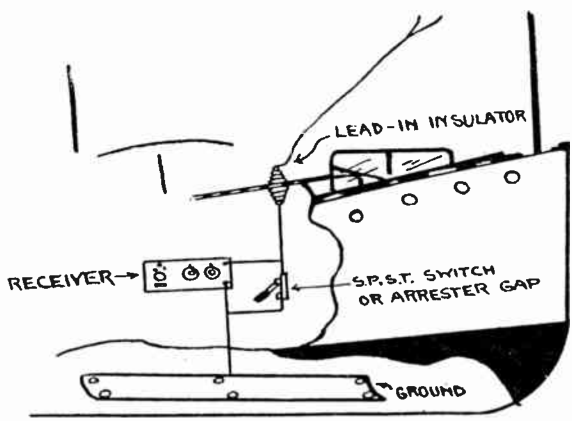


Fig. 27—A safety switch or gap should be provided. The ground can easily be effected by use of a metallic plate, and both instruments and gap are grounded to it.

capacity and this combined with its inductance gives the coil a fundamental wave-length of its own. The fundamental wave-length is the wave-length at which the coil will respond best, without the addition of any capacity or inductance other than that of the coil itself. For ordinary reception, the loop may be designed to be used at or near its fundamental wave-length.

The first step in designing a loop antenna is to decide upon its physical proportions, keeping in mind the factors mentioned in the discussion heretofore. A good idea of present practice may be had in a visit to a Radio store. Having chosen the most desirable size of the loop and the size of the variable condenser for tuning, the next question is the necessary number of turns of wire to wind upon it.

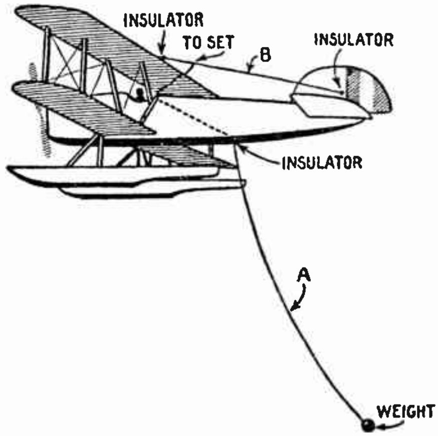
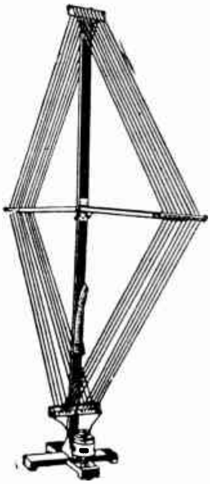


Fig. 28—Aeroplane antenna (A) which trails behind the plane when in flight, has a weight attached to its end, and is wound up on a reel before landing. The metal frame of the plane is used for a ground.

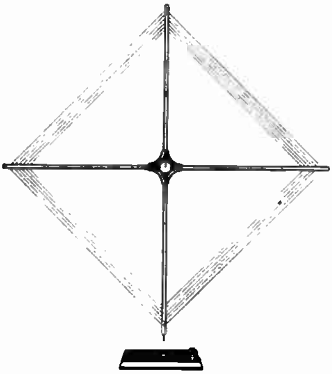
A LENGTH OF WIRE ON A LOOP

The length of wire on a loop alone has no direct bearing on the frequency or wave-length to which the loop will respond. The frequency depends on the inductance of the loop and the capacity of the condenser connected across its terminals, just as the frequency to which a coil will respond depends on its inductance and not on the number of feet of wire in the coil. Loop aerials of the average size and construction, when used to receive Broadcasting Stations, require about 85 feet of wire if the loop sides are short, and about 100 ft. with long sides. This wire should be flexible stranded double silk covered. Loop wire generally consists of 30 to 60 strands of very fine bare copper wire such as No. 28 or No. 20 DCC wire; solid or stranded wire may be of No. 14 or No. 16 gauge.

The frame work of a loop should have no metal inside of the turns of the wire. Any metal within the loop is, in effect, inside the field of a turning coil and the eddy currents set up in the metal cause a loss of energy. This means that the most suitable materials for the construction of the frame of a loop aerial are high grade molded and laminated compounds, such as formica, bakelite, celoron, etc., also well-prepared woods. All supporting points for the wire windings should be made of the best insulating material. It is not sufficient to depend on the insulation covering of the wire alone. If wood is used for supports, the wire should not rest directly against the wood, but should be carried upon some installation of greater resistivity.



A



B

Fig. 29—Two types of loop aerials in common use, the solenoid and spiral.

The two ends or terminals of the loop winding should be kept at the greatest possible distance from each other. They should never be connected to a duplex cable; this is to avoid the by-passing effects of the capacity between parallel wires and terminals that are close together.

SPACING OF WIRES

A loop aerial, like any other coil, has inductance which is desirable, and distributed capacity, which is undesirable. It is advisable to do everything possible to increase the inductance for a given length of wire and do everything possible to decrease the distributed capacity without too greatly affecting the inductance.

Inductance is increased by using more turns, greater length in each turn, and less spacing between turns. Distributed capacity is reduced by using fewer turns and more spacing between turns. From the above explanation it can be seen that these two requirements are opposed to one another, as we want more turns to increase the inductance, but fewer turns to reduce the capacity. We want less spacing to increase the inductance and more spacing to decrease the capacity.

THE NUMBER OF TURNS REQUIRED ON LOOP AERIALS

The following table shows the number of turns required on box loops of various dimensions when used with tuning condensers from .00025 to .0005 mfd. capacity. The loops are considered as being square, that is, with four sides of equal length. These sizes run from 18 inches up to 24 inches square. This table is based on 18, 20 and 24-inch coils wound with No. 20 DCC wire with turns spaced within 3, 4, 5 or 6 inches. The size of the loop depends on the space available. The number of turns and spacing depends on the capacity of the condenser used in

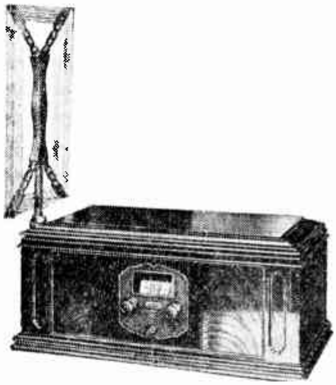


Fig. 30—Typical receiving set using a loop antenna.

tuning it. For example, suppose we wish to use a .00035 mfd. variable condenser and desire to build a loop 18 inches square and the space for the winding is to be 4 inches wide. Referring to the table under the heading "18-Inch Side," we find in the left-hand column the size of the variable condenser ".00035 mfd.," and following this to the right on the same line, to the third column under the heading "4-In. Wide," we find the number "17." This means that we will require 17 turns equally spaced within 4 inches in order to cover the broadcast band.

Dimensions are given both for length of the side of a square loop and for the area in square inches of the side of an oblong rectangular loop. A rectangular loop having the same area as the given square will operate satisfactorily with the number of turns specified for the square loop. The longer dimensions of the loop should not be more than twice its shorter dimensions. As an example, a loop having sides of 16 inches and 25 inches has an area of 400 square inches. A loop 20 inches square likewise has an area of 400 inches. The number of turns given in the column for loops 20 inches square are applicable then to loops with sides 16 and 25 inches long, or to any other combination of dimensions which yields an area of approximately 400 square inches.

In winding loops which are longer than they are wide and using the following table in determining the number of turns, it is always advisable to place at least one extra turn in the beginning to care for changes brought about by the difference in shape. The extra wire may then be removed if it isn't found necessary, this being known when the loop is tried out with the tuning condenser which will be regularly used. The added turn or turns may be supported in a temporary manner while testing.

LOOP AERIAL DATA

Capacity of Tuning Condenser	3-In. Wide	4-In. Wide	5-In. Wide	6-In. Wide
		18-Inch Side.		
.00025	19 T.	20 T.	21 T.	22 T.
.0003	17 T.	18 T.	19 T.	20 T.
.00035	16 T.	17 T.	18 T.	19 T.
.0005	13 T.	14 T.	15 T.	16 T.
		20-Inch Side.		
.00025	17 T.	18 T.	19 T.	20 T.
.0003	16 T.	17 T.	18 T.	19 T.
.00035	15 T.	16 T.	17 T.	18 T.
.0005	12 T.	13 T.	14 T.	15 T.
		24-Inch Side.		
.00025	15 T.	16 T.	17 T.	18 T.
.0003	14 T.	15 T.	16 T.	16 T.
.00035	13 T.	14 T.	14 T.	15 T.
.0005	11 T.	12 T.	12 T.	13 T.

ADAPTING A LOOP OPERATED RECEIVER TO AN OUTSIDE AERIAL

It is a very simple matter to adapt a loop set to an outside aerial. The necessary aerial coupling unit can be wound on a bakelite or cardboard tube 3 in. in diameter. The primary consists of 10 turns of No. 22 DCC wire. The number of turns for the secondary depends upon the capacity of the variable condenser used, as per example:

84 turns No. 22 DCC with .00025 mfd. Condenser.
72 turns No. 22 DCC with .0003 mfd. Condenser.
65 turns No. 22 DCC with .00035 mfd. Condenser.
50 turns No. 22 DCC with .0005 mfd. Condenser.

The primary is connected to the outside aerial and ground, the loop removed and the secondary leads connected to the loop posts on the set.

Fig. 32 illustrates how a light socket antenna can be used with loop type receivers. It will be seen that it is only necessary to wind one or two turns of wire directly over that of the regular

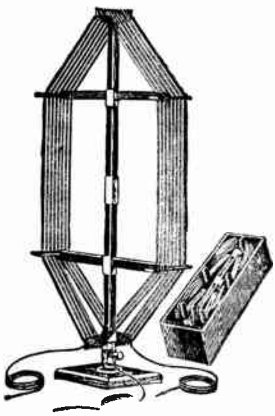


Fig. 31—Collapsible loop aerial used by many experimenters and in radio laboratories.

loop. One end connects to the light socket plug while the other is grounded. Such an arrangement will give your receiver, as a rule, a large increase in signal strength.

FIRE UNDERWRITERS' REGULATIONS FOR RADIO EQUIPMENT

For Receiving Stations Only. Antenna and counterpoise outside buildings shall be kept well away from all electric light or power wires of any circuit of more than 600 volts, and from railway, trolley or feeder wires, so as to avoid the possibility of contact between the antenna or counterpoise and such wires under accidental conditions.

Antennas and counterpoise where placed in proximity to electric light or power wires of less than 600 volts, or signal wires, shall be constructed and installed in a strong and durable manner, and shall be so located and provided with suitable clearances as to prevent accidental contact with such wires by sagging or swinging.

Splices and joints in the antenna span shall be soldered unless made with approved splicing devices.

The preceding paragraphs shall not apply to light and power circuits used as receiving antennas, but the devices used to connect the light and power wires to radio receiving sets shall be of the approved type.

Lead-in conductors shall be of copper, approved copper-clad steel or other metal which will not corrode excessively, and in no case shall they be smaller than No. 14, however, for bronze or copper-clad steel, not less than No. 17 may be used.

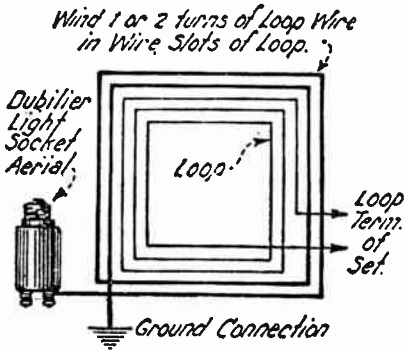


Fig. 32—Socket antenna and loop used together.

Lead-in conductors on the outside of buildings shall not come nearer than 4 inches to electric light and power wires unless separated therefrom by a continuous and firmly fixed non-conductor which will maintain permanent separation. The non-conductor shall be in addition to any insulating covering on the wire.

Lead-in conductors shall enter the building through a non-combustible, non-absorptive insulating bushing slanting upward toward the inside, or by means of an approved device designed to give equivalent protection.

Each lead-in conductor shall be provided with an approved protective device (lightning arrester) which will operate at a voltage of 500 volts or less, properly connected and located either inside the building at some point between the entrance and the set which is convenient to a ground, or outside the building as near as practicable to the point of entrance. The protector shall not be placed in the immediate vicinity of easily ignitible material or where exposed to inflammable gases or dust or flyings of combustible materials.

If the antenna grounding switch is employed, it shall in its closed position form a shunt around the protective device. Such a switch shall not be used as a substitute for the protective device.

It is recommended that an antenna grounding switch be employed, and that in addition a switch rated at not less than 30 amperes, 250 volts, be located between the lead-in conductor and the receiving set.

If fuses are used, they shall not be placed in the circuit from the antenna through the protective device to ground.

The protective grounding conductor may be bare and shall be of copper, bronze or approved copper-clad steel. The protective grounding conductor shall be not smaller nor have less conductance per unit of length than the lead-in conductor and in no case shall be smaller than No. 14 if copper, nor smaller than No. 17 if of bronze or copper-clad steel. The protective grounding conductor shall be run in as straight a line as possible from the protective device to a good permanent ground. Preference shall be given to water piping. Other permissible grounds are grounded steel frames of buildings or other grounded metal work in the building, and artificial grounds such as driven pipes, rods, plates, cones, etc. Gas piping shall not be used for the ground.

The protective grounding conductor shall be guarded where exposed to mechanical injury. An approved ground clamp shall be used where the protective grounding conductor is connected to pipes or piping.

The protective grounding conductor may be run either inside or outside the building. The protective grounding conductor and ground, installed as prescribed in the preceding paragraphs, may be used as the operating ground.

It is recommended that in this case the operating grounding conductor be connected to the ground terminal of the protective device.

If desired, a separate operating grounding connection and ground may be used, the grounding conductor being either bare or provided with an insulating covering.

Wires inside buildings shall be securely fastened in a workmanlike manner and shall not come nearer than 2 inches to any electric light or power wire not in conduit unless separated therefrom by some continuous and firmly fixed non-conductor, such as porcelain tubes or approved flexible tubing, making a permanent separation. This non-conductor shall be in addition to any regular insulating covering on the wire. Storage battery leads shall consist of conductors having approved rubber insulation. The circuits from storage batteries shall be properly protected by fuses or circuit breakers rated at not more than 15 amperes and located preferably at or near the battery.

TEST QUESTIONS

Number your Answers 15—2 and add your **Student Number.**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely; you'll get more out of your course, and better lesson service.

1. What is the function of an antenna?
2. Name the various types of antennas and describe three important types.
3. State the important points to remember when installing an outside aerial.
4. Draw a diagram showing the proper installation of an L type antenna.
5. Describe the construction of a ball antenna and state its advantages.
6. What is the purpose of the condenser used with an electric light socket plug?
7. State the advantage of using antenna wire having a thin coating of enamel.
8. What is a counterpoise?
9. How is a ground connection made on a boat?
10. Upon what does the frequency or wave-length of a loop aerial depend?

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INDUCTANCE AND CONDENSER DESIGN

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"Make the most of yourself, for that is all there is of you."
—Ralph Waldo Emerson.

USEFULNESS AS A CRITERION

A Personal Message from J. E. Smith

Anyone, who is undertaking to study, whether he is going through a school or college course, or is going to study by himself at home, wants to take up subjects according to whether they will, in a large way, be useful to him.

He does not want to consider simply whether they will help him in his business, profession, or other occupation. That side is important.

He wants also, however, to look at his life outside his daily work. Knowledge is useful to a man, or a woman, it seems to me, even if he employs it only for his own pleasure. If one is really interested in a subject, that is sufficient reason for studying it.

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INDUCTANCE AND CONDENSER DESIGN

In some of the earlier texts, the subject of *Inductance* and *Capacity* was discussed so that the student could gain some knowledge of what took place in a circuit containing inductance capacity. In practically all of the modern Radio receiving sets, inductances and capacities occupy a prominent position and in order to thoroughly understand the fundamental principles of Radio, it is necessary that the student have a detailed understanding of just what takes place in each of these component parts. It is the purpose, then, of this text to take up in detail, not only the theoretical principles of inductance and capacity, but to practically illustrate how these two components are used and the resulting action when they are included in a Radio circuit.

INDUCTANCE IN D. C. CIRCUITS

Specific cases and illustrations usually help to enlighten a student, and for this reason let us look at Figure 1 and study the effect of inductance.

First, let us study just what happens in an inductance or coil. It has already been learned that when an unvarying or direct current flows in a circuit, it encounters only the resistance of the circuit, and the magnitude of such a current is determined by the resistance and the applied voltage in accordance with Ohm's Law. Now when this current is forced through a coil, it sets up a magnetic field about the coil and this magnetic field is in proportion to the amount of current flowing and the number of turns in the coil. *By increasing either the current flowing in a coil or by increasing the number of turns of the coil, we can increase the strength of the magnetic field.* Therefore, the magnetic field is dependent upon the current and the number of turns. It seems reasonable, then, that if the field strength is proportional to the current and the number of turns that if we should in some way change the strength of the field, it would in some way react on the voltage and current applied to the coil.

Such is the case, because as stated previously, an electric current is always accompanied by a magnetic field and we can state the reverse of this by saying that a magnetic field always has the capability of producing an electric current.

If we have a steady, magnetic field and we place in this magnetic field, a wire or coil of wire, and cause this wire or coil to move, the lines of force of the magnetic field will induce in this wire or coil, a voltage and a current will flow in the coil or wire if the circuit be closed. Also, if the magnetic field is varied and the coil remains stationary, the lines of force will cut the wire of the coil and induce a voltage in the wire. Now let us see how this applies to an inductance coil alone.

When a current is passed through a coil, the magnetic lines of force of each wire interlink with those of the other and combine and set up a strong magnetic field. These lines of force, as they are starting to build up in the field, cut some of the other turns of the coil resulting in a voltage being induced in these turns. It then seems reasonable that a second voltage is present in this coil, and this is the case. The main point is, the induced voltage is in the opposite direction to the voltage applied to the coil. The reason for this is that the applied voltage to the coil forces a current through it and sets up a magnetic field in one direction; whereas the induced voltage set up in the coil is the result of the flux cutting the turns of the coil and hence a reversal of polarity between the two voltages.

This induced voltage which opposes the applied voltage is never as great as the applied voltage. However, in some Radio circuits it closely approaches the same value as that of the applied voltage. If the induced voltage of the back or counter E. M. F. (Electromotive Force), as it is sometimes called, should become as great as the applied voltage, no current could flow through the coil.

Suppose now that the applied voltage has overcome the induced or counter voltage and a steady rate of current is flowing through the coil. If the current should in some way be varied or the circuit broken so that current can no longer flow, the steady magnetic field surrounding the coil will collapse. As it collapses, the magnetic lines of force cut the turns of the coil and induce a voltage in the coil. In this last case, we have the applied current decreasing, and inducing another E. M. F. and in this case the E. M. F. is in the same direction as the applied voltage resulting in the induced E. M. F. tending to prolong the flow of current in the coil.

Summarizing the facts brought out together with the explanations, we have the proposition that when the current in an inductive circuit is increasing, the induced voltage is in such a direction that the total voltage acting in the circuit is decreased, and when the current is decreasing, the induced voltage acts to increase the total voltage of the circuit.

To more clearly impress this phenomenon on the mind of the student, it would probably be well to draw a comparison between inductance and something with which we are more familiar. *Inductance is very similar to inertia.* Inertia, as you know, is that property of a body which tends to keep it in a state of rest or to resist any change of momentum. Most all of us have had the experience of pushing a large ball or some object such as a roller used in rolling the grass on a tennis court;

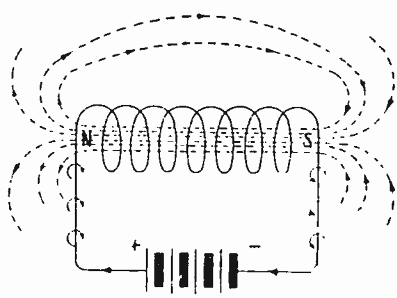


Fig. 1—Magnetic Field about a coil

in this case, we experience practically the same conditions as the electric current does in flowing through an inductance. When first trying to push the ball or roller and set it in motion, it takes a greater force to set it in motion than to keep it in motion. As soon as the roller has gained a certain amount of motion, if we decide to bring it to a sudden stop, it takes a greater amount of energy to stop it than it does to keep it in motion. This is just the same experience as the electric current has, because the applied voltage encounters a counter force when first trying to force the current through the coil and then when the current tries to decrease or stop, the force tries to prolong the current flow.

This phenomenon is referred to as "self-induction" or "self-inductance." "Inductance" is that magnetic property of a circuit that opposes any change in the flux and, therefore, any change in either the magnitude or the direction of the current in the circuit.

The unit of "self-induction" is defined as follows: If the rate of current change of one ampere per second gives an induced voltage of one volt, the coil has a self-induction of one unit. This unit is called the "henry"; *the "henry" is, however, too large a unit for most of the coils used in Radio work, so the sub-divisions of the henry are used. The millihenry is one thousandth of a henry* and the *microhenry is the millionth part of a henry.* The *prefix "milli" means the one-thousandth part of a unit and the "micro" means the one-millionth part of a unit.*

Sometimes, a still smaller unit is used, the *centimeter, which is the one-thousandth part of a microhenry.*

INDUCTANCE IN A. C. CIRCUITS

As the current in an alternating current (A. C.) circuit is periodically reversing its direction of flow, a moment's reflection will bring out the fact that inductance has a greater effect upon alternating current than it does upon direct current. In the direct current circuit, the inductance merely delays the current momentarily until the applied voltage can overcome the counter E. M. F. and then the current will assume a steady value until the circuit is broken or the current is decreased.

Previously it was brought out that whenever the current passing through an inductance changes, it causes a change in the magnetic field surrounding the inductance. The effect, then. of an inductance in an alternating current circuit is that the inductance causes two effects; one, the decreasing of the current and the other lagging of the current behind the voltage.

First, let us see just how the inductance decreases the current. *When a direct current flows through an inductance, it encounters only the resistance of the circuit, but when an alternating current flows through an inductance, the periodic reversals of the current are continually causing the field to change and in turn the field is opposing the flow of current.* This happens many times per second depending entirely upon the frequency of current reversals. This changing of the field represents a certain amount of work performed and in turn a certain amount of resistance to the flow of current is encountered. When speaking of this resistance that the inductance offers to the flow of alternating current, it is termed *reactance* instead of resistance. The symbol for reactance is usually the letter "X" and in order to differentiate between the different forms of reactances, a small letter "L" is sometimes placed to the right of the reactance, symbol, thus "X_L" to signify inductive reactance.

It can be seen, then, that the faster the current changes, the more the field is changed and it naturally follows that the more the number of changes in the field strength, the greater will be the reactance to the flow of current. The formula for the reactance of an inductance is as follows: $X_L = 6.28$ FL.

In this formula, 6.28 is a constant which it is necessary to employ, F is the frequency of the current in cycles per second and L is the self-inductance in henries in the circuit. To illustrate this, suppose we have an inductance of 5 henries in an alternating current circuit and that the frequency of this current is 60 cycles per second. According to the formula, then, the reactance presented by the inductance is equal to 6.28 times 60 times 5 or 1884. The reactance is always expressed in ohms so that in this case the reactance presented by the inductance in the above example is 1884 ohms.

Now let us see what takes place if we increase the frequency. Suppose as in the previous example, we have an inductance of 5 henries in a circuit, and the frequency of the current is 1000 cycles per second. In this case, then, X_L or the reactance would equal 6.28 x 1000 x 5 which equals 31,400 ohms. It can readily be seen then that *if either the inductance or the frequency of the current is increased, the inductive reactance is also increased.*

The other effect which inductance has on an alternating current is that it causes the current to lag behind the voltage. Figure 2 illustrates a curve showing how the direct current builds up in an inductance and that it does not momentarily rise to its maximum value. If there were no opposing voltage, the current would immediately rise to its maximum value and the line A-B would be a straight vertical line (like CB) instead of a sloping curve.

In the right-hand side of Figure 2 you will see a curve (DF) showing how the coil affects the current whenever the current is decreased. In this case, it can be seen that a certain time exists before the current ceases to flow in the inductance and instead of suddenly decreasing to zero value, it gradually decreases to the zero value. The fundamental principle brought out is that when the voltage is applied to the coil, a certain time exists before the current can build up to its normal value. In this case, then, we have a condition where the voltage momentarily leads the current.

Now bear in mind that in an alternating current circuit just as soon as the current starts through the coil, it induces a voltage in the coil which opposes the flow of current and slightly delays the flow of this current. By the time the current tends to assume a normal value, the applied voltage already has started falling off so that we again have the magnetic field affecting the flow of current by inducing a voltage which tends to prolong it for a certain length of time. The exact relation is this; while the induced voltage is delaying the current, the applied voltage has already passed through its maximum value and has started to decline and the applied voltage has reached zero by the time the current reaches its normal value. This then shows that the voltage runs ahead of the current whenever alternating current passes through an inductance.

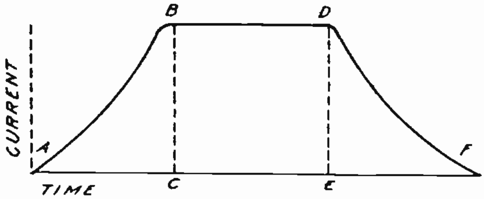


Fig. 2—Curve showing how an inductance affects the current in a circuit

MUTUAL INDUCTANCE

In one of the earlier paragraphs, it was stated that if a wire or coil was moved in a steady magnetic field, or if a coil was cut by a varying magnetic field, a voltage would be induced in this coil or wire. This, then, brings us to the second part of our circuit in which we include another coil such as in Figure 3. You can readily see that this is a part of a radio circuit. If the coil L2 is placed near the coil L1, and a varying current is passing through coil L1, the lines of force set up by the current passing through coil L1 will cut the second coil L2, and a voltage will be set up in this second coil. The amount of voltage set up in the second coil L2 is dependent upon the strength of the magnetic field of coil L1, and the proximity of the coil L2 to that of coil L1. If the second coil L2 is nearer the first coil L1, a greater number of lines of force will cut the second coil and the voltage induced in this second coil L2 will be much greater. Under the heading of "self-inductance," we learned that if the induced voltage was caused by the magnetism and current in the coil itself, the counter E. M. F. is then spoken of as the E. M. F. of self-induction. If the magnetism is due to some other coil, in proximity to the one in which the voltage is being induced, then the E. M. F. is spoken of as the E. M. F. of mutual induction.

This E. M. F. in the second coil, due to the *mutual induction,* is set up in the second coil whether the second circuit is open or closed. If, however, the second circuit is a closed one, then current will flow in it due to the induced voltage.

COUPLING THROUGH MUTUAL INDUCTANCE

From the foregoing, it would seem that there is some means of expressing the degree of coupling between two coils. Such is the case and this degree of coupling is sometimes spoken of

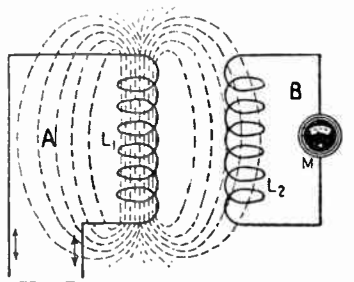


Fig. 3—Diagram Illustrating the mutual inductance between Coil L1 in Circuit A and Coil L2 in Circuit B

as the co-efficient of coupling or merely coupling. The co-efficient of coupling is the coupling existing between two inductively coupled circuits and is the percentage of the number of lines of force of the first coil that cut the second coil. If all the flux produced by one coil threads with all the turns of the other, the coils are said to have 100 per cent coupling; if but a small fraction of the flux produced by the first coil threads the turns of the second, the coupling is less. The co-efficient of coupling, then, is a measure of the percentage of the flux of the primary which links with the turns of the secondary. This could be stated in another way—that is, coupling is a measure of the portion of the energy in one circuit which may be transferred to another by these flux interlinkages. Whenever two circuits are near each other so that a transfer of energy takes place between them, they are referred to as coupled circuits.

The coupling between two coils may be increased by moving the coils closer together, by placing the coils on the same iron core as in a power transformer, or by making the coils parallel to each other. By each of these methods, the mutual inductance is increased. The main use of mutual inductance coupling is that energy may be transferred between two insulated circuits due to the flux interlinkages. "Coupler," "Tickler" and "Oscillation Transformer" are names applied to various types of mutual inductance couplings in Radio work where energy is transferred from a coil in one circuit to a coil in another. Figure 4 shows how the coupling can be changed in various ways.

CAPACITY AND CONDENSERS

Whenever two metallic conductors are separated by an insulator (dielectic) these two conductors may maintain a difference of potential by applying a suitable electromotive force.

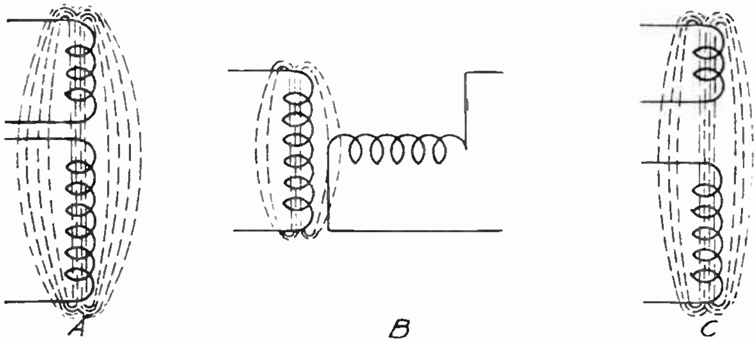


Fig. 4—Showing the affect of varying the coupling between coils

For instance, suppose A and B of Figure 5 are two conducting plates, with mica, air, or glass between them in the space C. *Such a device for storing electricity is called a condenser.* If the switch S is closed, it will be found that a momentary current will flow in the direction as shown, and indicated by the needle of the galvanometer G, but that this current will soon stop even though the battery still has an E. M. F. of 6 volts.

This stopping of current shows that the condenser has developed an electromotive force equal, but opposite, to the applied E. M. F. If the switch S be open and a suitable voltmeter applied to A and B, it will be found that the condenser has developed an E. M. F. of its own. In order that the difference of potential and an E. M. F. between A and B should exist, the electrons in the intervening space must have been re-distributed. We actually think that the plate A has a positive charge and the plate B has a negative charge, these charges having been set up by the current flowing for a certain time. Each plus charge on A is bound to equal minus charge on B, and we have established an electrostatic field between A and B, made up of charges bound by electrostatic lines. The electrons in the space C have been re-distributed, the strain between the electrons being represented by the electrostatic field.

DISCHARGE OF CONDENSERS

In Figure 5, we have a diagram showing how a condenser was charged. In Figure 6, we have connected to the previous circuit, another switch and a galvanometer. When switch S is closed and S-1 is open, the plates of the condenser will assume

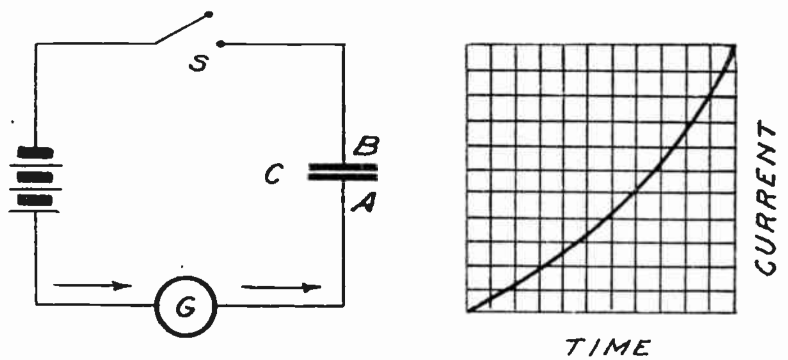


Fig. 5

a charge, the potential difference of which is the same as that of the battery. If switch S is then opened and switch S-1 is closed, the galvanometer G will indicate a flow of current. It was previously shown that the condenser developed a back pressure in opposition to the electromotive force of the battery. Naturally, therefore, the discharge current will flow in the opposite direction to the charging current. This flow of current will last for only a short length of time proving that the condenser has given up the charge which it held.

The discharge of the condenser is not momentary and it is illustrated by the curve shown to the right in Figure 6. In this case, you will notice that the condenser gradually gives up its discharge and that this curve is just the inverse of the charging curve shown in Figure 5. We will learn more about this slow discharging of the condenser later on.

ALTERNATING CURRENT FLOW IN A CONDENSER

By the definition of a condenser, no electrons can actually pass from one plate to the other; the plates are insulated from one another. If, however, a condenser is connected to a source of alternating E. M. F., current will flow in this circuit, as may be seen by the reading of an A. C. ammeter placed in series with the condenser.

Suppose a condenser having a certain capacity is connected to a line, the E. M. F. of which is periodically alternating. The condenser will, of course, take enough charge to bring the potential difference of its plate continually equal to that of the line to which it is connected. As this impressed E. M. F. continually rises in magnitude and direction, electrons must be continually running in and out of the condenser to maintain the plates at the proper potential difference. This continual charging and discharging of the condenser constitutes the current read by the ammeter. The electrons, the motion of which constitutes the current, do not actually pass from one plate of the condenser to the other through the dielectric; they merely flow in and out of the condenser. It can then be understood that the charging current of the condenser is dependent upon the frequency of the alternations. The greater the frequency, the greater the movement of electrons and hence, the greater the charging current. Other things being equal, the charging current of a condenser is directly proportional to the frequency of the impressed E. M. F. This should be contrasted to the inductive circuit in which the current varies inversely as the frequency.

The *reactance* (alternating current resistance) *of a condenser varies in an opposite manner to the reactance of an inductance.* The formula for the reactance of a condenser is given as follows: Xc equals $\frac{1}{6.28\ FC}$. In this formula, Xc represents capacity reactance of the condenser, 6.28 is a constant, F is the frequency of the current in cycles per second, and C is the capacity of the condenser in farads. The capacity reactance is expressed in ohms just as the inductive reactance was expressed in ohms. From this formula, it can readily be seen that the smaller the capacity and the lower the frequency, the greater is the reactance of the condenser and vica versa, the greater the capacity and the higher the frequency the smaller is the reactance.

To bring this out more clearly to the student, suppose we have a condenser of 1 mfd. capacity and we desire to determine its reactance when inserted in a circuit having a frequency of 60 cycles. As the microfarad is the one-millionth part of a farad, then the decimal .000001 farad is the same as 1 mfd. Substituting in the above formula, we then have

$$Xc = \frac{1}{6.28 \times 60 \times .000001}. \quad (1)$$

Solving the equation, we find that the reactance is approximately 2653 ohms. Now suppose that this same 1 mfd. condenser was

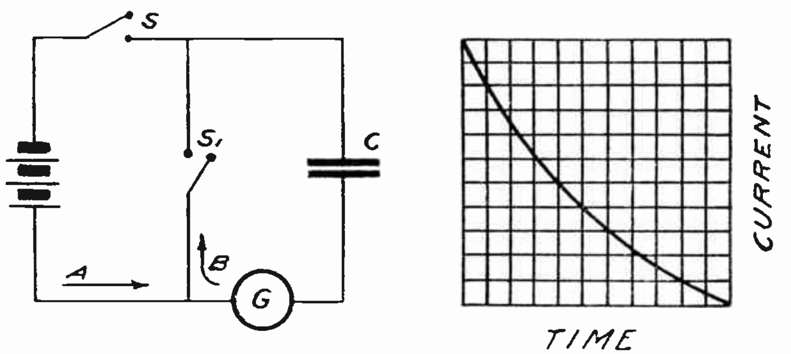


Fig. 6

inserted in an alternating current circuit, the frequency of which was 1000 cycles per second. From the above formula, then, we have

$$Xc = \frac{1}{6.28 \times 1000 \times .000001}. \quad (2)$$

Solving this equation, we find that the reactance at a frequency of 1000 cycles is only 159 ohms.

TYPE OF CONDENSERS

Fixed: The fixed condensers used in Radio circuits vary considerably in regard to the design. Each manufacturer has a special design which may or may not have its advantages. The capacity of the usual fixed receiving type of condensers is nearly standardized so that it is possible to buy a particular capacity designed to be used for a particular condition. The dielectric used in most of the ordinary receiving condensers is mica. However, paper is used considerably in the larger capacity condensers, especially those having a capacity of .1 mfd. or larger. Figure 7 illustrates several types of receiving fixed condensers.

VARIABLE CONDENSERS

It is generally more convenient to make a condenser continuously variable than to make an inductance of that kind, hence, the tuning of a Radio circuit is generally accomplished by using fixed inductances and a variable condenser. These variable condensers are usually made by having one set of the plates stationary and the other set of the plates can be rotated so as to intermesh the rotary plates between the stationary plates. There are three principal types of variable condensers

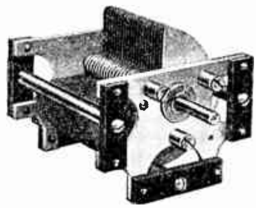
Fig. 7—Various types of Fixed Condensers

used in Radio receiving sets, the *straight line capacity type*, the *straight line wave-length type*, and the *straight line frequency type*.

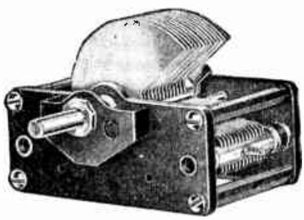
In Figure 8 the three different types are illustrated so as to show the shape of the plates used in each. There are, of course, several variations of each type but these illustrations will serve the purpose of bringing out the difference between the three types.

In the straight line capacity type, semi-circular rotor plates are used and the capacity is continuously variable, the capacity being in direct proportion to the angle of rotation of the rotary plates. When using a straight line capacity condenser in a tuned circuit, more than half of the Broadcast Stations will be tuned in at some point between zero and forty. This is due to the fact that the Broadcast Stations are separated 10 kilocycles apart and as the frequency increases very rapidly at the lower wave lengths, it can be easily understood that more than half of the available 10 kilocycle channels are between 200 and 300 meters.

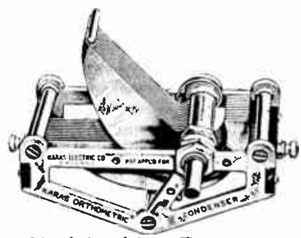
In the straight line wave-length type of variable condenser, the capacity is increased in such a ratio that the stations are tuned in at equal spaces on the condenser dial according to wave length. This is somewhat of an improvement over the straight line capacity type, but in this case also the stations are still crowded to a certain extent on the lower half of the condenser dial.



Straight Line Capacity
Variable Condenser



Straight Line Wave Length
Variable Condenser



Straight Line Frequency
Variable Condenser

Fig. 8

The straight line frequency condenser as can be seen, uses a shaft which is placed to one side of the center so that the capacity is varied in such a way that the stations are tuned in on the condenser dial and equally spaced according to frequency.

OSCILLATORY CIRCUITS

In Figure 9, we have a capacity C in series with an inductance L and a resistance R. The resistance R represents the direct current resistance of the inductance. It is never possible to have an inductance without having it contain some form of direct current resistance, and in order to bring out some of the fundamental principles, this direct current resistance is shown separately. The battery "B" is connected to this circuit by means of two switches S and S-1. When S-1 is open and S is closed, we have already found that the battery will force a current through the resistance R, the inductance L, to the condenser

C, and in so doing, a re-distribution of the electrons in the circuit is caused and the condenser C will gradually assume a charge until the potential difference between the two plates is equal to the potential of the battery. From our previous study, we have found that if a circuit is provided so that the condenser can discharge, it will gradually give off whatever charge it holds until its plates come to a state where no potential difference exists between the two.

Now bear in mind all the former principles that have been brought out in this text so far and let us see what happens when we connect a condenser and an inductance in series. Suppose we open switch S-1 and close switch S. The battery will gradually charge the condenser until it finally assumes a potential equal to the battery. Now by opening switch S, the battery circuit is open and the condenser remains in a charged condition. Now let us close switch S-1 so that a complete circuit is provided for the condenser to discharge. We learned previously that the condenser does not discharge instantaneously.

As the condenser discharges the inductance tries to prolong the flow of current and prevent a decrease in current. In so doing, the inductance causes more electrons to be drawn from the condenser and the balance of the circuit, and the result is that the inductance forces a current through the resistance to switch S-1 and to the other side of the condenser, causing the condenser to be charged in an opposite manner. Instead, then, of the condenser coming to a normal zero potential, the inductance has forced it to assume a charge in the opposite direction. As the magnetic field of the inductance finally comes to rest, we find that there is a difference of potential between the plates of the condenser, and as a circuit is provided for the condenser to discharge, the condenser, therefore, tries to discharge and causes another re-distribution of electrons through the switch S-1, the resistance R, the inductance L and to the other side of the condenser. The inductance tries to retard the current at first but after the current has built up to a certain rate and starts to decrease, the inductance tries to prolong it. The result is, then, that wherever the condenser tries to discharge, the inductance prolongs the discharge until the condenser is actually charged in an opposite manner. From this, it would seem that this charging and discharging would continue indefinitely. However, it must be taken into consideration that in each case when there was a re-distribution of electrons in the circuit and the condenser was charging or discharging, that the current flow in each case was opposed by the resistance and a loss in potential occurred in forcing the current through the resistance. As the resistance causes a loss in potential, then each successive charge of the condenser is at a smaller potential than previously. If the resistance R is very high, the successive charging and discharging of the condenser will in each case be considerably less, whereas if the resistance R is small, each successive charge of the condenser more nearly approaches the charge in the previous instance.

By definition, *an oscillatory circuit is one in which oscillations* (periodic reversals in the direction of flow of current) *can take place.* From the foregoing explanation, it can be seen then

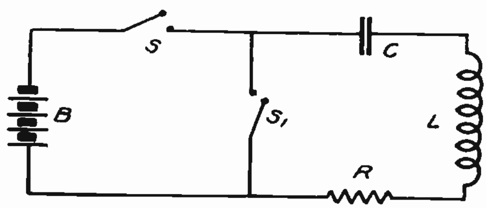


Fig. 9—Fundamental Oscillatory Circuit

that the circuit shown in Figure 9, composed of the condenser C, the inductance L and the resistance R, together with the switch S-1 composes an oscillatory circuit, because oscillations can take place in this circuit. In most cases, oscillations occur at a very high frequency and an oscillatory current is, therefore, a high frequency current which periodically reverses its direction of flow. In Figure 10, we have a graph or curve showing how the current circulates in an oscillatory circuit. When the condenser is uncharged, its potential is at zero just as shown at O. When the condenser is charging, a current circulates and the condenser gradually assumes a charge as represented by the line O-A. As soon as the switch S-1 is closed, the condenser begins to discharge and in doing so, the inductance tends to prolong the flow of current long enough for the condenser to be charged in the other direction as represented by the line from A to B. As the condenser has then been charged in the opposite direction, it tends to discharge and in doing so, the inductance tries to prolong the flow of current long enough for the condenser to become charged in the opposite direction as indicated by the line from B to C. It can be seen from this curve that the point C is not quite as high as the point A, and this indicates that the condition of the condenser when charged at the point C is not as great and it does not have as great a potential as when it was charged at the point A. These oscillations then gradually die away and each successive charge and discharge of the condenser is not as great as the previous one and the circuit finally assumes a normal condition where there is no current circulating in the oscillatory circuit.

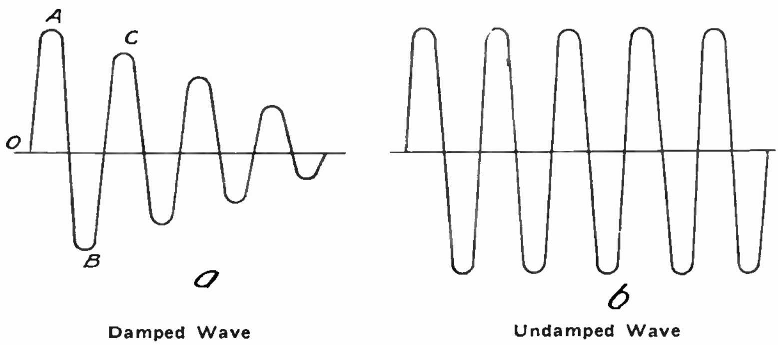


Fig. 10

Whenever a condenser discharges into an inductance and resistance, it creates such oscillations and these oscillations are known as damped wave oscillations because the amplitude of each successive charge is not as great as the previous one. This can be seen from Figure 10. *An undamped wave would be a wave in which all of the amplitudes are of the same height*—just as represented to the right in Figure 10.

This damping quality or the dying away of the wave is governed by the amount of resistance in the oscillatory circuit. The greater the resistance included in the oscillatory circuit, the shorter the time will be before the current in the circuit ceases to flow. If the resistance in the circuit is very low, the current tends to oscillate for a greater length of time. In Figure 11, we have an illustration of this showing how the oscillations are shortened or lengthened in time according to the amount of resistance in the circuit.

So far in our discussion of an oscillatory circuit, it has been presumed that the proportion between the capacity and inductance in the circuit was such that oscillations could take place. Unless such a proportion between the inductance, capacity and resistance in the circuit exists, oscillations cannot take place, and we shall now learn just what are the conditions which must be met before these oscillations can take place. It was just pointed out that if the resistance was increased, the damping was increased, and the length of time that the oscillations existed in the circuit was dependent upon the resistance. Theoretically, if the resistance is too high, only a very few oscillations will take place, and the resistance can be increased to such a point that no oscillations will occur at all. The condenser will

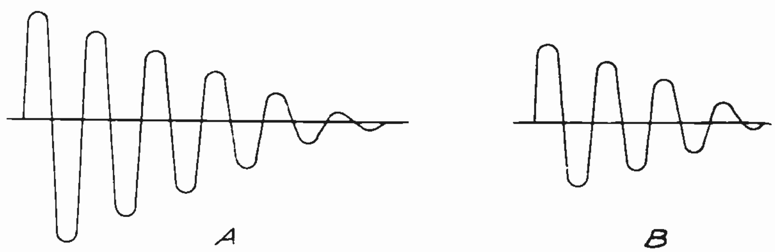


Fig. 11

merely discharge into the inductance and resistance and in doing so it will spend all of its energy in passing through the inductance and resistance and will not assume any charge in the opposite direction.

There is a balance between the inductance and the capacity which must exist and which governs the frequency of the oscillations. We previously learned that the reactance of an inductance was given as $X_L = 6.28 \times F \times L$. The reactance of a condenser is given as

$$X_C = \frac{1}{6.28 \times F \times C} \qquad (3)$$

By looking at these two formulas we can see that the inductive reactance increases with frequency, and that the capacitive reactance decreases as the frequency is increased. *Owing to this, there is a certain frequency at which the inductance and capacity reactance just balance each other resulting in a total reactance of zero.* Whenever such a condition exists, it is known as "*resonance*" because at that frequency the only resistance offered to the flow of alternating current is the direct current resistance included in the circuit. Without going into details as to the evolution of the formula, we find the formula for resonance is:

$$F = \frac{1}{6.28 \times \sqrt{LC}} \qquad (4)$$

From this formula, then, it is possible to determine the resonant frequency when the inductance and capacity of the circuit are known.

We have just discussed what is known as series resonance and this is the type of resonant circuit which is most used in Radio receiving circuits. In this case, the inductance L and the condenser C and the potential are all in series and this is known as series resonance.

There is another form of resonance known as parallel resonance and without going into detail, it can be stated that in parallel resonant circuits the opposite results are encountered as in the series circuit. In the parallel resonant circuit, the resultant reactance becomes infinitely high at the resonant frequency and the result is that the current is offered an infinitely high resistance and hence at this particular resonant frequency, the current is practically zero. As the series resonant circuits are much more common in Radio, the parallel resonant circuits will not be gone into at this time.

In Figure 12A we have a curve illustrating the current flowing in a series resonant circuit. At the resonant frequency when the two reactances balance each other, the current is at a maximum. It will be noticed that as resonance is approached from either direction, the current is rising and tends to increase. In Figure 12B we have another curve showing the effect of increased resistance on the resonance curve. It will be noticed that in this case the curve is not as sharp as in the previous case because the resistance has been increased and this materially broadens the resonance curve. Therefore, then, by decreasing the resistance in the oscillatory circuit, the resonance curve is sharpened and when the resistance is increased, the resonance curve is broadened. It would seem at first glance that the best oscillatory circuit for use in a Radio frequency receiver would be one which would have a very sharp resonance curve, but this is not always the case because it is generally desirable to amplify a certain band of frequencies instead of the frequency of the incoming carrier wave alone and since this is the case a slightly broader curve is more desirable. Figure 12C illustrates the ideal curve but this cannot always be obtained. It is, however, desirable to have the oscillatory circuit so designed that it will approach this type of resonance curve as nearly as possible.

DESIGN

The following *formulas, tables and curves given will enable one to design coils for use in Radio receiving sets.* Finding the inductance of a certain coil is an interesting problem and for that reason the formula for the inductance of a single layer close wound solenoid is given herewith:

$$L_S = \frac{A^2 \ N^2}{10b} \times K. \quad (5)$$

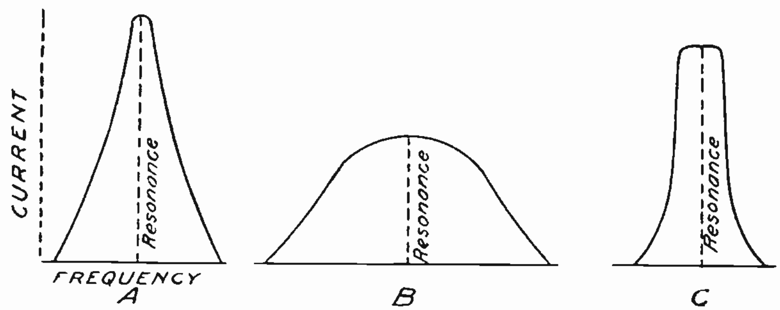


Fig. 12

In the above formula, Ls represents the self-inductance in micro-henries of the coil, A is the radius in inches of the coil, N is the number of turns of wire, 10 is a constant, b represents the length of the coil in inches and K is a constant which is determined from the diameter divided by the length of the coil, the value of K for different values can be found from Table 1.

In order to clearly understand the formula and the use of the table, let us take a concrete example and work it out and find the self-inductance of a single layer coil. Suppose it is desired to find the self-inductance of a coil consisting of 82 turns of No. 24 DSC wire, the diameter of the winding being 2 inches. As No. 24 DSC wire can be wound with approximately 41 turns per linear inch, the coil will be approximately 2 inches long.

As K is a function of the diameter divided by the length, it is noted that the diameter is 2 inches and that the length is

2 inches, hence 2 divided by 2 equals 1. Now refer to Table 1 and in the first column, "diameter over length," you will notice the figure 1 in this column. To the right of this figure 1 in the next column under "K" you will find the fraction .6884. This then is the fraction which must be employed for this length and diameter coil in order to make the formula come out properly.

Substituting these values for the letters in the above formula, we then have

$$L_S = \frac{1^2 \times 82^2}{10 \times 2} \times .6884 \qquad (6)$$

Simplifying the foregoing, we have

$$Ls = \frac{1 \times 6724}{20} \times .6884 = 336.2 \times .6884 = 231. \qquad (7)$$

The result is just slightly over 231 microhenries but this is close enough for all average purposes.

Having thus learned how to calculate the inductance of a certain coil, the next step is to find out what combination of inductance and capacity will respond to a given wave-length or frequency. Earlier in the text the formula for the frequency to which a circuit would respond was given as

$$F = \frac{1}{6.28 \times \sqrt{LC}} \qquad (8)$$

In that case the inductance and capacity was given in henries and farads. As these units are much larger than ordinarily used in Radio receiving sets, the formula can be simplified by stating that

$$F = \frac{1,000,000}{6.28 \times \sqrt{LC}} \qquad (9)$$

In this case, then, the inductance and capacity are given in microhenries and microfarads. From this formula it can be seen that there is a certain constant representing LC or the square root of LC which will be a certain value for each frequency. That is, as the numerator of the fraction 1,000,000 is a constant and 6.28 is a constant then the inductance and capacity are the only values which vary. This is the case, however, should it be necessary to work this formula out in each case, considerable time would be spent, so tables are given which show the relation of the inductance and the capacity for certain fre-

[illegible]

[illegible] Y[illegible] [illegible]

[illegible]

[illegible]

[illegible]

[illegible] appearance.

[illegible]

$L = 5$

[illegible] $LC = 50$ [illegible]

[illegible]

$LC = 30$

[illegible]

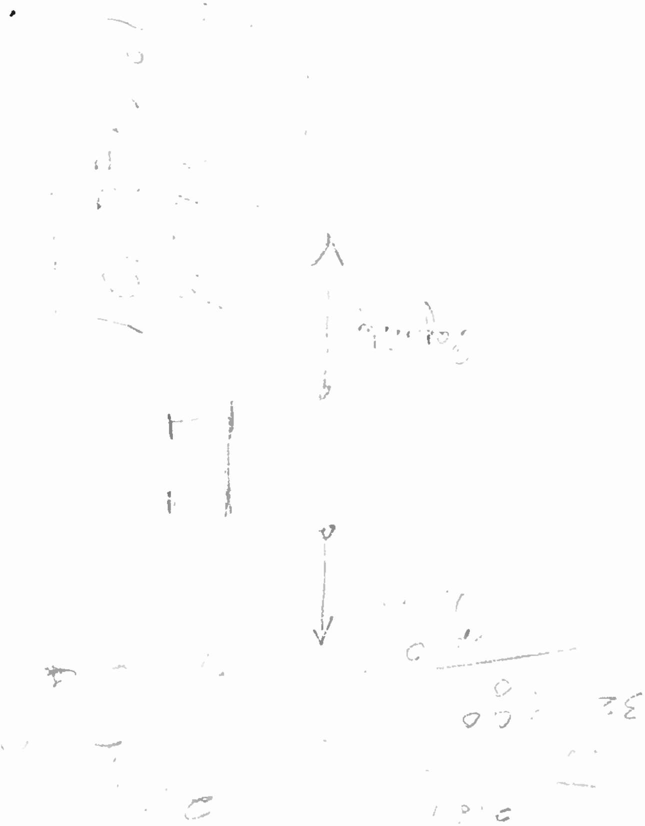


TABLE 1

VALUES OF K FOR USE IN SELF-INDUCTANCE FORMULA

Diameter / Length	K	Diameter / Length	K
0.00	1.0000	1.75	0.5579
.05	.9791	1.80	.5511
.10	.9588	1.85	.5444
.15	.9391	1.90	.5379
.20	.9201	1.95	.5316
0.25	0.9016	2.00	0.5255
.30	.8838	2.10	.5137
.35	.8665	2.20	.5025
.40	.8499	2.30	.4918
.45	.8337	2.40	.4816
0.50	0.8181	2.50	0.4719
.55	.8031	2.60	.4626
.60	.7885	2.70	.4537
.65	.7745	2.80	.4452
.70	.7609	2.90	.4370
0.75	0.7478	3.00	0.4292
.80	.7351	3.10	.4217
.85	.7228	3.20	.4145
.90	.7110	3.30	.4075
.95	.6995	3.40	.4008
1.00	0.6884	3.50	0.3944
1.05	.6777	3.60	.3882
1.10	.6673	3.70	.3822
1.15	.6573	3.80	.3764
1.20	.6475	3.90	.3708
1.25	0.6381	4.00	0.3654
1.30	.6290	4.10	.3602
1.35	.6201	4.20	.3551
1.40	.6115	4.30	.3502
1.45	.6031	4.40	.3455
1.50	0.5950	4.50	0.3409
1.55	.5871	4.60	.3364
1.60	.5795	4.70	.3321
1.65	.5721	4.80	.3279
1.70	.5649	4.90	.3238

quencies or wave-lengths, which have been found from this formula.

In Table 2 these values are given so that if we merely multiply the value of the inductance in microhenries by the value of the capacity in microfarads we obtain a certain result and by referring to this table we can locate the product of the inductance and the capacity in the column marked "LC." Then by referring to the column under "wave-length" the same line, we can tell the wave-length to which the circuit will respond or under the column K.C. the frequency is found. It can be seen that since this product of inductance and capacity is constant for a certain frequency, we could vary either the inductance or the capacity, but so long as the product of the two is the same we have not altered the frequency to which the circuit will respond.

Let us take a concrete example and see just how this table is used. Suppose we have a .0005 mfd. variable condenser and desire to know what inductance will be necessary in order to have the circuit respond to a wave-length of approximately 545.4 meters (550 kilocycles). By referring to the table in the column under "LC," we find that the product of the capacity and inductance is, for this frequency, equal to .083734. If the capacity is .0005, then by dividing the fraction .083734 by .0005, we can determine the inductance necessary. Thus, we find that the inductance should be a trifle more than 167 microhenries. Now suppose that we desire to know the lowest wave-length to which the circuit will respond. Unless the minimum capacity of the condenser is known, it is only possible to estimate this. Roughly, the minimum capacity of any variable condenser is approximately 10% of its maximum capacity. Therefore, the minimum capacity of a .0005 mfd. condenser is approximately .00005 mfd. In some cases the minimum capacity is lower than 10%, however, this is an average figure especially taking into consideration the capacity of the connecting leads to the condenser, etc.

Now if we have an inductance of 167 microhenries and we desire to know the minimum wave-length the circuit will respond to when tuned by a variable condenser having a minimum capacity of .00005, we multiply 167 by .00005 and obtain a result of .00835. Trying to locate this last figure in the column under "LC" we note that this figure is lower than the lowest, or first figure, given in this column and, therefore, the circuit will respond to some wave-length less than 189.87 meters (1580 kilocycles).

TABLE 2

VALUES OF INDUCTANCE CAPACITY

Inductance in Microhenries, Capacity in Microfarads

Wave Length	K.C.	$\sqrt{LC}$	LC	Wave Length	K.C.	$\sqrt{LC}$	LC
189.87	1580	.10072	.010144	291.2	1030	.15452	.023876
191.08	1570	.10138	.010277	293.9	1020	.15603	.024345
192.30	1560	.10202	.010408	296.9	1010	.15757	.024828
193.54	1550	.10268	.010543	300.0	1000	.15915	.025328
194.79	1540	.10334	.010679	302.8	990	.16076	.025843
196.07	1530	.10402	.010820	305.9	980	.16240	.026022
197.36	1520	.10470	.010962	309.1	970	.16407	.026919
198.67	1510	.10540	.011109	312.5	960	.16578	.027483
200.00	1500	.10612	.011261	315.6	950	.16787	.028080
201.34	1490	.10681	.011408	319	940	.16931	.028665
202.70	1480	.10753	.011562	322.4	930	.17113	.029285
204.08	1470	.10826	.011721	325.9	920	.17474	.030534
205.41	1460	.10900	.011881	329.5	910	.17489	.030590
206.89	1450	.10976	.012047	333.1	900	.17684	.031272
208.33	1440	.11052	.012214	336.9	890	.17882	.031976
209.79	1430	.11128	.012365	340.7	880	.18084	.032703
211.26	1420	.11218	.012566	333.3	870	.18293	.033463
212.76	1410	.11283	.012831	348.8	860	.18506	.034247
214.28	1400	.11368	.012922	352.9	850	.18724	.035058
215.82	1390	.11451	.013112	357.1	840	.18947	.035896
217.39	1380	.11530	.013294	361.4	830	.19175	.036768
218.97	1370	.11617	.013495	365.8	820	.19409	.037670
220.58	1360	.11700	.013689	370.3	810	.19649	.038608
222.22	1350	.11789	.013898	375.0	800	.19894	.038768
223.88	1340	.11878	.014008	379.7	790	.20146	.040584
225.56	1330	.11966	.014318	384.6	780	.20608	.042468
227.27	1320	.12056	.014534	389.6	770	.20668	.042716
229.00	1310	.12149	.014759	393.4	760	.20932	.043820
230.76	1300	.12254	.015026	400.0	750	.21220	.045028
232.55	1290	.12337	.015190	405.4	740	.21722	.047184
234.37	1280	.12434	.015460	410.9	730	.21802	.047532
236.22	1270	.12531	.015702	416.6	720	.22104	.048858
238.09	1260	.12631	.016050	422.5	710	.22416	.050247
240.00	1250	.12732	.016210	428.5	700	.22736	.051692
241.12	1240	.12848	.016507	434.7	690	.23065	.053199
243.90	1230	.12939	.016731	441.1	680	.23429	.054890
245.90	1220	.13045	.017017	447.7	670	.23754	.056425
247.93	1210	.13153	.017300	454.5	660	.24114	.058148
250.00	1200	.13261	.017585	461.5	650	.24545	.060240
252.10	1190	.13376	.017891	467.0	640	.24868	.061741
254.23	1180	.13487	.018189	476.0	630	.25264	.063826
256.41	1170	.13602	.018503	483.8	620	.25670	.065894
258.62	1160	.13722	.018829	491.8	610	.26065	.067938
260.86	1150	.13840	.019154	500	600	.26525	.070357
263.15	1140	.13961	.019490	508.4	590	.26975	.073874
265.48	1130	.14084	.019835	517.3	580	.27440	.075295
267.85	1120	.14213	.020201	526.3	570	.27922	.077963
270.1	1110	.14340	.020511	535.7	560	.28421	.080774
272.6	1100	.14468	.020932	545.4	550	.28937	.083734
275.1	1090	.14601	.021318	555.5	540	.29476	.086883
277.6	1080	.14736	.021713	566.0	530	.30030	.090180
280.2	1070	.14874	.022223	576.9	520	.30607	.093678
282.8	1060	.15010	.022530	588.2	510	.31207	.097387
285.5	1050	.15157	.022973	600.0	500	.31830	.099023
288.3	1040	.15303	.023418				

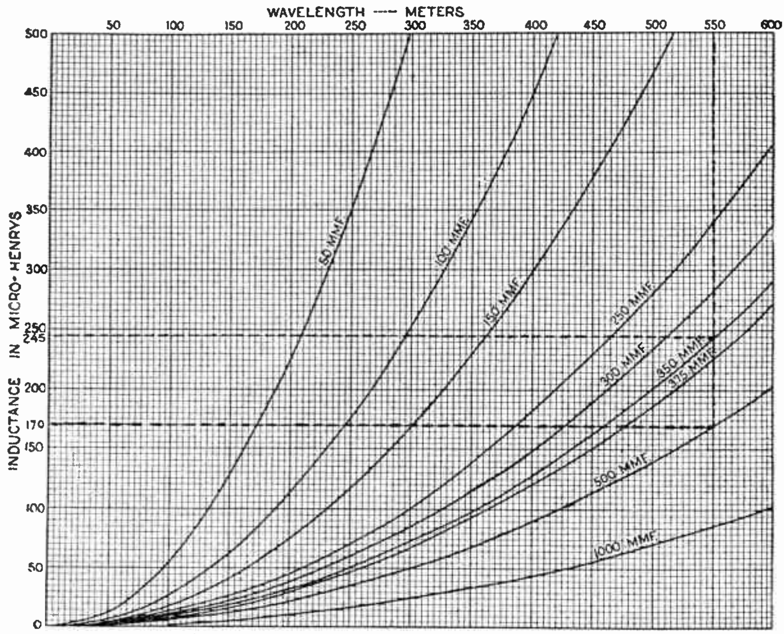
For those who are interested in designing coils by some means which does not necessitate the use of the formulas given, the following tables and charts will be found useful.

It might be interesting to take a few examples and work them out so as to show the flexibility of the charts. Suppose the receiver being designed requires a coil not more than 2 inches in diameter and 2½ inches long. In Figure 13 the 50 mmf. curve represents the curve for a .00005 mfd. condenser; the 100 mmf. a .0001 mfd. condenser; the 150 mmf. a .00015 mfd. condenser; the 250 mmf. a .00025 mfd. condenser; the 300 mmf. a .0003 mfd. condenser; the 350 mmf. a .00035 mfd. condenser; the 375 mmf. a .000375 mfd. condenser; the 500 mmf. a .0005 condenser and the 1000 mmf. curve a .001 mfd. condenser.

If the maximum wave-length to be reached with a .0005 condenser is 550 meters then locate this wave-length on the upper horizontal line and follow this point downward until it intersects the 500 mmf. curve. It will be noticed that the 550 meter line intersects the 500 mmf. line 4 spaces above the 150 line shown to the left representing microhenries. The dotted line running from the intersection of the 550-meter line to the left-hand column indicates then that the inductance should be 170 microhenries. Now refer to Figure 15 for coils 2″ in diameter and on the left-hand column locate the point 170 microhenries. Then following this to the right to the 2½″ curve, which represents coils 2½″ long, the intersection occurs directly under the line representing 30 turns per inch. Therefore, then, the coil should be wound with some wire having such a diameter that 30 turns to the linear inch can be wound. Referring then to Table 3, showing the number of turns per inch for the various size wire, we find that the coil could be wound with No. 20 enamel, No. 20 SS, or No. 22 DCC wire as all of these have a diameter so that approximately 30 turns per inch can be wound.

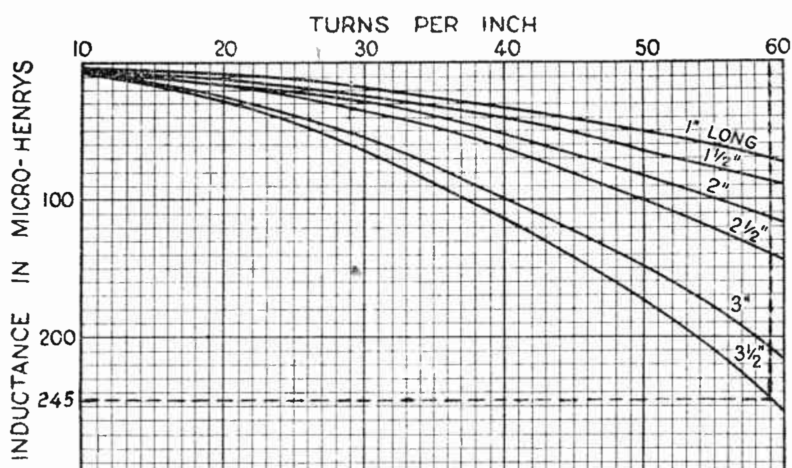
The given example shows that one can decide on the coil and determine the number of turns per inch for the most suitable condenser, or can decide on the condenser and determine the physical characteristics of the coil necessary to cover the desired wave band most suitably.

Let us work out a more practical example. Suppose we wish to use a variable condenser having a maximum capacity of 350 mmf. (.00035 mfd.). This is a good value and the curve for this capacity in Figure 13 is not too abrupt in its upward bend. If 550 meters is the highest wave-length we wish to reach, we



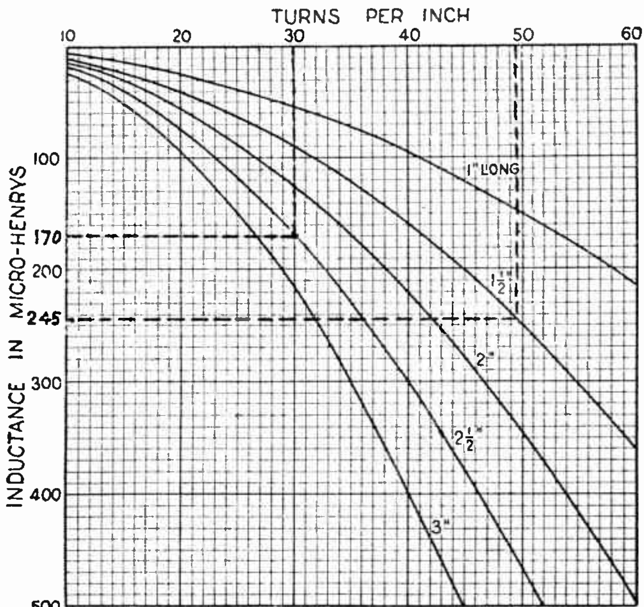
INDUCTANCE - CAPACITY CURVES

Fig. 13



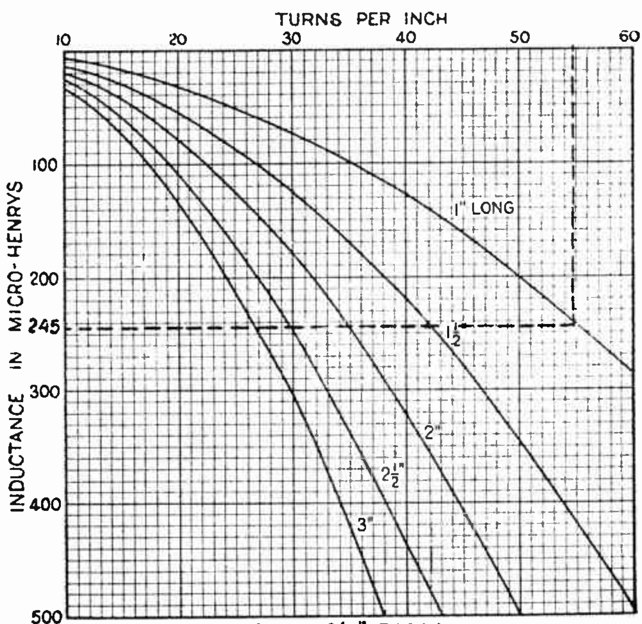
COIL 1" DIAM.

Fig. 14



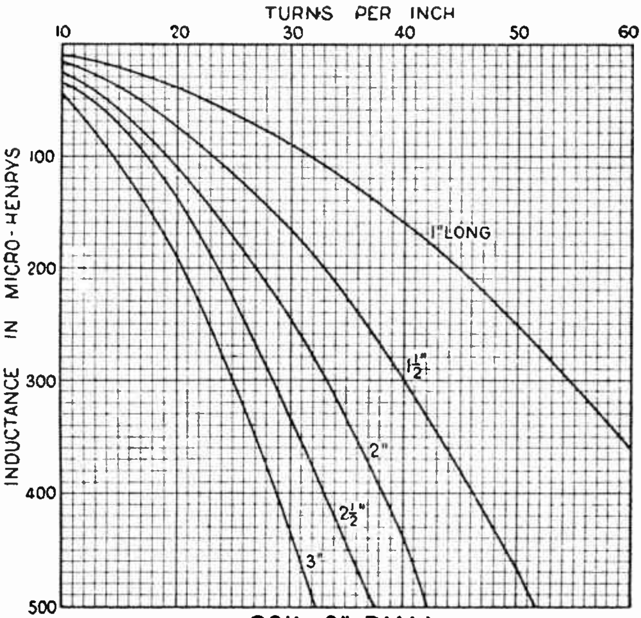
COIL 2" DIAM

Fig. 15



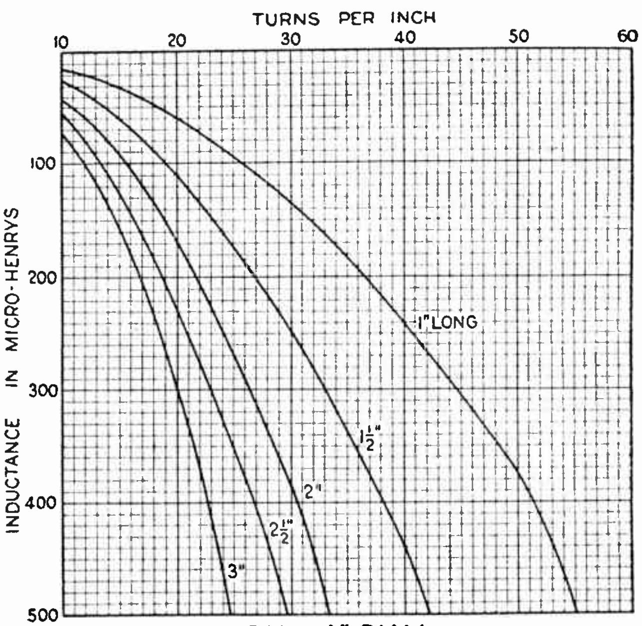
COIL 2½" DIAM.

Fig. 16



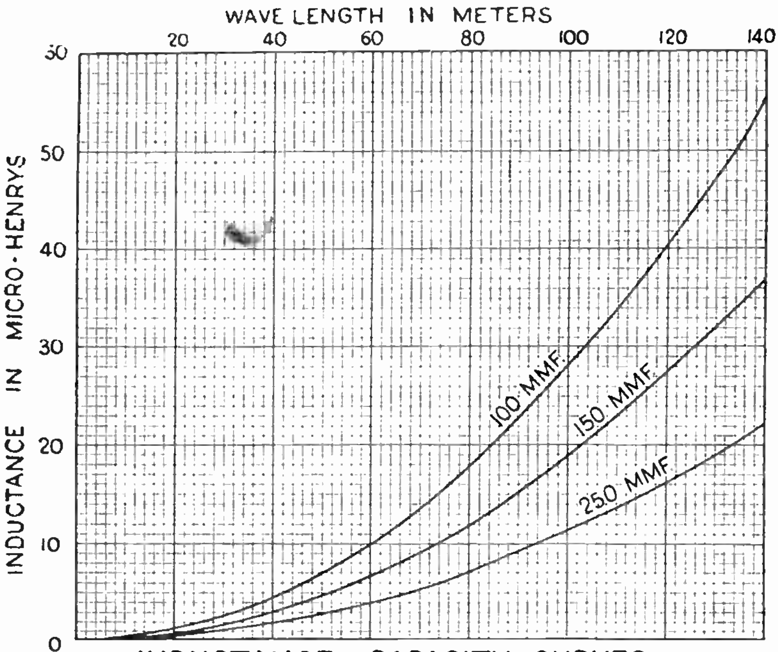
COIL 3" DIAM

Fig. 17



COIL 4" DIAM.

Fig. 18



INDUCTANCE - CAPACITY CURVES
Fig. 19

TABLE 3

WIRE TABLE

		TURNS PER LINEAR INCH			
B & S Gauge	Enamel	Single Silk	Double Silk	Single Cotton	Double Cotton
16	18.9	18.9	18.3	17.9	16.7
18	23.8	23.6	22.7	22.2	20.4
20	30	29.4	28.0	27.0	24.4
22	37	36.6	34.4	33.9	30.0
24	46	45.3	41.8	41.5	35.6
26	58	55.9	50.8	50.2	41.8
28	73	68.5	61.0	60.2	48.6
30	91	83.3	72.5	71.4	55.6
32	116	101	84.8	83.4	62.9
34	145	120	99.0	97.0	70.0
36	182	143	114.0	111.0	77.0
38	228	168	129	126.0	84.0
40	286	194	144	140.0	90.0

find that by referring to Figure 13 the value of the inductance required is a shade under 245 microhenries. Now, by referring to the chart of Figure 14, for a coil 1″ in diameter, it will be found that it is just possible to reach an inductance value of 245 microhenries by using a coil 3½″ long. However, a coil 2″ in diameter as shown by the curve in Figure 15 is satisfactory providing it is an even 1½″ long. If we increase the diameter of the proposed coil to $2\frac{1}{2}''$, it need be only $1''$ long (Fig. 16) to reach the required inductance, but a wire capable of being wound 55 turns to the inch would be required. The most satisfactory coil would probably be one with a diameter of $2''$ and a length of $2\frac{1}{2}''$. One of the reasons for this is that a coil of less length would require a small gauge wire in order to get the necessary number of turns per inch of coil.

The exact number of turns for the primary of a radio frequency transformer depends somewhat on the circuit in which the transformer is used and also the exact type of apparatus used in the construction of the entire receiver. If too many turns are used on the primary winding the Radio frequency tubes will oscillate. Therefore, the primary windings should be so designed that the tubes are just below the oscillation point.

Generally speaking, the primary winding is approximately one-third of the secondary winding. The exact number can be determined only by experiment, although 15 to 25 turns are generally used.

TEST QUESTIONS

Number your answer sheet 16-2 and add your **student number.**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

1. How may a voltage be induced in a coil of wire?
2. What is inductance?
3. What two effects does an inductance have upon an alternating current?
4. When are two circuits said to be coupled?
5. Define an oscillatory circuit.
6. What governs the damping of a circuit?
7. What term is used to denote that the inductive and capacitive reactance just balance each other?
8. What is the wave-length of a circuit when "LC" equals .028665?
9. What is the approximate value of inductance to use with a .00035 mfd. condenser in order to tune to a wave-length of 550 meters.
10. Give the size and kind of wire to use when it is desired to make a coil 1 inch long having 27 turns.

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REGENERATION, OSCILLATION AND NEUTRALIZATION

Originators of Radio Home Study Courses
··· Established 1914 ···
Washington, D. C.

CONCENTRATION ESSENTIAL

A Personal Message from J. E. Smith

Essential to effective study is concentration. The posture in which a person is best able to concentrate is the best posture for study so far as that person is concerned.

A similar state of affairs is discovered when one comes to consider the best time for study. There is no best time for study, for all students. The puritan view, still held to a considerable extent in some quarters, is that study can best be done in the early morning. However, there are persons who are especially fond of the early morning air and light and like to arise to enjoy them. Other persons reach their maximum effectiveness in study in the early afternoon. Still others, late at night. The thing is partly a matter of habit; partly, in all probability, a matter of one's nervous condition.

Most of us, of course, have to fit our study in with other work, we cannot arbitrarily set apart what hours we please for study. We can, however, exercise some choice among our spare hours. Most of us can at least determine to study either in the early morning or in the evening, whichever time we find by actual experience will be best suited to us.

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NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

REGENERATION, OSCILLATION AND NEUTRALIZATION

A preliminary definition usually gives one a fair understanding of the subject to be dealt with. With this in view, the three definitions below are given before proceeding with a detailed study of the underlying principles of each.

Regeneration is the process of "feeding back," in proper phase, energy from the plate or output circuit of a vacuum tube, into the grid or input circuit so as to strengthen the oscillations in the grid circuit and gain additional amplification.

Oscillation or Oscillating as applied to a vacuum tube is the state or condition of a vacuum tube and its associated circuits where regeneration has been increased to the point where the tube and its oscillatory circuit act as a generator of self-sustained oscillations (alternating current).

Neutralization is the process of "feeding back" opposite phase energy from the output circuit, or from another circuit, into the grid or input circuit so as to decrease regeneration and prevent oscillation.

Read these definitions over several times so as to implant them in your memory forever.

THE ARMSTRONG REGENERATIVE FEED-BACK CIRCUIT

It is possible to take a simple vacuum tube circuit and make certain additions to it and by the proper adjustment to increase its sensitiveness several times. The special addition that is necessary is usually a plate coil which is in series with the plate circuit and in inductive relation with the grid circuit, so that any changes in the plate current will induce additional voltage into the grid circuit. This idea was developed and patented by E. H. Armstrong and is known to all as the "Armstrong Feed-Back Circuit."

One of the easiest ways of using the Armstrong idea is given in connection with Figure 1. It will be seen that this circuit is practically the same as some of the circuits previously given in the earlier texts with the exception that there is now an extra coil placed in the plate circuit. This coil known as the tickler coil is connected magnetically to the coil in the local tuned circuit L1 C1. By connecting magnetically, we mean that the two coils are placed in such position with respect to each other that when the magnetic field of one changes, it induces a voltage in the other.

HOW THE TICKLER COIL WORKS

A simple explanation of the action of the tickler coil and the effect produced in the tuned circuit L1 C1 is as follows: The signal current flowing in the antenna induces voltages in the local tuned circuit L1 C1 which is tuned to the signal frequency. Current is thus caused to flow in the L1 C1 circuit and it is to be remembered that this current is really caused to flow because of the effect of the changing magnetic field set up in L by the signal current, acting on coil L1 to produce voltage in L1. The grid potential will go up and down at the same frequency as the signal

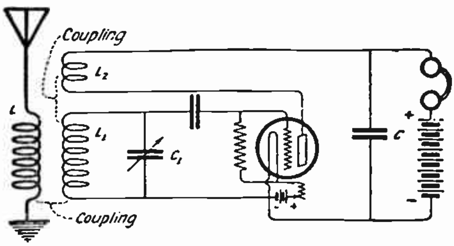

Fig. 1—Armstrong Regenerative Circuit.

current and so will cause the plate current to rise and fall correspondingly. This changing plate current flowing through coil L2 will give here a corresponding changing magnetic field which reaches out from L2 to L1 because of their proximity. This changing magnetic field in L1 from L2 will so act as to give a voltage in L1 which helps out the voltage induced in L1 by the signal current in the antenna. In other words, the changing plate current caused indirectly by the signal current in the antenna, so acts as to help the signal current in the antenna to produce bigger currents in L1 C1. It is the amount of current in L1 C1 which determines the strength of the signal heard in the telephones. The regenerative action, as it is called, is controlled in amount by the proximity or relative position of coil L1 and the tickler coil L2. The closer these coils are together, the greater is the regenerative action and the louder is the signal up to a certain limit. If the magnetic coupling of L1 and L2 is made too tight, the tube circuit may give all kinds of queer noises—sometimes a series of clicks at the rate of one or more per second or humming or squealing noises, depending principally on the size of the grid condenser and grid leak. If such noises are obtained, the coupling between the tickler coil L2 and L1 should be reduced until they disappear.

THE TUNED PLATE CIRCUIT

Another form of regenerative circuit is shown in Figure 2. In this case, it will be noted that instead of having a tickler coil magnetically coupled to the grid coil, we have two variable inductances in the form of variometers. One of these inductances (L2) is in the grid circuit so as to tune this circuit to resonance with that of the desired signal and make this circuit responsive to the same frequencies. The second variable inductance (L3)

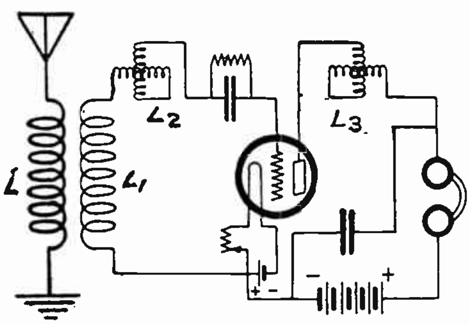

Fig. 2—Tuned grid and plate regenerative circuit.

is included in the plate circuit and by tuning this circuit to resonance with the grid circuit and incoming signal, regeneration can be accomplished as in the tickler feed-back method previously described. As the plate circuit of the tube is tuned and brought into resonance with the grid circuit, a feed-back of energy from the plate to the grid circuit takes place through the capacity existing between the grid and plate of the tube. It can be seen by looking at Figure 2 that the grid and plate act as the plates of a condenser with a potential applied to each plate and any fluctuations in the plate or grid circuit voltages will charge and discharge this condenser, causing a transfer of energy between these circuits. Therefore, then, as the plate circuit is tuned or brought into resonance with the grid circuit, a transfer of energy will take place between the two circuits and any change in voltage or current in the plate circuit will be impressed on the grid circuit. This, then, tends to increase regeneration by introducing into the grid circuit a voltage from the plate circuit, and. as this voltage is in phase with the voltage of the grid circuit, it strengthens and builds up the grid circuit oscillations resulting in regeneration.

HOW "FEED-BACK" INCREASES SENSITIVITY

The statement has been made that by feeding back a voltage from the plate circuit into the grid circuit, the oscillations will be strengthened and this in turn strengthens the plate current which passes through the head telephones or loudspeaker device and thus a louder response is heard. Let us go further into this subject and see just how this is accomplished and what takes place in the tube circuits when a voltage is fed back from the plate circuit into the grid circuit.

The following explanation of regeneration is based on the action of the resistance in an oscillatory circuit. It is the basis

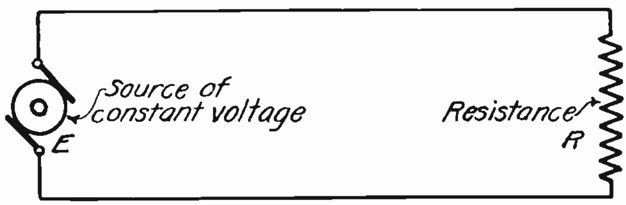

Fig. 3—Constant voltage forcing current through a resistance.

of the understanding of just what takes place in an oscillatory circuit and how regeneration can be accomplished.

In order to bring out the exact condition and just what takes place in this circuit, it will be necessary to review some of the elementary circuits and see what happens in them and then apply the principles learned to the circuit under consideration at the present time.

Figure 3 represents an electric circuit containing a source of voltage E, and a resistance R connected in series. If the voltage is constant in value, a current also constant in value will flow through the circuit and the value of the current will be limited by the resistance. The smaller the resistance, the greater the current and vice versa. In this case, maximum current value is reached almost instantly. There is nothing to retard the flow of current except the resistance and the voltage instantly forces the current through this resistance.

If the same constant potential is applied to a circuit containing resistance and inductance in series, as in Figure 4, the current does not reach its maximum value immediately, but gradually rises from zero to its final value. The reason that the current takes some time to reach its final value is that the inductance in an electric circuit behaves as an inertia and retards the growth of current. Such a circuit is said to have a time constant which depends upon the value of the inductance and resistance. This time constant is a measure of the length of time it takes for the current to build up to its final maximum value.

If in the above circuit containing an inductance and resistance, there is a current flowing and the impressed voltage is removed, the current will gradually drop to zero. When the voltage is removed, the current that is flowing has all its energy dissipated in the resistance in the circuit and since there is no longer an impressed voltage to maintain this current, it dies down to zero. The greater the resistance, the less time it takes for the

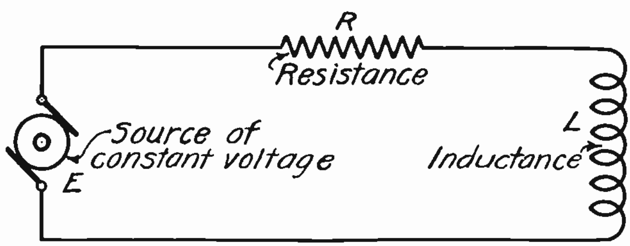

Fig. 4—Constant voltage forcing current through a resistance and inductance.

current to die down to zero; the less the resistance, the more time it takes for the current to die down to zero. Suppose that while the current is still flowing, the resistance, by some means, is reduced to zero. What happens? At the instant the resistance is reduced to zero, the current has a definite value. Since there is now no resistance to consume the energy of the current and there is no resistance to oppose the flow of current, the latter will continue to flow in the circuit regardless of the presence of the impressed voltage. This is a very important fundamental truth and should be mastered so that the following statement can be understood. If the impressed voltage is removed at the instant the resistance of the circuit decreases to zero, then the current will continue to flow for a certain time and at that value which it had at the instant the impressed voltage was removed.

Let us now consider oscillating current circuits, as in Figure 5; namely, circuits containing resistance, inductance and capacity. The principles and facts outlined previously for direct current hold here also, except for these changes; in the first place, the current is oscillating or alternating. When the oscillating voltage is applied, an oscillating current flows and builds up in the circuit gradually. As with direct current, it takes an appreciable time for the oscillating current to build up to its maximum value. The time it takes is again determined by the time constant of the circuit which, in this case, is determined by the value of the inductance, capacity and resistance.

This current which builds up in value when the voltage is impressed is called "forced oscillation," since the existence of the current depends solely upon the presence of an applied external voltage. The frequency of this "forced oscillation" is the same as the frequency of the impressed voltage, regardless of what the natural frequency of the circuit is.

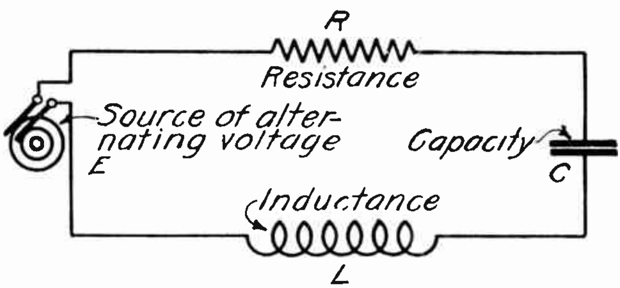

Fig. 5—Oscillatory circuit with an A. C. voltage applied.

When this applied alternating voltage is removed, the forced oscillating current decreases to zero exactly as in the case of direct current and for the same reason. The time it takes for the current to drop to zero depends largely upon the value of the effective resistance in the circuit. The greater the resistance, the less time it takes for the energy of the current to be consumed and hence the less time it takes for the current to drop to zero and vice versa. When the current drops rapidly to zero, it indicates that the effective resistance is extremely high. The circuit is then said to be "highly damped" and the circuit has a high decrement and vice versa.

Thus far the action of the oscillatory circuit is the same for alternating current as the action of the previously described circuit for direct current. We now come to an important difference. An oscillatory circuit has a natural frequency of vibration or oscillation of its own. This natural period is determined by the value of inductance and capacity in the circuit. If an instantaneous electrical impulse of any sort is applied to such a circuit, it will vibrate—i. e.; an oscillatory current will flow through it and the frequency of this oscillation will be the same as the natural frequency of the circuit. Such an oscillation is called a "free oscillation." This free oscillation dies down to zero after the voltage pulse is removed for the same reason and in exactly the same way as the forced oscillation when the impressed voltage is removed.

Thus when an external alternating voltage is applied to an oscillatory circuit, two oscillations result; one, a forced oscillation having the same frequency as the applied voltage, in which the oscillations last as long as the voltage is impressed; two, a free oscillation having the same frequency as the natural frequency of the circuit. While the forced oscillation persists during the time the voltage is impressed, the free oscillation dies out. The forced oscillation overcoming the free oscillation.

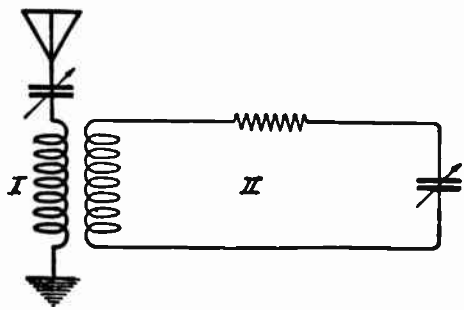

Fig. 6—Applying the antenna signal voltage to an oscillatory circuit.

In place of the alternating current generator applying the impressed voltage to the circuit, you may consider the generator replaced by an antenna circuit inductively coupled to an oscillatory circuit as shown in Figure 6. In this case, the voltage impressed on the oscillatory circuit will be that due to the voltage induced in the circuit by the signal voltage in the antenna circuit. The forced oscillation in circuit II will have the same frequency as the signal voltage in the antenna circuit I and the free oscillation will have the frequency of circuit II. The value of these oscillations will be a maximum, however, when the two circuits are in resonance—i. e., when the frequency of the antenna circuit I and circuit II coincide.

In this case, the forced and free oscillations will have the same frequency. This is the general case in all Radio circuits, since Radio circuits coupled to each other are generally tuned to each other.

In the general case here described, it is the forced oscillation which is of the greatest importance and the free oscillation which is of negligible importance as far as the production of signals is concerned. The free oscillation, while it lasts a finite time is practically instantaneous and dies down to zero, while the forced oscillation persists as long as the applied voltage (which is the received signal in the antenna) lasts, which is many times longer than the free oscillation.

Now as the effective resistance in the circuit decreases, the oscillating current for a given voltage increases. When the effective resistance reaches zero, the current has reached a very large value. If now the impressed voltage is removed, the current continues to flow in the circuit at the value it had when the voltage was removed. Once the current has been started in a circuit and the effective resistance reduced to zero, this current will continue to flow, regardless of the presence of an external voltage, since there is no resistance to consume this energy or damp the cur-

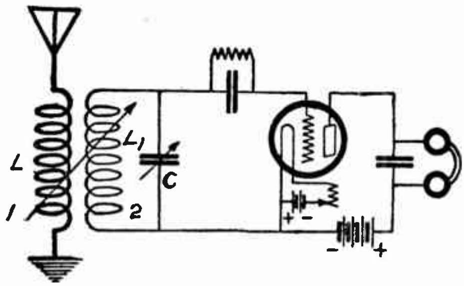

Fig. 7—A non-regenerative vacuum tube circuit.

rent. As there is now no impressed voltage and current flows, this current may be regarded as free oscillation.

Let us now consider the application of the above outlined principle to the regenerative receiver. Figure 7 is a circuit diagram of a simple Non-Regenerative receiver. The signalling voltage in the antenna is impressed by induction on the secondary circuit 2 consisting of L1 C1 and a free and forced oscillation will, therefore, flow in the secondary circuit. The free oscillation dies out in a very short period of time, as explained above, while the forced oscillation builds up in value until its further growth is limited by the resistance of the secondary circuit. As a result, the audibility will be limited in the same way. If it were now possible to introduce some means whereby the resistance of the secondary circuit could be gradually decreased, there would result a corresponding increase in the oscillatory current, thus producing louder signals. This is the effect that occurs in the regenerative receiver.

To understand how this is accomplished, suppose we connect in series with the telephones in Figure 7 a coil T whose position may be altered with respect to the secondary coil L such as in Figure 8. This coil T called the tickler, produces regenerative action. Suppose the position of this coil is such that it has no effect on the coil L, thus its axis may be perpendicular to the axis of coil L or it may be at a considerable distance from coil L so that in either case there is no transfer of energy from one coil to the other by induction. In this case, conditions will be practically the same as for the circuit in Figure 7; i. e., the signal is just simply limited, for a given received voltage, by the circuit resistance.

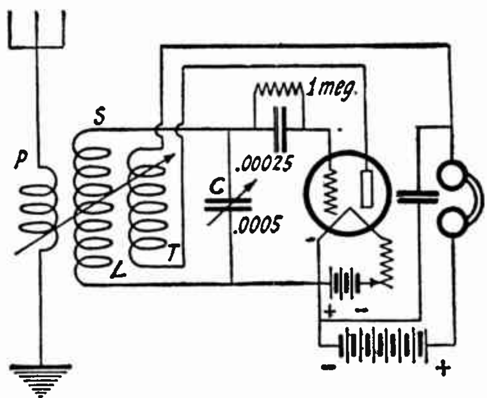

Fig. 8—Coupling a tickler coil to the grid coil to secure regeneration.

Now suppose that the tickler coil T in Figure 8 is changed in position so that it is either moved up closer and closer to coil L, or it is located so that its axis is more and more parallel to the axis of coil L. The coupling between the coils is thus increased, and due to this increased coupling, there will be a greater transfer of energy between the two circuits. A voltage will be induced in coil L by the current in tickler T, and as the coupling increases, this induced voltage will also increase. This induced voltage will have the effect of overcoming or counteracting the opposing resistance reacting on the entire circuit, thus resulting in increasing the oscillation current over its original value. The more the tickler coupling is increased, the larger is the voltage induced in coil L and the more is the circuit resistance counteracted, with the result that both current and signal strength become greater and greater. In other words, the effect of regeneration is to decrease the effective resistance of the oscillatory circuit by introducing additional voltage of the same frequency and phase, thereby, resulting in large increases in current and greater audibility of the signal. As the regeneration increases, we see that in effect the resistance of the circuit is made to decrease.

Hence, from the principles explained earlier in this lesson, it will take a longer time for the free oscillations to die out, for the smaller the resistance in the circuit, the less the damping of the circuit. Now suppose the coupling between the tickler and coil L is made so close that the voltage induced in coil L is sufficient to counteract entirely the effective resistance. In this case, the resistance of the circuit will in effect be reduced to zero. Since there is no effective resistance now to impede the flow of current, the free oscillations will continue to flow. However, when the effective resistance of the circuit drops to zero, the circuit becomes unstable and hence slight variations in filament current, plate voltage, or in the circuit will result, generating self-sustained oscillations, which will destroy any amplification. These self-sustained oscillations will have a paralizing effect on the tube, and will drown out any other oscillations which may be present.

This, then, is the limiting condition of regenerative amplification. So long as the tickler coupling does not result in completely nullifying the circuit resistance, regenerative amplification can be obtained. As soon as the coupling becomes great enough, resulting in reducing the circuit resistance to zero, the free oscillations persist and destroy any amplification of signal voltage which may have been secured.

What, then, regenerative amplification accomplishes is this: It reduces the circuit resistance from a high value to an extremely low value, but higher than zero, and thereby increases the current to a very large value; hence, also, the increase in audibility.

SUPER-REGENERATION

Apparently, further amplification which might be obtained by a continued increase in regeneration—i. e., a continued decrease in circuit resistance below zero to negative values, is prohibited by the introduction of self-oscillation. It is obvious that if this decrease in circuit resistance could be effected without the introduction of self-sustained oscillations, amplification of enormous values would be obtained.

In this case, we would have a circuit with a negative resistance. We learned how a positive resistance had the effect of limiting the value of forced oscillation current, and damping out the free oscillation current. We also learned that when the resistance in the circuit was reduced to zero, the forced oscillation current was maintained at the value it had when the resistance became zero, while the free oscillation was not damped out, but continued to flow at the value it had when the resistance became zero. When a circuit has a negative resistance, not only is there no resistance to limit the value of the forced oscillation

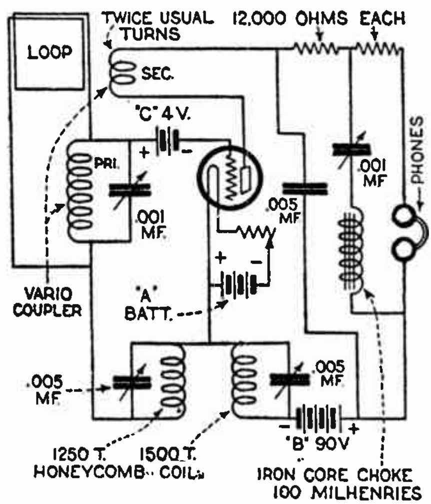

Fig. 9—A typical super-regenerative circuit.

current or to damp the free oscillation, but an exactly opposite effect is had—namely: whatever free oscillation current there is in the circuit at the time the resistance should become negative, steadily increases in value and approaches infinity.

In the case of the circuit having a positive resistance, it was noted that it was the forced oscillation which was of dominant importance, most of the energy being in the forced oscillation. However, in the case where the resistance is negative and the free oscillation steadily increases in value, it is this free oscillation which is of major importance and the forced is of minor importance. Furthermore, this free oscillation has the property of starting with a value which is proportional to the applied voltage (in the case of the signal, it is proportional to the antenna voltage), and during any finite period of time the free oscillation maintains this proportionality. Hence, it will be seen that since the free oscillation in a negative resistance circuit may rise to enormous values, and since this value is proportional to the applied signaling voltage, it will repeat the transmitted signal with tremendous amplification, provided the circuit does not break into self-oscillation which will destroy any amplification.

As in regeneration, so in this case, it is the self-oscillations, which are generated when the circuit resistance becomes unbalanced, that destroy the amplification which would otherwise be obtained. If some means could be devised to prohibit the generation of these paralizing self-oscillations, the tremendous amplifying effect of the free oscillations could be secured. This is precisely what is done in the Armstrong Super-Regenerative receiver.

Armstrong discovered that if a regenerative circuit having a negative resistance is made positive at intervals so that the circuit is alternately positive and negative, the circuit will not generate self-sustained oscillations which will paralize amplification. It takes a certain finite time for a negative resistance circuit to break into self-sustained oscillation. Up to the instant when the circuit is ready to generate the undesired oscillations, the circuit resistance is negative and hence the enormous amplification possible with this circuit is secured. At the instant when the circuit is ready to oscillate on its own, it is made to have a positive resistance, thus restraining the tendency to oscillate and the amplification secured is, therefore, not destroyed. In Figure 9, we have a circuit diagram of a typical Armstrong Super-Regenerative receiving set.

OSCILLATION

By referring to the definition of Oscillation or Oscillating Vacuum Tube as given in one of the earlier pages of this lesson, it can be understood that under certain conditions a vacuum tube can be caused to act as a generator of alternating current.

In reality, of course, a vacuum tube does not act as a generator of alternating current because it has a direct current applied to its plate circuit and, therefore, it in reality acts as a converter of power and changes direct current into alternating current of a definite frequency.

From the preceding explanation of regeneration, it was seen that when the feed-back voltage from the plate into the grid circuit becomes great enough to make the resistance of the oscillatory circuit zero, then, the tube will act as a generator of self-sustained oscillations. Thus, oscillation is merely a step further in regeneration, or it is over-regeneration because regeneration increases up to the point where the induced voltage reduces the oscillatory circuit resistance from a positive value almost to zero and then beyond this point regeneration is known as oscillation.

By referring to Figure 8, it is noticed that a tickler coil is placed so as to feed back some voltage from the plate circuit to the grid circuit. It was not stated previously that before regeneration can take place a certain condition must be met. This condition is that the connection to the plate or tickler coil

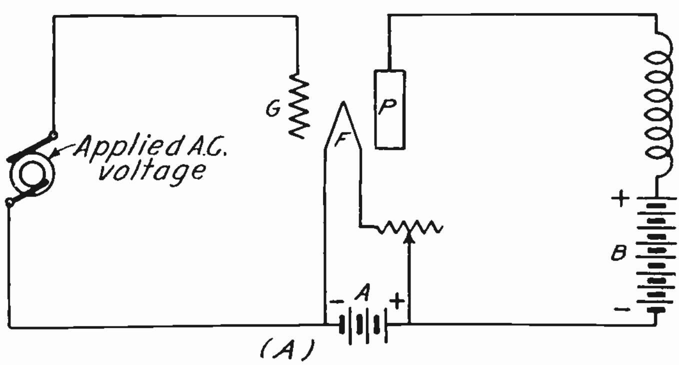

Fig. 10A—Alternating current applied to the grid circuit of a vacuum tube.

must be such that the voltage induced in the grid coil will be in phase with the voltage in the grid coil and assist it to build up the oscillatory circuit voltage. If the induced voltage be out of phase with the oscillatory circuit voltage so that it is directly opposed to it, then the induced voltage will not be assisting the voltage in the grid circuit and it will not build up the oscillations but will diminish and decrease them. From this, it can be seen that the magnetic field set up by the tickler coil must be such that the induced voltage will be in phase with the voltage in the grid circuit. If this magnetic field of the tickler coil caused by the variations in the plate current induces a voltage of opposite phase in the grid circuit, then oscillation and regeneration will not take place. This magnetic field can be reversed by reversing the connections to the tickler coil, because the plate current flows only in one direction and merely varies in magnitude.

Let us go further into the action of the vacuum tube as a generator of alternating current and see what happens in the plate circuit. Steady quantities of plate current, plate voltage and grid voltage do not enter into consideration except as they fix the plate circuit resistance, etc. The plate current of an oscillating tube can then be regarded as an alternating current. (The student should bear in mind that actually, of course, the plate current is a fluctuating one, and that it never reverses its direction of flow but is regarded as an alternating current because the variations in the plate current follow the variations in the alternating voltage applied to the grid). Under ordinary circumstances, we can treat the plate current as if it were a purely alternating current because it fluctuates in a positive and negative direction above and below its average value and follows all the laws of an alternating current, but it must be borne in mind that this is a varying plate current and not a strictly alternating current which periodically reverses its direction of flow.

The voltage which produces the alternating component of the plate current is impressed on the grid; this alternating grid voltage produces changes in the plate current just as though an alternating voltage had been introduced directly in the plate circuit. But, the grid voltage is much more effective in controlling the plate current than would be the same voltage introduced directly into the plate circuit, and is greater by the amplification factor of the tube. We can, then, consider a three element oscillating vacuum tube, having an alternating voltage impressed on the grid and filament and compare it to another vacuum tube having an alternating voltage in the plate circuit equal to the grid voltage applied to the first vacuum tube but greater than this by the amplification factor of the tube. We, then, forget the grid of the tube exists, except when it is necessary to consider the amount of current taken by the grid, but this sometimes has an important effect on the operation of the tube.

This viewpoint is illustrated in the diagram shown in Figures 10A and 10B. In Figure 10A is shown the actual circuit, with the B battery forcing the plate current to flow. This current is made to increase and decrease by the action of the alternating voltage applied in the grid circuit. The equivalent circuit is shown in Figure 10B and this is the one we use in deriving the relation of current and voltage of the oscillating tube. We suppose there is an alternating current generator between the filament and plate, generating a voltage greater than the voltage which was applied to the grid circuit of the tube in Figure 10A by the amplification factor of the tube and that the internal resistance of this generator is equal to the internal resistance of the three element tube. This plate resistance depends for its value on the steady voltages used in the grid and plate circuits.

Actually in a three element vacuum tube the value of the plate resistance varies with the magnitude of the plate current (alternating component), not only increasing when too much current is drawn from the tube, but actually varying during the cycle. It can be noticed by referring to Figure 10B that the alternating current generator will increase and decrease the voltage which is applied between the plate and filament of the tube

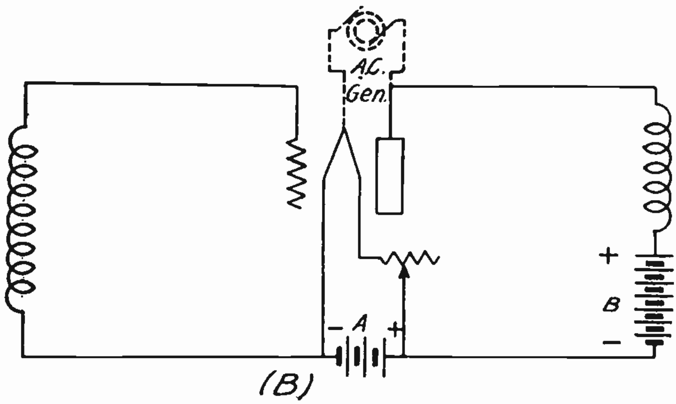

Fig. 10B—Theoretical circuit for illustrating alternating component of plate voltage and current.

and this increase and decrease of voltage will cause an increase and decrease of plate current accordingly. Therefore, then, we have an alternating component of plate current which rises and falls from a steady value and this rising and falling is in exact accordance with the alternations of the generator.

It can then be understood that an alternating voltage applied to the grid circuit of a tube produces an alternating component on the plate current which rises and falls according to the alternations applied to the grid.

Since there is no time existing between the application of the grid voltage and the change produced in the electronic stream and plate current, therefore, the plate current is in phase with the grid voltage. Now let us see what happens in regard to the plate voltage and grid voltage. Due to the fact that an inductance is inserted in the plate circuit, making it necessary for the plate current to flow through this inductance, we find that this inductance throws the plate current and plate voltage out of phase. The actual relation is that the alternating component of the plate voltage is 180 degrees out of phase with the plate current. This is an important factor which must be borne in mind and which will be made use of later on.

In order for a vacuum tube to operate efficiently as a generator of alternating current power, it is necessary that certain conditions must be fulfilled. One of these requirements is that there must be some sort of load or resistance in the plate circuit which is equal to the plate resistance of the tube. It is also necessary to have such reactions occurring in the circuit to which the tube is connected so that when the plate current undergoes variations, the plate potential and grid potential both undergo the same variations of potential in opposite phases, and that the relative magnitude of these two potential variations be properly adjusted for the tube being used. The fundamental requirements of the problem can be readily specified. There must be a coupling between the plate circuit and the grid circuit so that variations in the plate current produce voltage variations in the grid circuit. This coupling between the two circuits must be such that the voltage induced in the grid circuit is in phase with the grid voltage and will assist any oscillations occurring in this circuit. Also, the voltage introduced into the grid circuit must be of such an amount that it will change the normal voltage of the grid and thus react and cause variations in the plate current accordingly; the plate current can then react and introduce further variations in the potential of the grid.

Since any variations in the potential of the grid cause similar variations in the plate current and then the plate current reacts on the grid voltage, it seems that there is some limit to this cycle or else we would have a continually increasing potential applied to the grid circuit. The limiting factor in this case can be determined, of course, from the fact that the plate current can never reverse its direction of flow. The variations in the grid voltage, no matter how great, can never cause a reversal in the flow of the plate current and the most that can be done is for the grid to become so negative that it will actually cut off any flow of current in the plate circuit. When this condition is reached, then the capacity of the tube is reached and further increases in the variation of the grid voltage will not cause any further variations in the plate current, because the plate current is cut off entirely for a certain amount of time. The reason why the plate current is cut off for a certain length of time, of course, is due to the effect on the electronic stream flowing between the filament and plate of the tube when the grid becomes negative. Since this electron stream flows in one direction only, therefore, the plate current can only flow in one direction only, and since the negative values of grid potential produce a decreasing plate current, then the limiting factor of oscillation is for the grid to become so negative that it will actually stop the flow of any plate current at all.

RECEPTION OF UNMODULATED CONTINUOUS WAVES

If an unmodulated continuous wave signal is impressed upon the grid circuit of a non-regenerative detector, there will not be any response in the headphones or loudspeaker. This is due

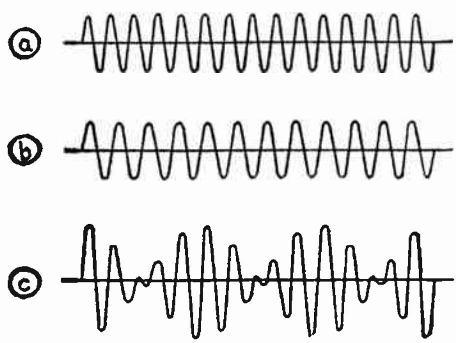

Fig. 11—Graphical representation of the "beat" principle.

to the fact that the radio frequency potentials applied to the grid cause corresponding radio frequency variations in the plate current and if the amplitudes of these variations do not change in an audible manner, then the headphone or loudspeaker cannot make a sound because there is no audio frequency variation and the diaphragm on the loudspeaker cannot respond to the radio frequency variations of the plate current and if it could, the human ear would not respond to such high frequency variations. This has previously been explained under "Detection" and the necessity for modulation or varying the amplitude of the radio frequency wave was brought out.

Since most radiotelegraph stations now use continuous waves instead of damped waves, some means must be provided whereby it is possible for a vacuum tube detector to detect the presence of these signals. Radio invention, therefore, borrowed from the musical science and other sciences some principles which have long been known in these sciences. One of these principles is the adaptation of "beat" or the combination of two different frequencies in order to produce a frequency entirely different to either of the two.

We are not all musicians but most of us have had the experience of listening to some kind of a musical instrument. Take for example a piano. If one key of the piano is pressed, a certain note is heard. If another key is pressed, another note is heard. Now, if two keys are pressed at the same time, the combination of the sound produced is entirely different from the sound produced when either of the keys were pressed separately. This is due to the fact that each string of the piano which was caused to vibrate by the touching of the key had a definite frequency and vibrated at this definite frequency. When the two keys were touched, we had two different strings vibrating at different frequencies and each emitting sound waves of a different frequency. These different vibrations when received by the ear produced a third vibration which was equal to the difference between the two vibrations. In the first case, suppose that the first key which was touched caused the string to vibrate at a frequency of 1,000. If the second string vibrated at a frequency of 800, then the third frequency produced by the combination of these two frequencies was 200, which is equal to the difference between the frequencies of the two strings. When such a condition exists and a third frequency or sound is generated, caused by the combination or the mixing of two other frequencies or sounds, it is referred to as a "beat" or "beat frequency."

Similarly, if two sources of undamped electrical oscillations of constant amplitude act simultaneously upon the same circuit, one having a frequency of 1000 kilocycles and the other a frequency of 1001 kilocycles per second, we will also have a beat frequency existing in the circuit having a frequency of 1 kilocycle. The amplitude of the resulting beat frequency will successively rise to a maximum and fall to a minimum at the rate of 1000 times per second, the difference between 1000 kilocycles and 1001 kilocycles. If these two frequencies be impressed on the input circuit of a detector tube, the variation of the resulting beat frequency will produce an audible note having a frequency of 1000 cycles (1 K. C.) in the plate circuit of this detector tube. If one of the two frequencies is the received signal in the antenna, and the other is generated locally, we have "beat" or "heterodyne reception." In the receiving telephone, a musical note is heard whose pitch is readily varied by a slight variation of the frequency of the local generating circuit.

Figure 11 illustrates graphically this principle, (a) represents the incoming oscillations impressed on the antenna by the approaching wave; (b) represents the locally generated oscillations that are impressed also on the input circuit of the detector tube, and (c) represents the resultant beat frequency that exists and becomes audible in the headphones or the loudspeaker.

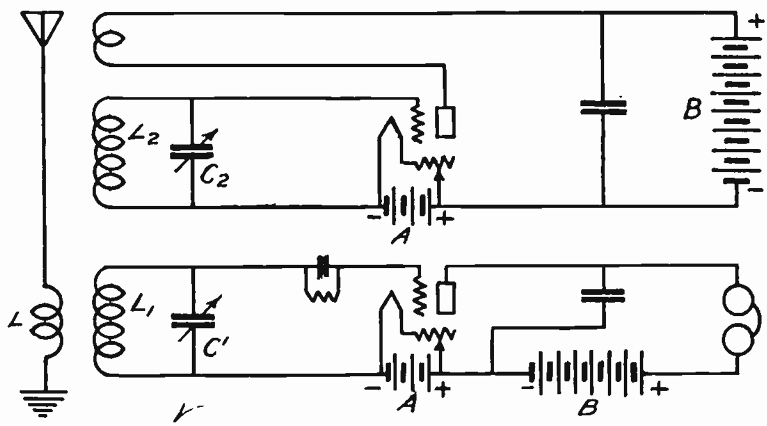

Fig. 12—Circuit diagram using a separate Heterodyne.

It will be noticed by close observation that the waves of (a) and (b) differ slightly in frequency and that as the peaks of (b) come in phase with the peaks of (a) and coincide with these peaks, that the peaks of the wave (c) gradually rise. When the peaks of (b) do not coincide with the peaks of (a), then the peaks of the wave (c) are at a minimum.

From the foregoing, it can be seen, then, that in order to create this beat frequency, it is necessary to have some form of generator of high frequency alternating current. From the foregoing explanation of the action of a vacuum tube as an oscillation generator, it can be seen that an additional tube could be used and this tube caused to act as a generator of oscillations. If such a second tube and circuit is placed near the detector so that the oscillatory circuit of the local generator is in inductive relation with the tuning circuit of the detector, then by varying the frequency at which the local generator is oscillating, the two frequencies can be impressed on the grid or input circuit in order to create the beat frequency.

In Figure 12 such a combination of circuits is shown. By varying the capacity of condenser C2, the frequency of the oscillations generated in the circuit L2 C2 is varied and the beat frequency existing in the circuit L1 C1 is caused to vary. This variance between the frequency of the two circuits can be made any desirable amount. If the oscillations generated in the local circuit L2 C2 have a frequency of 1100 kilocycles and the incoming frequencies impressed on the antenna and oscillating circuit L1 C1 have a frequency of 1000 kilocycles, then a beat frequency exists which is equal to the difference of these two frequencies

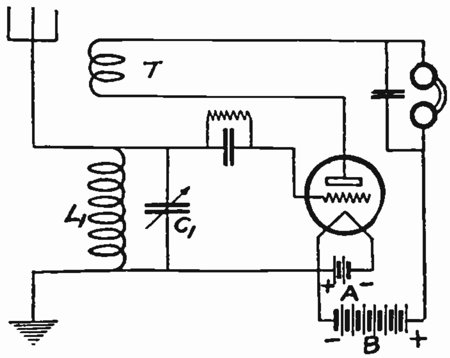

Fig. 13—The Autodyne circuit is simply a regenerative circuit.

or 100 kilocycles. As this beat frequency is not within the audible frequency limit, it is, therefore, necessary at all times to adjust the circuit L2 C2 so that it is generating a frequency which will beat with the incoming frequency and the difference between these two frequencies will create a third frequency which is within the audible band of frequencies which usually lies between 30 and 10,000 or 15,000 cycles. In most cases, the beat frequency usually corresponds to approximately 800 to 1000 cycles because the human ear is usually most sensitive to approximately 1000 cycles.

In the case just described where a separate source of locally generated high frequency oscillations is used to be impressed on the detector circuit, the scheme is generally known as "heterodyne reception" and the separate generator of oscillations is sometimes referred to as the "heterodyne oscillator" or simply as a "separate heterodyne." We shall now see how it is possible to produce the same results and eliminate this separate heterodyne oscillator or source of local oscillation.

When one vacuum tube is used to generate the source of high frequency oscillation and at the same time receive the incoming signal and the two are mixed in order to create the beat frequency, this form of reception is referred to as the "Autodyne" method.

In Figure 13, we have a simple form of the ordinary regenerative type of receiver using the tickler feed-back method of regeneration. Previously in this lesson it was stated if the coupling between the tickler coil T and the inductance L1 was increased to

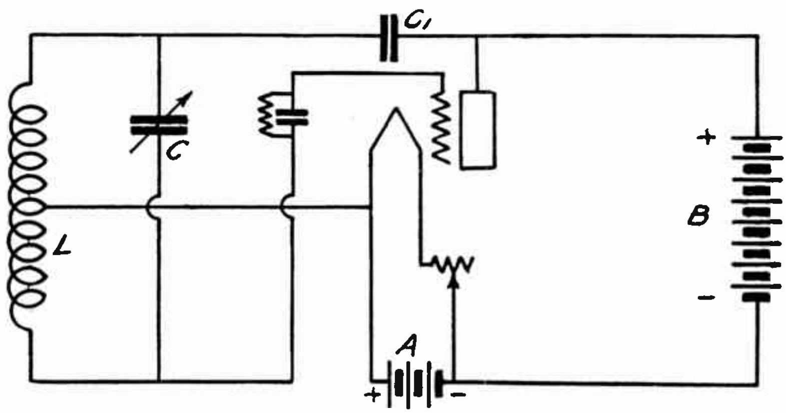

Fig. 14—Circuit diagram showing the Hartley Circuit.

the point where the feed-back voltage induced in the circuit L1 C1 was enough to reduce the effective resistance of this circuit to zero, then the tube would act as a generator of self-sustained oscillations. Therefore, we have one of the requirements necessary for beat reception; the generator of local oscillation.

By adjusting the tickler coil so that the detector circuit acts as a generator of self-sustained oscillations, and by varying the capacity of C1 so that the L1 C1 tuning circuit is adjusted to a slightly different frequency from that of the incoming signal, we have the other requirement for beat reception. Suppose that the incoming oscillations impressed on the antenna and L1 C1 circuit have a frequency of 1000 kilocycles. By adjusting the capacity of condenser C1 so that the L1 C1 circuit responds or is tuned to 1001 kilocycles, the 1000 kilocycle oscillations impressed on the antenna circuit will also be impressed by conduction on the L1 C1 circuit, but since this circuit is tuned to a slightly different frequency, the current in L1 C1 will not be as strong as if this circuit was tuned to exactly 1000 kilocycles. Nevertheless, the result of the incoming oscillations will cause oscillatory currents to flow in L1 C1 even though they are of slightly less amplitude and these oscillations will mix with the other oscillations in this circuit which are caused by the tube acting as a generator. Therefore, then, we have the second requirement for beat reception and that is, that we have the local generator circuit and also the tuning circuit. Since these two

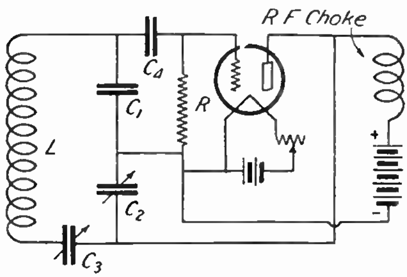

Fig. 15—The Colpitts oscillator circuit.

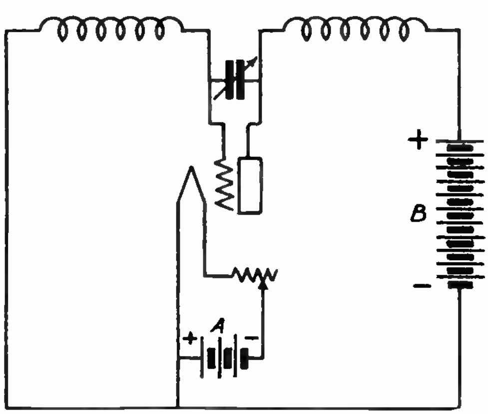

Fig. 16—A type of oscillator circuit proving very popular.

frequencies introduced in L1 C1 are different by 1000 cycles or 1 kilocycle, we have identically the same results and the same oscillations impressed on the grid of this circuit as we have in the case where a separate oscillator or heterodyne was used. The variations impressed on the grid circuit will rise and fall at a frequency of 1000 cycles per second and will cause changes in the plate current and the variations in the plate current will rise and fall at an audio frequency also and these are detected and reproduced by the loudspeaker or headphones.

It has been stated that the tickler coil connections could be reversed and the effect of oscillation or regeneration could be increased or decreased. There is a definite rule for the connections to the tickler coil in order for oscillation to take place.

Suppose that the grid coil and the tickler coil were both wound on the same winding form and the turns were wound in the same direction—then, in order for the tube to oscillate, it would be necessary that the grid be connected to one of the outside end terminals and the plate to the other outside end terminal, or that the plate be connected directly to the inside end of the plate coil and the grid be connected to the inside end of the grid coil.

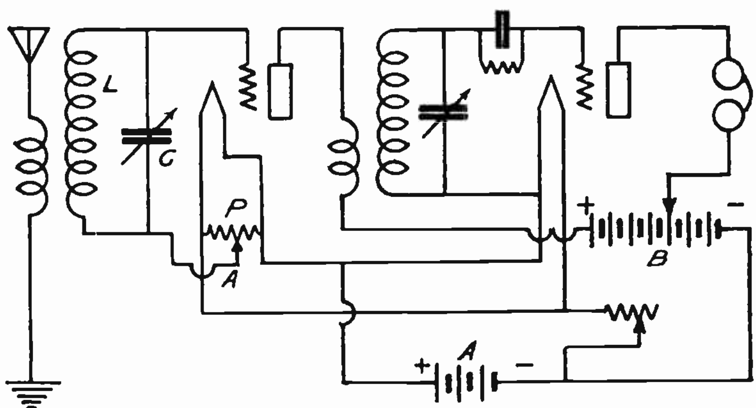

Fig. 17—Potentiometer control of grid bias.

This will keep the two magnetic fields in such relation that the induced voltage will be in phase with the grid circuit voltage. If these connections are reversed, regeneration and oscillation will not take place.

By referring to Figure 14, we have another form of circuit which is used considerably when an oscillating vacuum tube circuit is desired. It can be noticed that in this case only one coil is used and the grid connected to one end of this coil, whereas the plate is connected to the other end and the filament is connected to a center tap on the coil. This form of oscillator circuit is commonly referred to as the "Hartley" type. It will be noticed that the condenser C1 is connected in series between the plate and one end of the coil. This condenser can either be a fixed or variable type and its main purpose is a blocking condenser to keep the D. C. plate voltage off of the inductance L and the grid of the tube. If it is a fixed condenser and of the proper capacity so as to allow the correct amount of feed-back to take place, then the circuit will act as a generator of alternating current. If it is a variable condenser and of the correct capacity, the amount of feed-back can be controlled and regeneration accomplished just as in the tickler type where the amount of induced voltage fed back was regulated by the magnetic coupling between the two circuits. In this case, the coupling is controlled by varying the capacity instead of varying the magnetic coupling. The condenser C controls the frequency at which the tube oscillates. There are two other types of oscillators shown in Figures 15 and 16 and later on in one of the advanced text-books, these circuits will be taken up in detail.

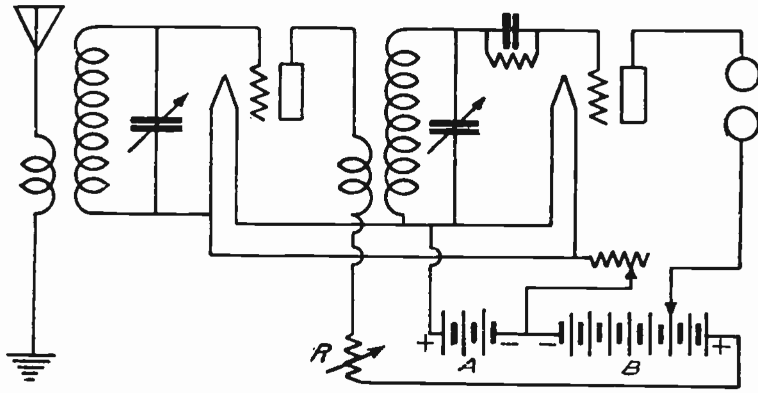

Fig. 18—Reducing the plate voltage by a variable resistance, reduces the tendency to oscillate.

NEUTRALIZATION

From our definition of "Neutralization" and what has already been explained, it can readily be seen how some forms of neutralization can be accomplished. Under the explanation of oscillation, it was shown that if the induced voltage was in opposite phase to that of the voltage in the grid circuit, then regeneration and oscillation could not take place because the induced voltage would not assist the oscillations in the grid circuit and cause them to build up, but would decrease these oscillations.

After broadcasting became popular and it was necessary to use stages of radio frequency amplification preceding the detector circuit, considerable difficulty was experienced due to the feed-back between the elements of the tubes themselves. In this case, the plate circuit, of course, was not tuned. However, it is not necessary to have both the grid and plate circuits tuned; a tuned grid circuit with sufficient inductive reactance in the plate circuit, may set up oscillations with no other coupling than that between the elements of the tube. This becomes increasingly likely as the oscillator circuit is made more efficient (less resistance) and as the circuit is adjusted for higher frequency. Thus, a radio frequency, transformer coupled, tuned amplifier, may operate well at the larger values of the tuning condenser (lower frequencies); but if the capacity is varied, causing the circuit to respond to a higher frequency, the tuning becomes sharper, denoting to one skilled in Radio the presence of regenerative action. As the higher frequencies are approached, the oscillations occur easier and these are set up in the tuned circuit. For the re-

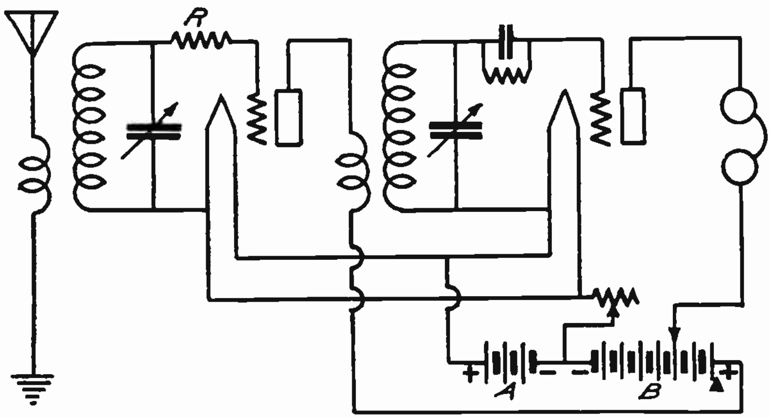

Fig. 19—Resistance inserted in the grid circuit to prevent oscillation.

ception of broadcast signals, the amplifier becomes useless due to the distortion caused by the circuit generating self-sustained oscillations.

Various schemes have been devised to control these oscillations in tuned amplifiers, in which the resistance of the oscillatory circuit is sufficiently increased at the higher frequencies to offset the tendency of the tube to generate oscillations. The first scheme used for the control of such undesirable oscillation is shown in Figure 17. This scheme is often referred to as potentiometer control, stabilizer, or a losser method. A high resistance potentiometer (200-400 ohms) P is connected directly across the "A" battery and the tube input circuit, L-C, is connected at the filament end to the sliding contact A. Thus the average grid potential (grid bias) can be given any value between that of the negative end and that of the positive end of the "A" battery.

Figure 18 illustrates another method for controlling regeneration and oscillation, in which a variable high resistance is connected in the plate circuit of the tube so as to regulate the amount of current and voltage applied to the plate. By lowering the voltage applied to the plate, the tendency to oscillate is decreased.

Another method for controlling oscillation under the losser scheme is shown in Figure 19. This scheme is used in some of the later receiving sets and the resistance (R) in the grid circuit merely introduces enough loss and raises the resistance of this circuit; hence the feed-back occurring between the elements of the tube never decreases the effective resistance of the tube circuit to the point where self-sustained oscillation can take place.

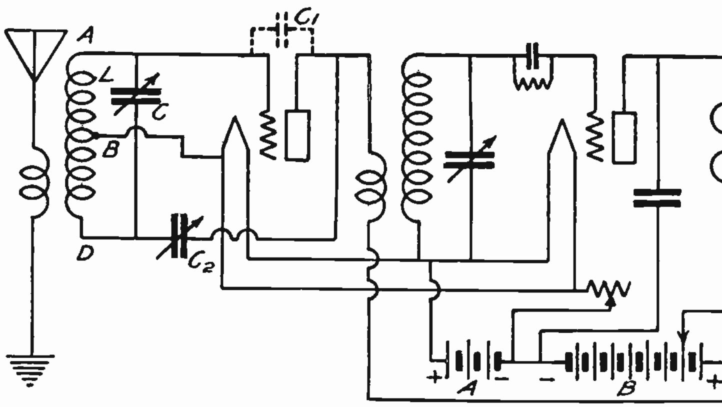

Fig. 20—The Rice or grid form of neutralization.

TRUE NEUTRALIZATION

It is evident from previous explanations that if the grid potential is not allowed to change, due to the change in plate potential, feed-back or regenerative action could not occur. Another opposing voltage may be introduced in the grid circuit by an electromagnetic coupling between the grid and plate circuits. Such an expedient can be expected to work over a comparatively narrow frequency band. However, as it is not possible to just balance a capacitive feed-back by a magnetic feed-back throughout a wide range of frequencies, the magnetic feed-back must be made adjustable if such a scheme is to be most effective, and the receiving set operator will have to change the magnetic coupling as he changes the tuning capacity. The better scheme is to utilize another capacitive feed-back between the plate and grid circuits and so arrange the circuits that the voltage impressed on the grid through this added condenser is just equal and opposite to that impressed on the grid through the plate-grid capacity. It will be seen that this scheme involves the selection of a suitable point in the grid circuit and connecting this point to the plate through the added balancing condenser, or the selection of a suitable point in the plate circuit and connecting this point to the grid through the balancing condenser. In case the circuit arrangement is such that the suitable point called for cannot be located, it may be necessary to add another coil in one or the other circuits, or to seek a point in a circuit coupled to the grid or plate circuit.

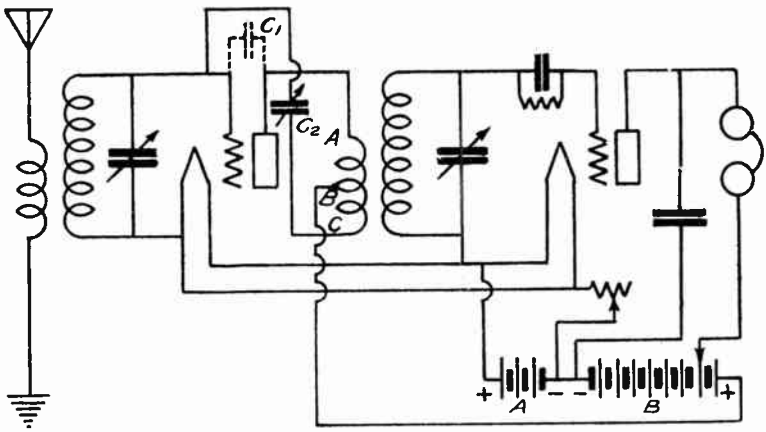

Fig. 21—The so-called "plate form" of neutralization.

Many sets have been put on the market in which this balancing scheme has been employed; some of them neutralized from grid circuit to plate and others neutralized from plate circuit to grid.

In Figure 20 is shown one method of applying neutralization, this being of the grid form. This scheme is also referred to as the Rice system of neutralization. The filament is connected, not to the end of the coil, A-D, of the input circuit, but at an intermediate point B which may be the middle. Then condenser C2 is connected as shown, and, if point B is the midpoint of coil A-D, then condenser C2 is given the capacity equal to the grid-plate capacity of the tube, indicated in Figure 20 by the condenser C1. Merely by inspection, it can be appreciated that any tendency to make the L-C circuit oscillate, due to voltage from the plate being impressed on the point A through condenser C1 will be nullified by the equal and opposite voltage impressed on point D through C2. Thus, a change in plate voltage cannot start oscillations in the L-C circuit. It will be further appreciated that any disturbance set up in the L-C circuit cannot affect the plate voltage as condenser C1 and C2 will produce equal and opposite effects on the plate for any current circulating in the L-C circuit.

It is not necessary to have point B (Fig. 20) in the middle of coil L at all; it might be anywhere in the coil and the scheme will

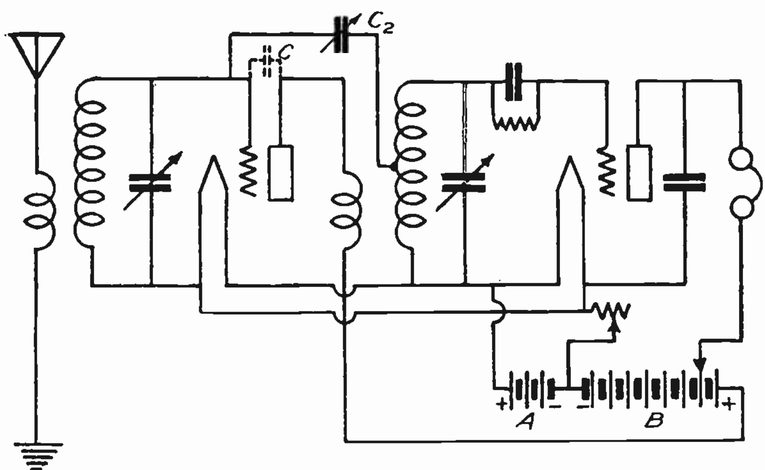

Fig. 22—The Hazeltine system of neutralization.

still work providing the capacity of condenser C2 is properly chosen. It will be appreciated that to get equal and opposite voltages on the plate, the ratio of condensers C1 and C2 must be fixed by the ratio of voltages across B-D and B-A. But condenser C1 cannot be altered as it is inherent in the tube, so condenser C2 is the one that must be changed to effect neutralization. This is so adjusted that the ratio of C1 to C2 is the same as the ratio apparent from D-B to B-A. The fewer turns there are in coil L from B to D, the larger must be C2 to balance the effect of C1.

In Figure 21 is shown one arrangement for effecting neutralization from the plate side of the vacuum tube. As it is normally impossible to find a point directly in the plate circuit which has the opposite potential to that of the plate, we have recourse to the same expedient as used in Figure 20. Instead of making the B plus connection to the end of the plate coil at C, we connect it at a midpoint B. Then, point B will go up and down in potential in phase opposite to the potential of the plate, just the same as in Figure 20, point D and A have opposite voltages. In Figure 21, the neutralizing condenser C2 is connected between point C and the grid. If point B is not the midpoint of coil A-C, then C2 will have a different capacity than C1, its value being greater as the turns from B-C are fewer.

In Figure 22 is shown the Hazeltine scheme of neutralization. Here the point of potential opposite that of the plate is found in the secondary of the plate circuit transformer—that is, in the input circuit of the next tube. In Figure 22, the point is shown as an intermediate one on the secondary coil but this point may, of course, be the end of the coil. In this scheme, it is important that the primary and secondary coils of the plate transformer be connected with proper relative polarity, otherwise this point will have a voltage of the same phase as that of the plate and then, of course, the neutralizing circuit will act to help the normal regenerative action of the tube.

TEST QUESTIONS

Number your Answer Sheet 17-2 and add your Student Number.

1. What is regeneration?
2. Draw a circuit diagram of the Armstrong regenerative circuit.
3. What is the meaning of neutralization?
4. What determines the natural frequency of an oscillating circuit?
5. When will a vacuum tube act as a generator of self-sustained oscillations?
6. Is it possible for the plate current to reverse its direction of flow?
7. Draw a circuit diagram of a receiver that can be used for the reception of unmodulated continuous waves.
8. Draw a circuit diagram illustrating the Hartley type of oscillator.
9. Do oscillations in a radio frequency amplifier occur easier at high or low frequencies?
10. In Figure 20 is it necessary to have point B in the middle of coil L?

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RADIO BATTERIES THEIR CONSTRUCTION AND OPERATION

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A Personal Message from J. E. Smith

Most persons, nevertheless, do find it worthwhile to have a definite time and a definite place to study. What the place and time are does not matter so much as their definiteness and regularity. One should plan how much time he can give to study, not setting up too much time at first, at what hour and on what days he will do the work, and where he will do it.

Then he should stick to his plan. For success in writing, study, or any other occupation that requires concentration, a keeping to one's plans counts enormously.

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RADIO BATTERIES AND THEIR CONSTRUCTION

The entrance of many forms of tubes, both for receiving and transmitting, has created a demand for a direct-current source of supply which is free from even the slightest fluctuation in voltage. For a long while primary cells usually of the so-called dry cell type, and secondary (or storage) batteries far outrivalled any other source of power for use with a vacuum tube receiving set, but the popularity of various battery "Eliminators," the general name applied to any battery substitute, is steadily increasing.

Before investigating at length the available sources of power, it would be well to call to mind the type of demand or load that will be imposed upon them. First, there is the filament of the tube which is usually of the five volt type and consumes .25 ampere, although there are others which operate at a pressure of 1.5 volts and consume .25 ampere and still others which function at a 3 volt pressure and draw .06 ampere. Generally, therefore, it may be stated that a suitable source of power for the filament or "A" circuit (as it is more commonly known) is one of a comparatively *low voltage*, capable of delivering a *fair load* for a considerable time at a constant pressure, or in other words of low voltage and of substantial current capacity.

Second, there is the plate of the tube which is to be maintained at a voltage depending upon the type of tube and the use to which it is put, a soft detector tube requiring only from about 16 to 22½ volts while a hard tube may be used with from 45 to 150 or more volts on its plate. The current consumed in either case is very small, being expressed usually in milli-amperes so that a suitable plate or "B" source of energy is one of high *voltage*, preferably supplied with taps, whose *current* capacity need not be very high.

Third, since there is extremely little current flowing in the grid circuit of a tube, the current capacity of the "C" or grid battery is practically of no importance. The battery is usually tapped to provide voltages ranging from 1.5 to 9 volts, although the new power tube UX120—requires a 22½ volt bias.

DRY CELL BATTERIES

The dry cell, of the size and type well known, in external appearance at least to even the most inexperienced layman, is suitable as an "A" or filament battery in any set where the current demand is not too high or too prolonged. A dry battery composed of several dry cells, much smaller in size than the one just mentioned, connected together and sealed in a compact block, serves as a good all around "B" or "C" battery depending upon the number of cells used.

The modern dry cell is the result of extensive experimenting that began when Volta discovered that an electrical pressure or voltage was developed between two unlike metals placed in contact with certain liquids. He learned by research that all metals have a relationship to each other, and if one metal such as zinc is brought into contact with another metal such as iron, an electric current will flow. This phenomenon can be readily demonstrated by any one. One of the simplest experiments is to take a copper penny and a silver dime and lay between the two a moistened piece of paper. If the two terminals of a pair of phones are placed one on the dime and the other on the penny, a click will be produced in the phones. *This* indicates that, in the circuit consisting of the penny, the moisture, the phones and the dime, a current is flowing which is caused by the voltage or electromotive force being produced by the contact of the two dissimilar metals.

A scale for the different metals has been worked out, showing which metals are most positive and which are least positive. The following list is so arranged that the metal first on the list becomes positively electrified when touched by any taking rank after it:

+ Zinc
Lead
Tin
Iron
Copper
Silver
Gold
— Graphite.

For example, zinc is more positive than iron, but iron when used with graphite becomes the positive element. In the experiment given above the copper penny is more positive than the silver dime.

Going still further, Volta found that certain liquids acted in a similar manner when brought into contact with metals.

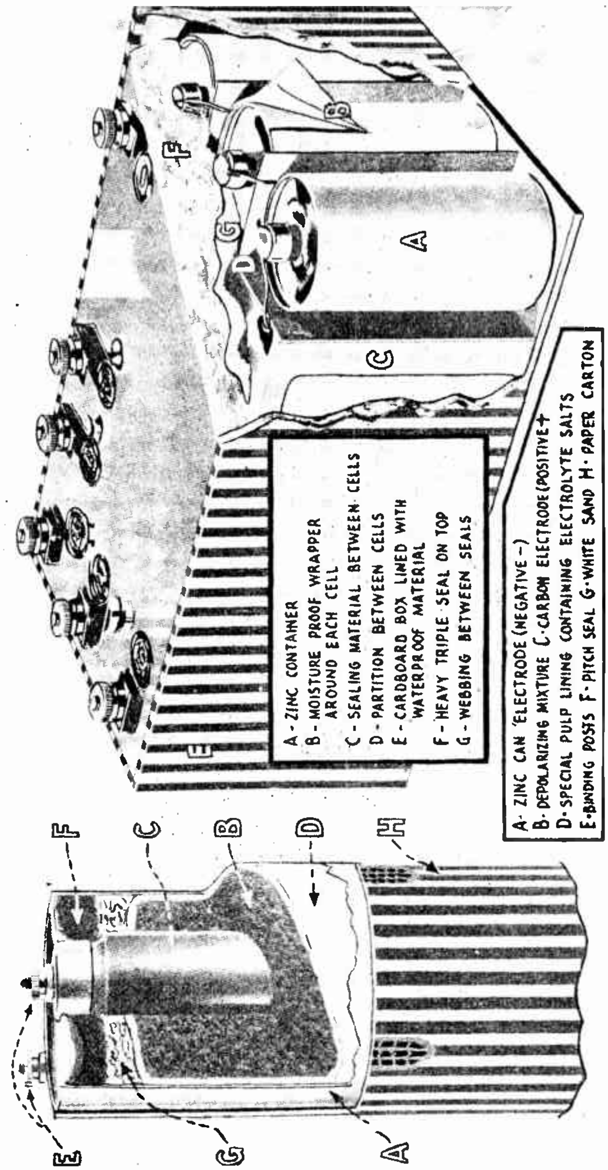


Fig. 1.

He found that by virtue of the chemical action between the liquid and the metals, a source of voltage can be produced that will cause a current to flow when the unit is connected to an outside source. *He therefore had a device that converted the chemical action between the liquid and metals into electrical energy.*

The dry cell in common use at the present time is an outgrowth of the Leclanche cell, which is a voltaic cell with poles or electrodes of carbon and zinc immersed in a solution of sal-ammoniac. The zinc unites with the sal-ammoniac (NH_4CL) forming zinc chloride ($ZnCL_4$) ammonia (NH_3) and hydrogen (H). This chemical action causes the zinc to become negative with respect to the carbon so that a current of electricity will flow in a wire connecting them. However, this action is hindered and eventually stopped by the bubbles of hydrogen (—) which collect on the carbon (+), practically substituting a sheet of hydrogen for the carbon. This action is called polarization. To prevent this, an oxidizing agent, manganese dioxide (MnO_2), is packed around the carbon pole to combine with the hydrogen preventing the latter from collecting on the carbon. This action is called depolarization. The E. M. F. resulting from this combination of elements is 1.5 volts regardless of the size of the elements. The current capacity is, however, affected by the physical dimensions of the zinc and carbon electrodes.

In the accompanying Figure 1, we have the modern dry cell, which strictly speaking is not "dry" at all as will appear, with the zinc can forming one of the electrodes. On the inner side of the can is a paper liner saturated with a solution of sal-ammoniac. Between the liner and the carbon pole, there is a layer of "mix" which consists of carbon and a high grade ore of manganese dioxide thoroughly mixed. The carbon serves as an electrical channel for the passage of the current to the carbon pole, reducing the internal resistance of the cell, while the manganese dioxide changes the hydrogen to water. Near the top of the cell is a layer of sawdust and sand. This space affords an expansion chamber for excess gas and electrolyte. The cell is sealed with pitch to retain the liquids and to prevent evaporation.

Battery manufacturers have designed a dry cell, which although exteriorly similar to those used for door-bell and ignition systems, has a life that is double that of its prototype. This result is attained by using special mix material to maintain high *closed* circuit voltage during heavy current drain, and by employing a special electrolyte which saturates a special pulp paper line of low electrical resistance but of great mechanical strength.

"B" batteries are an assembly of small dry cells soldered together in series, i. e., the carbon of one to the zinc of the next, usually in blocks of 15 or 30 cells giving 22½ and 45 volts, respectively. See Figure 1. The construction of the individual cell is the same as in the larger size just described. In the assembled block "A" is a one-piece seamless zinc can which requires heavier, more pure and more uniform metal than a solder can, all of which add to the life of the cell. Also, it prevents any leakage through a weak joint and eliminates voltage differences on the inside of the can, a condition which might cause stray currents and potential differences and results in noisy voltage fluctuations and short-lived battery.

Fig. 2
22.5 Volt "B" Battery
Vertical Type.

Fig. 3
"C" Battery, Large Size.

"B" is the moisture-proof wrapper around each cell, one of the ways in which individual insulation is secured.

"C" is a sealing material between cells to provide additional insulation and prevent movement between cells.

"D" is the water-proof partition between cells, another feature in the individual cell insulation and a means of confining internal moisture due to cell discharge within the compartment.

"E" is the heavy water-proof non-metallic insulating material, the first line of defense against moisture getting into the battery. As it is non-conducting, it will not collect stray currents and produce capacity effects between adjacent batteries.

"F" is the heavy triple seal over the top, another factor of safety which adds to the strength of the battery and increases the moisture-proof qualities.

"G" is the webbing between seals, adding to the strength of the top.

The cells are sometimes arranged in two vertical layers to reduce table space.

TABLE 1
Dry Cell Batteries for Various Vacuum Tubes

	CLASSIFICATION OF TUBES WITH RESPECT TO NECESSARY BATTERY AND TUBE FILAMENT CURRENT		DRY CELL BATTERY TUBES				Storage Battery Tubes	
			Low Current	High Current				
VACUUM TUBES CHARACTERISTICS	Vacuum Tube Style Number		UV or UX 199 C 299 DV 1	WD 11 WX 12	UV or UX201A C301A	UX-120	UX-112 UX-112A	UX-210
	Filament Volts		3.0	1.1	5.0	3.0	5.0	6.0
	Filament Amperes		0.06	0.25	0.25	0.125	0.5 UX112A 0.25	1.1
	Rheostat Ohms		30	6	6	20	6	None
BATTERY VOLTS	"A" Battery Volts (Filament Battery)		4.5	1.5	6.0	4.5	6.0	6.0
B	"B" Battery Volts (Plate)	Tube as Detector	22.5 to 45	22.5 to 45	22.5 to 45	Not a Detector	90.	Not Used
		Tube as Amplifier	45 to 90	45 to 90	45 to 112.5	135 Audio Amplifier	157.	90
	"B" Battery Current (Plate) Milliamperes	"B" Volts 22.5 / No. "C" Volts 45 / 90	0.3 1.5 4.0 These currents can be reduced by a "C" voltage	0.4 1.5 4.0	0.6 1.5 4.0	6.5 When used with high Voltage	Det. 2.4 Amp. 5.8	3.0
	"C" Battery C Volts (Grid Bias) Tube as ampl.	"B" Volts 45-67.5 67.5-90 90-112.5	1.5 to 3.0 3.0 to 4.5	1.5 to 30 3.0 to 4.5	1.5 to 3.0 3.0 to 4.5 4.5 to 6.0	22.5 Not used as a Detector	Det. 6.0 Amp. 10.5	4.5

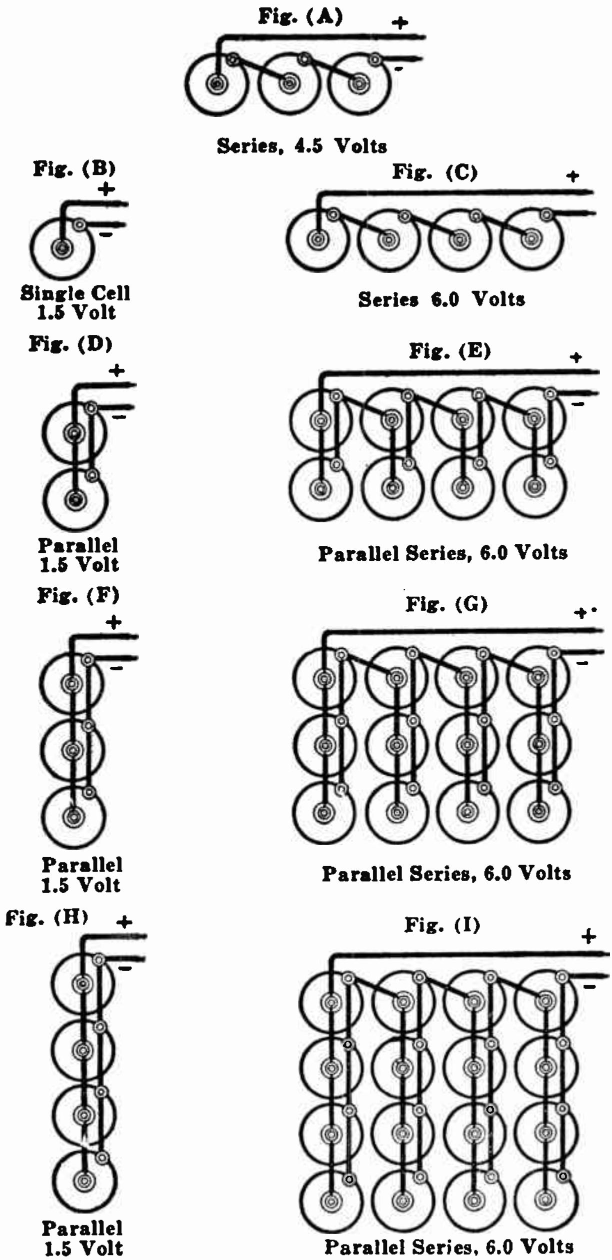


Fig. (A)
Series, 4.5 Volts
Fig. (B)
Single Cell
1.5 Volt
Fig. (C)
Series 6.0 Volts
Fig. (D)
Parallel
1.5 Volt
Fig. (E)
Parallel Series, 6.0 Volts
Fig. (F)
Parallel
1.5 Volt
Fig. (G)
Parallel Series, 6.0 Volts
Fig. (H)
Parallel
1.5 Volt
Fig. (I)
Parallel Series, 6.0 Volts

Fig. 4.

A "C" battery is identical in construction with one of the "B" type, the difference being only that it is usually composed of three or four cells instead of 15 or 30 resulting in, of course, a correspondingly low potential. Fig. 3.

Table I will be extremely helpful in the selection of proper "A," "B" and "C" batteries for a given installation.

CONNECTING BATTERIES

Explaining the terms "Series" and "Parallel" which are applied to modes of connecting batteries; cells are connected in **series** when the positive pole of one is connected to the negative of another, the resulting voltage being the sum of the voltages of the individual cells. For example, two dry cell "A" batteries in series will produce double 1.5 volts or a total of

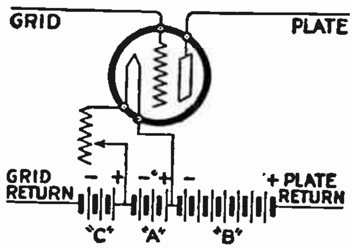


Fig. 5.—Connections for A, B, C Batteries in a Radio Set.

3.0 volts at the terminals. In "B" batteries, usually fifteen cells are soldered together in series and the voltage is, therefore, 22.5 volts. Series connection has no effect on the amount of current which can be taken out at the leads as the current must flow through each cell in turn, and it is limited by the smallest amount produced by the zinc of any one cell.

Series connection multiplies the voltage and does not affect the current capacity.

Plate I on page 9 shows four illustrations of A and B batteries assembled in various ways for operating Radio receiving sets.

Parallel connection of dry cells is made by connecting the positive of one to the positive of the other and the negative to the negative, see Fig. 4, B, D, F, H. In parallel connection there is no change of the voltage, but the arrangement is equivalent to increasing the amount of zinc surface and this results in an increase of the available energy as current. As a matter of fact, doubling the number of cells in parallel more than doubles the available energy. Parallel connection, therefore, is recommended to reduce the unit cost of battery energy.

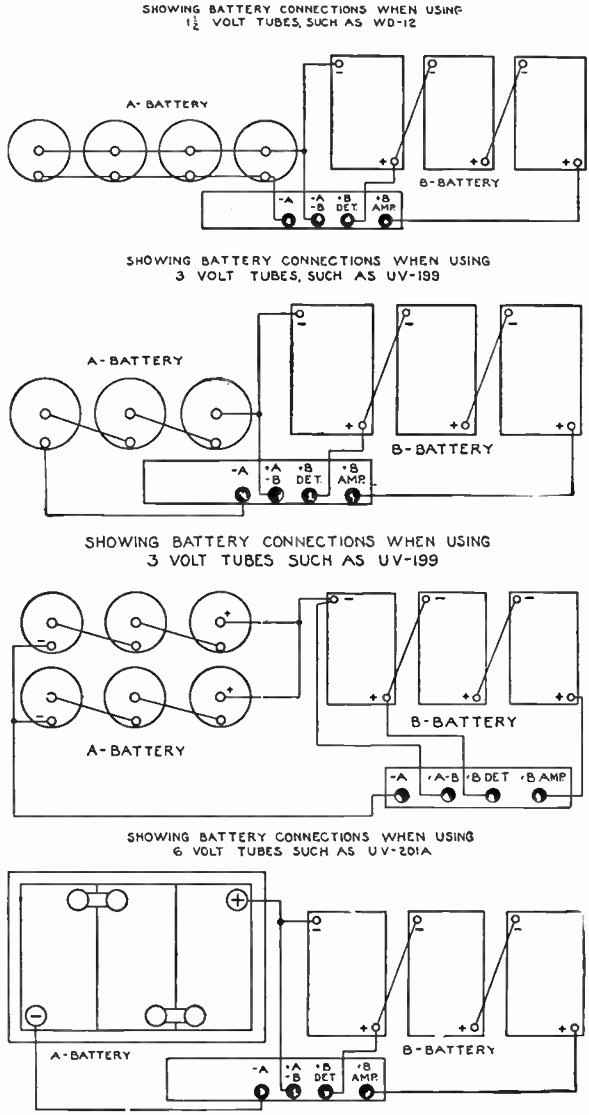


Plate I.

With vacuum tubes which must have a definite current, it is seen that by connecting the dry cells in parallel the necessary current is divided between the cells. For example, a 0.25 ampere tube when connected with cells in parallel has the current divided depending on the number of cells thus connected. With two cells, each would furnish 0.125 ampere; with three cells, each would furnish 0.0833 ampere. As the current in a cell is reduced the cell becomes more efficient and lasts longer. This explains why parallel connections between cells will reduce the cost of battery energy.

Parallel connection multiplies the available current capacity and does not affect the voltage.

Dry cells are sometimes connected in **parallel series** when it is desired to increase both the current capacity and the voltage. For example, if the current capacity is to be doubled, or the current drain per cell cut in half, two cells are connected in parallel thus increasing the zinc area. If the voltage is then to be trebled, three of such parallel connected units are wired in series. Referring to Fig. 4, figures (e), (g), (i), one can imagine that each set connected in parallel vertically is equivalent to one large cell of 1.5 volts and the current increased proportionally and that any number of these units are then connected in series increasing the voltage proportionally. Fig. (f) shows three cells in parallel, Fig. (c) four cells in series and Fig. (g) three cells in parallel and four in series.

TESTING BATTERIES

The dry cell type of "A" battery of the standard size can be tested by touching the terminals of an ammeter across the binding posts of the cell. A new and fresh cell should give a reading of 30 to 35 amperes.

The proper way to test either a "B" or "C" battery is to use a good high resistance voltmeter. The open circuit voltage, that is with no load other than the voltmeter, should be 1.5 per cell.

The "A" battery needs replacing if the signal strength is below normal, when the filament rheostat is moved to the furthest "on" position. It is also indicated to the eye by a dimming of the filament in the tube.

While the nominal voltage rating of a 15 cell "B" battery is given as 22.5 volts, the actual voltage of a satisfactory "B" cell is slightly under 1.5 volts. Consequently, the complete battery, when tested on a voltmeter, may not test quite 22.5 volts, but it should not be considered defective for this reason.

The minimum working "B" voltage of a detector tube is about 17 volts. Therefore a "B" battery should give results until its voltage drops to this figure. Some "B" batteries, when their voltage drops, cause noise in the phones and, if this is the case, the battery should not be used. A low voltage "B" battery may produce weak or wavering signals.

The "C" battery should be replaced when its voltage has dropped to 1.0 volt per cell. An exhausted "C" battery usually produces distorted signals.

STORAGE BATTERIES

The batteries just described are "primary" batteries, that is, they are capable of spontaneously generating electric energy without being supplied by some outside force. As no doubt the student will recall, this generation of electricity is at the

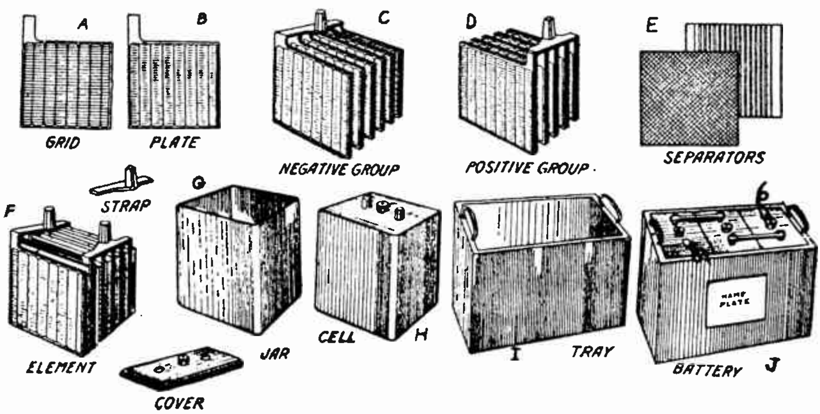


Fig. 6.—Parts of a Standard Storage Battery.

expense of the zinc electrode which is consumed or, more correctly, changed to zinc chloride. It is evident that as the zinc is eaten away the capacity of the cell decreases until eventually it becomes "dead." There is no way of reviving a dry cell when the zinc has been so destroyed and the cell must be discarded.

In contradiction to this "primary" type of battery which although it generates its own power must be thrown away after a comparatively short time, there is a "secondary" type known as the storage battery which must first be supplied with electrical energy or "charged" before it is capable of delivering current but has the advantage that it can be "recharged" almost an indefinite number of times.

To prevent a possible misunderstanding, it must be stated that the term "storage" is not the proper term. There is no storage of electricity. A current of electricity flowing through a secondary battery merely changes the composition of some of the components of the battery in such a manner that it will deliver current for a time. Although there is actually no storing of electricity, the practical effect is the same as if there were.

We may divide storage cells into two principal types, as follows:

1. The Lead cell.
2. The Edison cell.

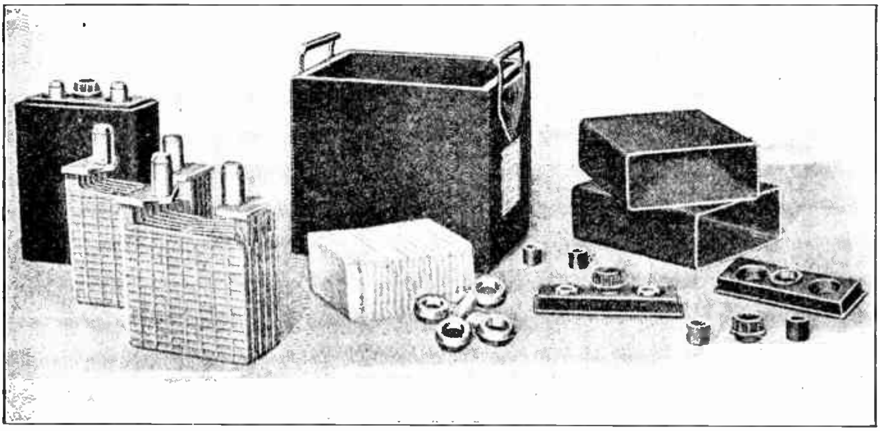


Fig. 7.—Partly Assembled Lead Storage Battery.

THE LEAD CELL

The lead cell has plates of lead and lead oxide and an electrolyte of dilute sulphuric acid. Although the physical appearance of lead "A" and lead "B" batteries differ, the general construction of the elements is the same and the action identical.

A popular type of storage "A" battery is made of a number of lead plates (see Fig. 6) containing holes or grooves which are coated with a paste made of red lead or litharge (see Fig. 8-B). Alternate plates are connected to different terminals, those connected to the negative terminal being one more in number than those connected to the positive terminal. The plates are placed in a vessel containing a dilute solution of sulphuric acid added. (See Fig. 7). A current of electricity is then caused to flow through the cell for a number of hours, the result being that hydrogen gas collects on the plate from which the current leaves the cell. This hydrogen gas combines with the oxygen of the plate, leaving the paste in the form of spongy lead. At the same time, the place at which the current enters the cell is absorbing oxygen, converting the paste into lead peroxide. Finally, one

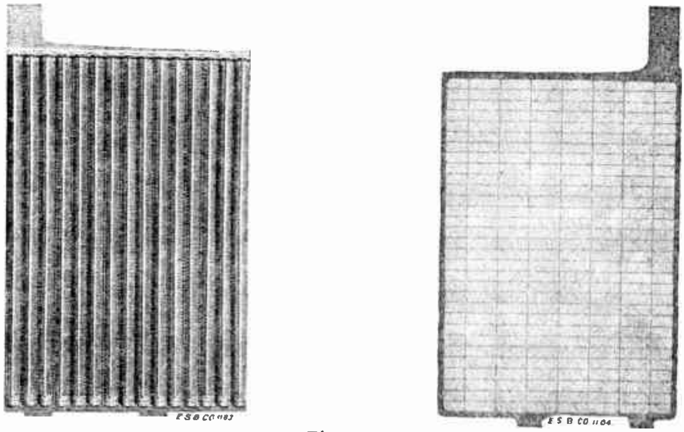


Fig. 8.

A
The Positive Plate

B
The Negative Plate

plate will be filled with spongy lead, forming the negative plate while the other plate is filled with lead peroxide and is termed the positive plate. (Fig. 10—discloses an "Exide" battery, or

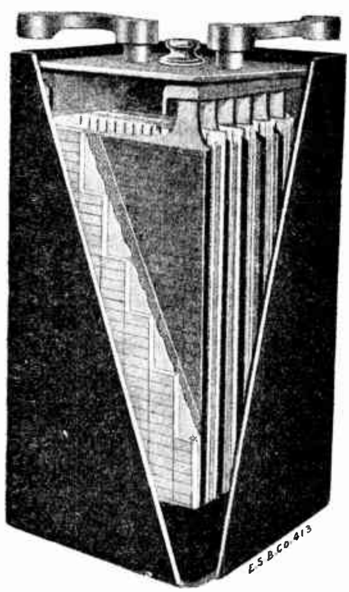


Fig. 9.—Cutaway View of an Assembled "Exide" Lead Cell.
Courtesy of The Electric Storage Battery Co.

number of cells in a common casing, using this construction). On discharge a reverse action takes place.

When a cell is placed on discharge the current is produced by the combination of the sulphuric acid of the solution with the active material of the plates. The product of this combination is lead sulphate and water. The lead sulphate fills the pores of the active material, and the water is left in the solution, causing it to become thinner. The volume of sulphate formed by this combination is greater than the volume of lead which entered into the combination. The result of this is that as the discharge goes on, the sulphate which fills the pores in the plates prevents the action of the solution on the active material. Therefore, the voltage will gradually drop as more and more sulphate

Fig. 10.—Exide Storage Battery, Showing Parts of One Unassembled Cell.

is formed. The voltage of a lead cell at the beginning of discharge is ordinarily about 2.1 while the lower limit is 1.75. The voltage at normal discharge rate should not be allowed to drop below 1.75, because after this point is reached the voltage falls off very rapidly.

In charging, direct current of greater voltage than the open circuit potential of the storage battery is caused to flow through the cells in an opposite direction to that which the current takes when the cell is discharging.

The sole object of charging, then, is to drive the sulphate from the plates back into the solution, thus leaving spongy lead on the negative plate and lead peroxide on the positive.

Chemical Action on Discharge. Consider Fig. 11. The sulphuric acid, H_2SO_4 acts chemically upon the lead plate, Pb, and is broken up into positively charged H_2 and negatively charged SO_4. The SO_4 unites with the lead plate, forming lead sulphate, $PbSO_4$, and gives up its negative charge to it. The hydrogen carries its positive charge to the lead peroxide plate, where it gives it up, and unites with the oxygen of the lead peroxide, forming water H_2O. The sulphuric acid in contact with the peroxide plate is also broken up in to H_2 and SO_4. The H_2 of this portion of the acid also unites with the oxygen of the lead peroxide and forms more water. The SO_4 part of the acid instead of going over to the negative plate unites with the lead, Pb, of the lead peroxide plate and forms lead sulphate, $PbSO_4$, on the positive plate. Thus both plates are being reduced to lead sulphate $PbSO_4$. The cell continues to deliver

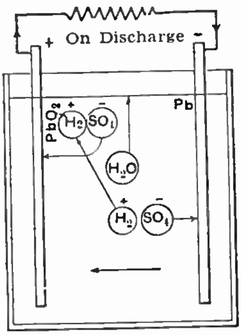


Fig. 11.—The Chemical Action of Lead Storage Cell on Discharge.

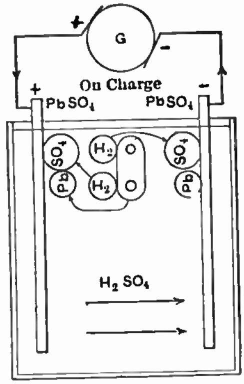


Fig. 12.—Chemical Action of Lead Storage Cell on Charge.

current until the plates are entirely reduced to lead sulphate, when of course, all action will cease, since there would be but one kind of material present, and a battery requires two kinds. The practical limit of discharge, however, is reached long before both plates are completely reduced to the same material.

Note two things which are taking place when a cell is discharging:

1st. The acid is continually growing weaker. This results in a lower E. M. F.

2nd. The active materials, lead and lead peroxide, are being replaced by lead sulphate, which has a much higher resistance and is more bulky than the active materials. It therefore takes up more space in the holes of the grids and tends to buckle them; especially if the cell is discharged very rapidly and the lead sulphate forms quickly.

The chemical equations for the different actions on discharge and charge may be written as follows:

Discharge

→

$$PbO_2+Pb+2H_2SO_4=2PbSO_4+2H_2O$$

←

Charge

or

DISCHARGING		CHARGING	
Positive Plate	Negative Plate	Positive Plate	Negative Plate
PbO_2	Pb	$PbSO_4$	$PbSO_4$
+	+	+	+
H_2	SO_4	O	H_2
+		+	
H_2SO_4		H_2O	
Produces		Produces	
$PbSO_4$	$PbSO_4$	PbO_2	Pb
+ $2H_2O$		+ $2H_2SO_4$	

Chemical Action in Charging.—Refer to Fig. 12. Assume both plates to consist of lead sulphate, $PbSO_4$. When a current from an outside source G is sent through the cell, it breaks up the water which has been formed during **discharge** into positively charged hydrogen H_2 and negatively charged oxygen O. Part of the positively charged hydrogen is now attracted to the negative plate and unites with the SO_4 of the lead sulphate, forming sulphuric acid, H_2SO_4 and leaving pure spongy lead at the negative plate. The negatively charged oxygen O flowing against the current is attracted to the positive plate. Here it unites with the lead Pb of the lead sulphate $PbSO_4$ plate and forms lead peroxide, PbO_2. The SO_4 part of the positive plate is finally united to the rest of the hydrogen liberated when the electric current broke up the water H_2O in H_2 and O. This action forms still more sulphuric acid, and a positive plate of lead peroxide. When all the lead sulphate has been changed over to lead peroxide and pure lead, the battery is re-stored to the state it was in before it was discharged, and is now ready to furnish current again.

Note that the acid has been growing denser during charge, therefore the E. M. F. must have been increasing as the charging continued.

CARE OF LEAD STORAGE CELLS

From a study of the chemical action of a storage cell and the physical results of this action, we can determine what treatment such a cell should receive in order to give the most efficient service.

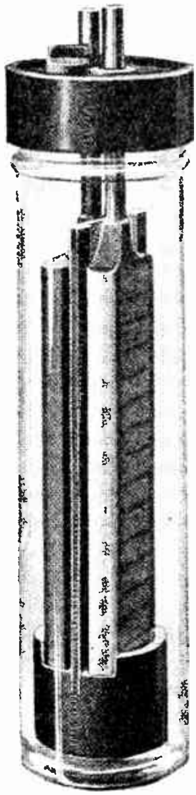


Fig. 12-A.—Showing Construction of a Lead Type "B" Battery Cell.

In the first place, it should be said that storage batteries should have the care of a conscientious skilled attendant. They are costly in the first place and easily ruined. Without proper care they deteriorate at an alarming rate. The main points to be avoided are the following:

(1) *Too rapid charging or discharging.*

(2) *Use of impure electrolyte.*

(3) *Use of too dense or too light electrolyte.*

(4) *Over-charging and over-discharging.*

The harm that may result from disregarding these points is evident on inspection of the chemical actions.

Although all lead cells are identical in operation, they vary somewhat in the specific form of some of their elements. One form of plate construction used in the Exide has been outlined.

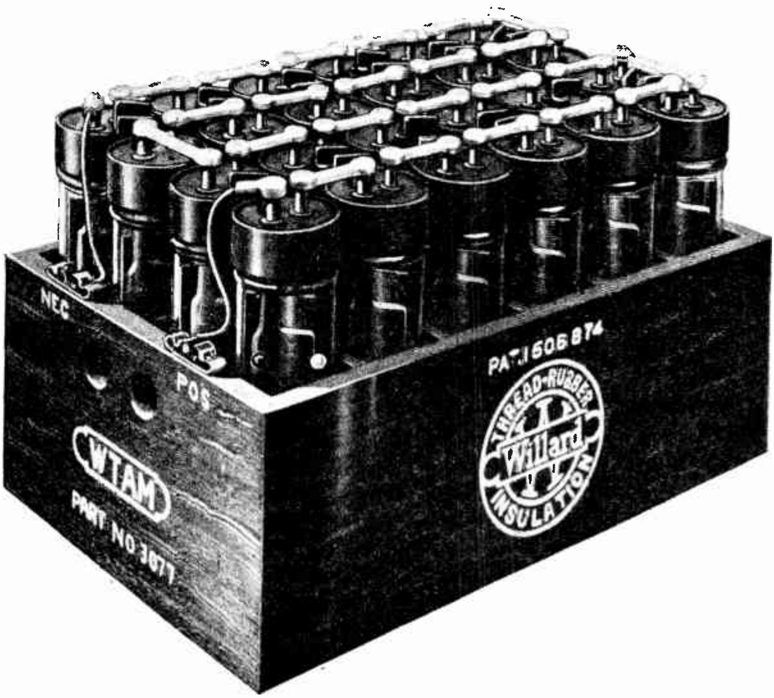


Fig. 12-B.—A 24-Cell Lead Type "B" Battery Unit, Equivalent to a 45 Volt Unit.

Another type very similar to the "Exide" has the trade name "Ironclad Exide." Instead of a perforated plate filled with peroxide of lead, the Ironclad-Exide positive plate is made up of a series of vertical tubes of hard rubber, filled with active material (see Fig. 8-A), each tube having a central metallic core joined to the top and bottom bars of the plate. The tubes are slotted horizontally to admit the electrolyte. The negative plate of spongy lead is identical with that of the "Exide" cell. With both types of cell, sheets of hard rubber or wood are used to separate the plates.

The "chloride" cell has a positive plate made by filling the openings of a perforated cast-lead plate with coils of soft corrugated lead ribbon. The cast grid serves not only as a rugged support, but also as a good conductor. The box type negative plate consists of a grid of vertical and horizontal ribs forming square pockets, which are closed on each side by perforated sheet lead to retain the active material.

Other things being equal, the greater the number of plates in a cell, the greater is its *current* capacity.

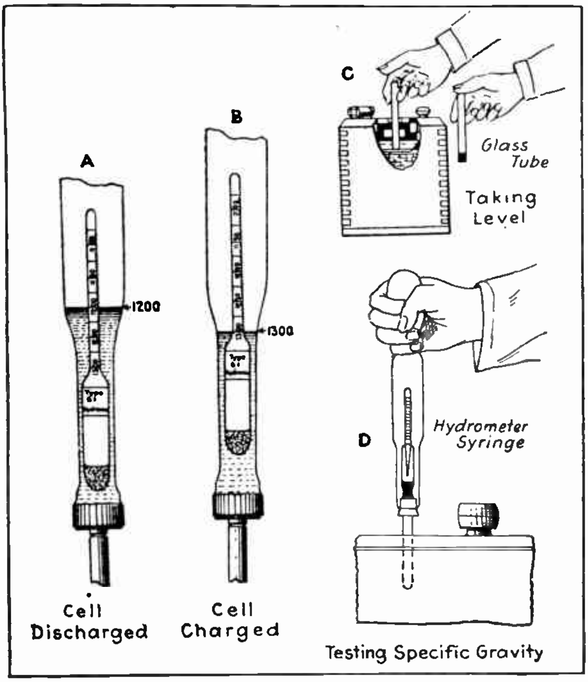


Fig. 13.—Illustrates the method of reading the hydrometer and determining the condition of a storage battery.

The storage "B" cell is a miniature of the type used for filament lighting as is evidenced by Fig. 12-A. A 45 volt unit is shown in Fig. 12-B.

There are two general methods of determining the state of charge, or condition of a storage cell. The first is by taking a voltmeter reading *while the cell is discharging at its normal rate.* It should be about 2.05 volts, somewhat higher immediately after charge. The voltage under the condition stated should *not be allowed to drop below 1.75.*

A more satisfactory test is by taking a specific gravity reading of the electrolyte. When studying the chemical action of the cell we saw that the battery solution grew lighter as the cell was discharged and heavier as the cell was recharged, therefore, it is apparent that its density is a reliable index of its state of charge.

The device employed in determining the specific gravity of the electrolyte is called a "hydrometer." The hydrometer proper (see Fig. 13) is a glass tube closed at both ends, and somewhat enlarged at the lower end. It is suitably loaded at its lower end so that it will float in a vertical position in a sample of the battery solution, which is drawn up into the syringe barrel. Inside the hydrometer a paper scale, graduated from 1.300 at the bottom to 1.100 at the top, is placed. The reading is taken by noting where the level of the solution in the syringe crosses the hydrometer scale. Care should be taken that the hydrometer should float freely in the electrolyte. When the battery is in a fully charged condition, the specific gravity reading should be approximately 1.275-1.300 depending on the age of the cell. When the reading drops to 1.170 the battery should be put on charge.

The instructions of the manufacturer of the particular battery used as to the correct, fully-charged hydrometer reading and the permissible drop before recharging is necessary, *should be carefully followed.*

NOTE: Over-discharging, undercharging and excessive over-charging are all injurious to the plates of the cell causing buckling of plates, loosening of active material, and other disastrous effects, chemical in nature.

The rate of charge and discharge should not be excessive if the battery life is to be conserved since both cause loosening of the active material. About 2 to 5 amperes is a conservative charging current for the filament batteries and ¼ ampere for the plate battery. Lead storage batteries should not be allowed to stand long in a discharged or nearly discharged condition since the lead plates become sulphated, i. e., turn to lead sulphate and are no longer active.

The level of the electrolyte should be maintained about ⅜ to ½ inch over the tops of the plates by adding pure water to compensate for evaporation and decomposition. In this connection, it should be recalled that hydrogen is evolved during the charging process and since this gas is inflammable and forms an explosive mixture with air, it is advisable to keep naked flames away from the vicinity of the battery vents during the charging period especially after the battery begins to "gas."

The cells should be kept clean and dry, allowing no dust or debris to collect on the tops. Acid spray or moisture in combination with dust or other particles will cause a leakage from the positive to the negative terminal.

To put a battery in wet storage that is to be out of commission for less than a year, the most satisfactory result can be obtained by charging continuously at a very low rate, which is so low that gassing is avoided and yet giving enough charge to maintain the batteries in good condition. This type of charge is termed "Trickle Charge." It has the advantage of keeping the batteries in condition for immediate service.

If this method is impossible or impractical under the particular circumstances, put on charge at the proper current rate and continue the charge until the specific gravity of the electrolyte in all cells, as shown by the hydrometer syringe, has held at a maximum (ceased to rise) for a period of five hours and all the cells are gassing freely. When fully charged, place the battery where it will be dry, cool and free from dust. To avoid freezing in cold weather special care must be taken that water is added just before and not after charging.

Once every four months during the out of service period, remove filling plugs and add water, replace plugs and give battery what is known as a "freshening charge," that is, charge until all cells have been gassing freely and evenly for one hour. Then the battery may be allowed to stand for another four months. Disconnect terminals to prevent loss of charge.

The unit of capacity of any storage battery is the ampere-hour. This is generally based on an eight-hour rate of discharge.

Thus a 100 ampere-hour battery will give a continuous discharge of 12½ amperes for eight hours. Theoretically it should give a discharge of 25 amperes continuously for four hours, or 50 amperes for two hours. As a matter of fact, however, the ampere-hour capacity decreases with an increase of discharge rate.

The capacity of a cell is proportional to the exposed area of the plates to which the electrolyte has access, and depends on the quantity of active material on these plates.

The capacity of batteries depends, therefore, on the size and number of plates in parallel, their character, the rate of discharge and also the temperature. Taking the eight-hour rate of discharge and temperature of 60 degrees F. as standard, the capacities which are obtained in American practice are from 40 to 60 ampere-hours a square foot of positive plate service (equals number of plates in parallel multiplied by the length of the breadth reduced to square feet and by 2).

The terms "cell" and "battery" should not be confused by the student. A "cell" is one unit consisting of a set of positive and negative plates immersed in a solution contained in a single jar or container; while a "battery" is made up of two or more cells connected either in series or parallel.

The same term "battery" is used in many other fields of engineering, such as for example, two or more guns are called a battery, two or more steam boilers acting together are called a battery of boilers.

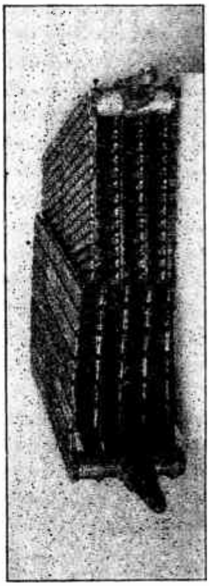
The three things which determine the voltage of a battery are first the type of cell (dry cell, 1.5 volts; lead cell, 2 volts); second, the number of cells in the battery, and third, the method of connecting these cells together.

EDISON CELL

This cell differs from the lead cell in both construction and material. The plates of the "Edison" are made of iron oxide and nickel and immersed in a solution of caustic potash.

Construction of the Edison.—The positive plate of the Edison cell consists of a nickel steel grid or frame which supports thirty perforated steel tubes filled with alternate layers of pure flake nickel and nickel hydrate, while the negative plate consists of a nickel steel grid which supports twenty-four steel pockets filled with iron oxide and a small quantity of metallic mercury. The addition of pure flake nickel in the positive plate increases the conductivity of the active material, and likewise the metallic mercury increases the conductivity of the negative plate. A view of these plates is given in Fig. 14. Each cell has a number of positive and negative plates arranged in alternate order, the positive being connected to one terminal and the negative to the other. The electrolyte is a 21% solution of potassium hydrate (caustic potash) and a small amount of lithium hydrate. It is claimed that caustic potash is a preservative of nickel, steel, and therefore there is no deterioration of the cell due to standing in a discharged or partially discharged condition. The water added to this type cell should be free of impurities as in the case of the lead type cell.

Figure 15 shows a cut-away view of the assembled Edison cell.



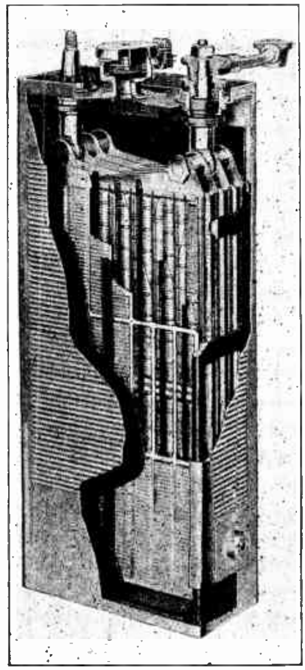


Fig. 14.—Plates of Edison Cell. Fig. 15.—Assembled Edison Cell.
Courtesy of the Edison Storage Battery Co.

Notice:—The student's attention is called to the fact that he is not required to study the following paragraph on the

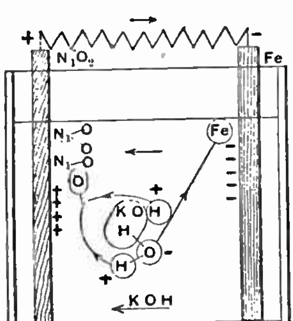


Fig. 16.—Action within Edison cell on discharge.

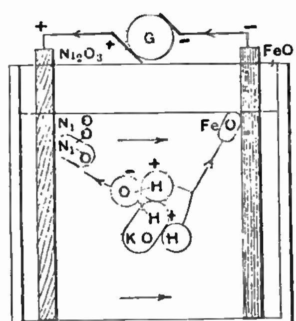


Fig. 17.—Action within Edison cell on charge.

chemical action of the Edison cell. One may, however, be interested in the subject matter and a brief explanation of the symbols will be of great help to him. Ni is Nickel, O is Oxygen, H is Hydrogen and Fe is Iron. For example, $NiOH_2$ means one part of Nickel, one part of Oxygen and two parts of Hydrogen.

Chemical Reaction of the Edison Cell.—When the cells are *first charged*, the nickel hydrate, $NiHO_2$, is changed to nickel oxide NiO_2, and the iron oxide, FeO, is reduced to metallic Fe. The cell may thus be considered to consist of a positive plate of nickel oxide, NiO_2, and a negative plate of pure iron, Fe.

The following equations show the chemical reaction:

Discharge →

$$Fe+2NiO_2+H_2O+KOH=FeO+Ni_2O_3+H_2O+KOH$$

← **Charge**

DISCHARGE

Positive Plate		Negative Plate
NiO_2 } NiO_2		Fe
+		+
H_2	———	O
	+ KOH	
	Produces	
Ni_2O_3		FeO
	+ H_2O + KOH	

CHARGE

Positive Plate		Negative Plate
Ni_2O_3		FeO
+		+
O	———	H_2
	+ KOH	
	Produces	
{ NiO_2 NiO_2		Fe
	+ H_2O + KOH	

On Discharge.—The nickel oxide, NiO_2, probably goes to a lower oxide of nickel, Ni_2O_3; that is, there are only three parts oxygen to two of nickel, instead of two oxygen to one of nickel. The oxygen thus liberated is negatively charged and goes over to the iron plate, gives up its negative charge, and unites with the plate to form iron oxide, either FeO or Fe_2O_3. The electrolyte neither loses nor gains strength in the process and therefore remains at the same density throughout discharge and charge, thereby making gravity readings of no value for indicating the state of charge or discharge. The potassium hydroxide seems to act merely as a catalyzer or carrier. Figure 16 shows the action on discharge.

On Charge.—The iron oxide, FeO, is broken up and the negatively charged oxygen leaves the iron plate, travels back

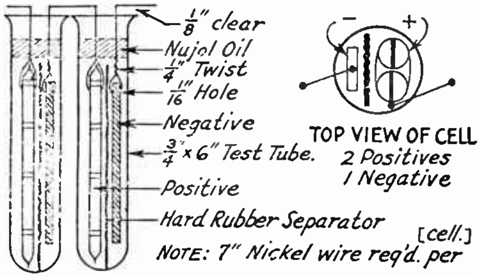


Fig. 18.—Edison Type of "B" Battery Cell.

against the current through the cell and unites with the positive nickel oxide, Ni_2O_3, and forms a higher oxide, NiO_2. Figure 17 shows this action during charge.

The "Edison" "B" battery is made up of a series of test-

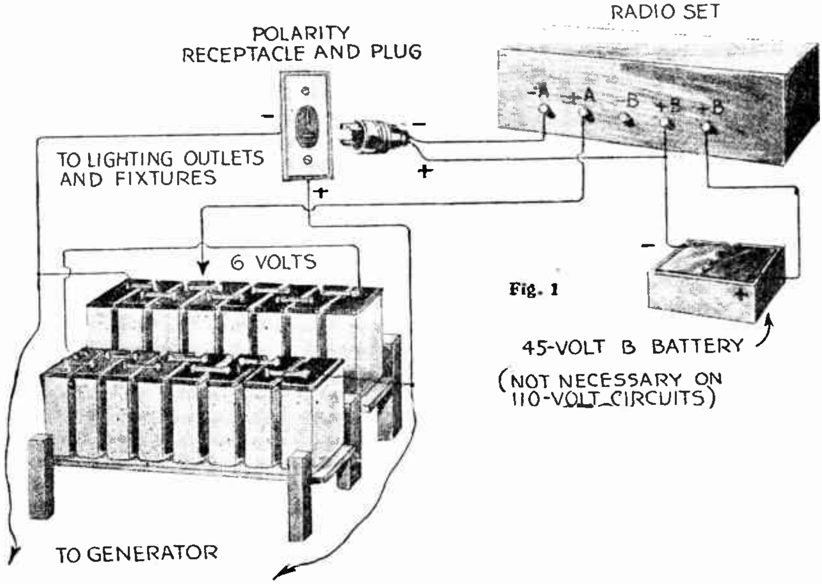


Fig. 19.—Wiring Diagram for Supplying Filament Working Current From a Farm Lighting Battery System, by Tapping Three Cells.

tubes each containing one or two of the perforated steel tubes that comprise the plate of the larger filament battery and a section of the negative plate of the same (as shown in Fig. 18).

A layer of oil is above the top of the electrolyte to prevent creeping. The assembly is usually placed in a rack if the battery is of home construction or in a sealed container if made commercially.

Since the specific gravity of the electrolyte does not change as in the lead cell, such a reading does not indicate the condition of charge of an Edison battery. The voltmeter test is the only available one. This type cell has a maximum voltage of 1.2 and a minimum of .9.

How to operate a receiver from a 32 volt farm lighting plant.

Thousands of American homes are equipped with independent lighting plants that supply a D. C. source of power which can be utilized to directly operate a radio set eliminating the use of a special "A" or "B" battery.

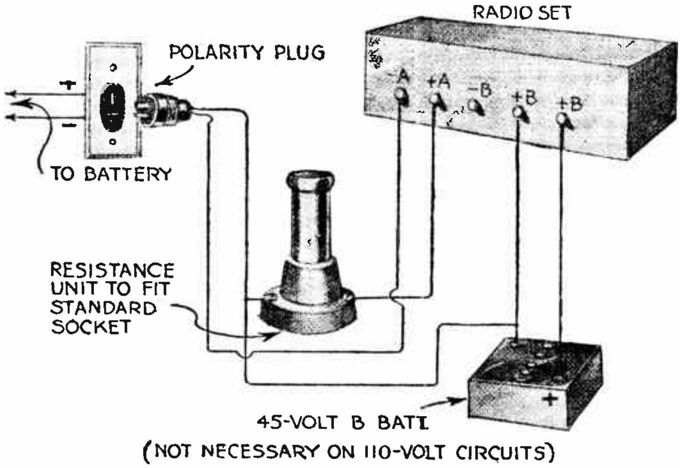


Fig. 20.—Diagram of Connections for Filament Current Supplied from 110 D. C. Source with Resistance in the Circuit.

Most of the lighting units comprise either a 32 volt or 110 volt storage battery which is automatically maintained in a charged condition by a generator.

If your home is equipped with a 32 volt system, you can dispense with all extra batteries for your radio set if your receiver uses only one tube. A multi-tube set, however, requires more than 32 volts, so that with such a set it still will be necessary to use one block of "B" battery to obtain the correct plate voltage for the amplifier tubes.

With the 110 volt system, the voltage will be found ample for all requirements.

Figure 19 shows one way to hook up the receiving set to either the 32 volt system or the 110 volt system, provided different sets of cells are used successively so that the drain will be equally distributed over all of the cells. *No connection is necessary to the minus "B" binding post, because this post is connected inside the set with either the minus or plus "A" binding post and this connection is already made for you in the battery itself.*

Figure 20 illustrates another way of connecting up which obviates the long lead from "A" of the set to the terminal of the battery.

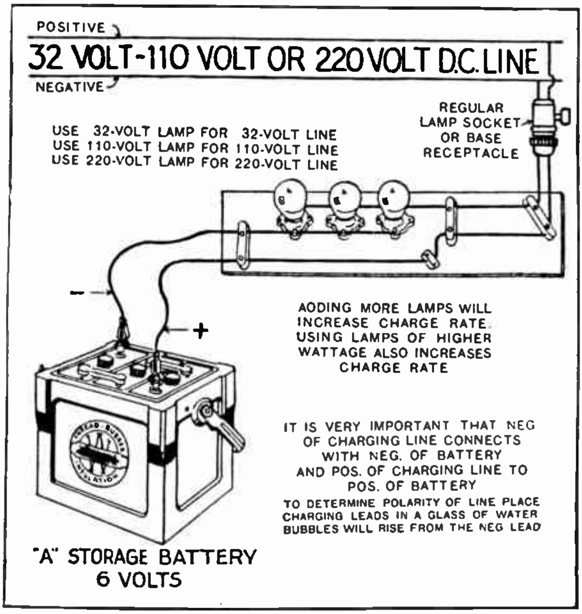


Fig. 21.—Charging a Storage Battery From a D. C. Line Using Lamps as Charging Resistance.

Table No. 2 gives the value of the fixed resistance that should be used with the hook-up shown in Fig 20 to cut down the voltage for the filament circuit when from one to five .06 ampere or quarter-ampere storage battery tubes are used on either 32 or 110 volts. If the battery is situated a considerable distance from the receiving set, the resistances specified for 32 volt circuits may have to be cut down somewhat, owing to the drop in voltage over the line.

There is one point that should be mentioned in connection with the circuit of Fig. 20. Do not turn off or remove one

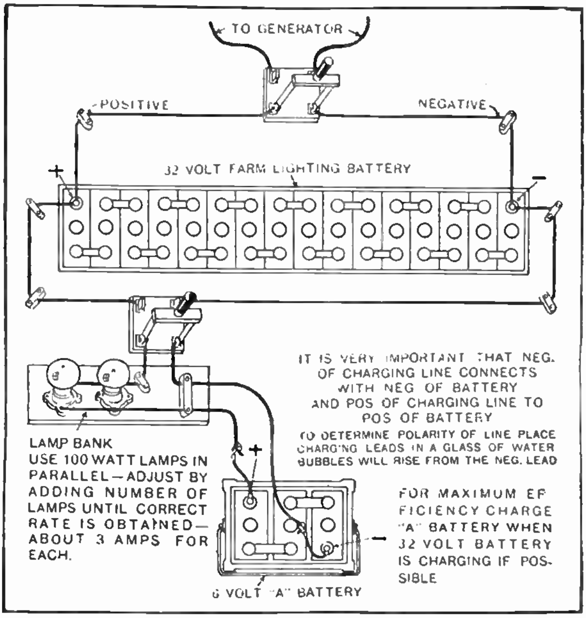


Fig. 22.—Charging a 6-Volt Storage Battery From a 32-Volt Farm Lighting System.

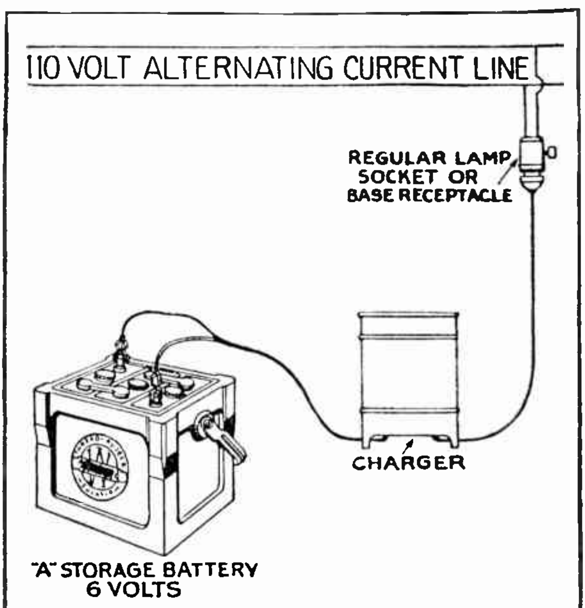


Fig. 23.—Charging a 6-Volt Storage Battery From 110-Volt A. C. Line Using a Rectifier to Change the A. C. to D. C.

(YE IBM)

199 — B (67.5 / 90)
C (3.0 / 4½)

<u>M10</u>

Sug'

a Batt terminals on rcvr

Size of "R" depends on tube used in rcvr tube from the socket while the current is turned on, as this will throw an extra load on the other tubes and they might burn out.

TABLE NO. 2

No. of tubes	.06-Ampere Tubes 32 volts	.06-Ampere Tubes 110 volts	Quarter-Ampere Tubes 32 volts	Quarter-Ampere Tubes 110 volts
1	450 ohms	1750 ohms	100 ohms	420 ohms
2	230 "	870 "	55 "	210 "
3	150 "	590 "	36 "	140 "
4	115 "	440 "	27 "	105 "
5	90 "	350 "	21 "	84 "

If a multi-tube set is to be employed, there will be an objectionable hum if the generator is operating while the set is being used. It will be worth while having a service man install a switch near the set to cut the generator off when it is desired to receive.

TEST QUESTIONS

1. Explain the difference between "A." "B" and "C" types of dry cell radio batteries.

2. How many single unit cells are used in a 45 volt "B" battery and how are they connected?

3. Show by a drawing the arrangement of dry cell batteries for supplying filament current to a five-tube set using UV-199 tubes.

4. What type and voltage "C" battery would you use on the amplifying tubes (UV or UX-199) with a 67.5 or 90 volt plate battery (see table I)?

5. Name the tests in checking the condition of a dry cell filament battery.

6. What is the difference between the primary cell and the storage cell?

7. Explain how to test the specific gravity of an electrolyte.

8. Mention a few important requirements for the proper care of a storage battery.

9. What things determine the voltage of all batteries?

10. Show by drawing the wiring diagram for connecting a 32 volt lighting system to the filament circuit of a one-tube receiver.

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HETERODYNE RECEPTION OF RADIO WAVES

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HETERODYNE RECEPTION OF RADIO WAVES

No one can have any contact with radio communication today without hearing very frequently the term **"Heterodyne."** Newspaper articles discussing the general subjects of radio regulations and interference make frequent use of the term. It is also extensively used in descriptive matter with respect to radio sets and certain types of radio reception. The term "Super-Heterodyne" is applied to a particularly well-known receiving set which depends for its operation upon the heterodyne principle. This principle is so deeply involved in the science of radio communication and in so many ways that we are going to discuss it very fully in this text. When we have finished you should thoroughly understand the terms and the phenomenae with which it is associated.

THE PRODUCTION OF BEATS

If you have access to a piano you can perform the following experiment: Strike the white key which is known as middle C. This produces a sound frequency of 256 cycles per second. Referring to this white key as key number one, the eighth key below is low C. The frequency produced by striking it will be one-half of 256 or 128. Now referring to this as key number one, the eighth key below this might be referred to as extra low C. The frequency produced by striking it will be 64 cycles. Now strike the key which is just below extra low C, as we have called it. The frequency which would be produced by striking this key is approximately 60 cycles per second.

You have now located a white key upon your piano, which when struck produces a frequency of 64 cycles and a second white key next to it which when struck will produce a frequency of 60 cycles per second. Strike the two keys simultaneously. You will at once notice a distinct throbbing sensation which is somewhat unpleasant to the ear. The intensity of the sound produced appears to go up and down periodically. The phenomenon which you have just observed is known as the production of beats. The throbbing which you have noticed is caused by a variation in intensity in the tone as heard by your ear.

Referring now to Fig. 1, let us assume that the upper time graph labeled A represents a pure tone of 64 cycles and that the time graph B represents a pure tone of 60 cycles. If we add the ordinates of curve A to those of curve B and plot underneath a third curve, we have a graph such as is shown by curve C of Fig. 1. The number of cycles shown in each curve of Fig. 1 in each case is the number which would be produced in ½ second. The graphs would have to be twice as long to show the total number per second.

You will note that the curve C is not constant in amplitude. The intensity first rises and then falls. It is this rise and fall in intensity which produces the throbbing you have noticed. If the frequency of one of the piano keys is 64 cycles and of the other is 60 cycles, then there will be four amplitude peaks per second in curve C, or, as we usually refer to the phenomenon, the *beat frequency* produced will be the *difference* between 64 and 60 cycles which is 4 cycles.

Let us now assume that we are one hundred or more miles distant from a radio broadcasting station whose carrier frequency is 1,000,000 cycles (1,000 kc) and that a hundred or more miles in the other direction from us there is located another radio broadcasting station whose carrier frequency is 1,001,000 cycles (1,001 kc). We will also assume that receiving conditions are such that if either station were operating alone, we would have no difficulty in hearing it. If, however, both stations are operating simultaneously, we will notice in our receiving set a very strong whistle or note which makes it impossible for us to receive a satisfactory program from either station.

There are two characteristics of this note which are worthy of mention. In the first place, its frequency remains fairly constant, providing, of course, the carrier frequencies in use by the two stations are held constant. In the second place, the note is often louder than the program from either station. We are becoming acquainted with a type of interference known as "heterodyne" interference and the phenomenon we are studying is very similar to that we studied by the aid of the piano.

In our piano experiment, we were dealing with two frequencies, one 64 cycles and the other 60 cycles, both of which lie within the range of audibility of the human ear. The beat frequency which was produced by "interference" between these two audible frequencies was so low as to be inaudible. It, therefore, manifests itself as a throbbing in intensity of the tone as received by the ear. The two frequencies we are now dealing with are well above the range of audibility. The ear will not respond directly to a frequency of 1,000,000 cycles, nor will it respond to a frequency of 1,001,000. However, the simultaneous reception of these two frequencies by a particular receiving set, and the action of the detector when the two frequencies are applied to it produce a third frequency in the detector circuit and in the audio-frequency amplifier which is equal to the difference be-

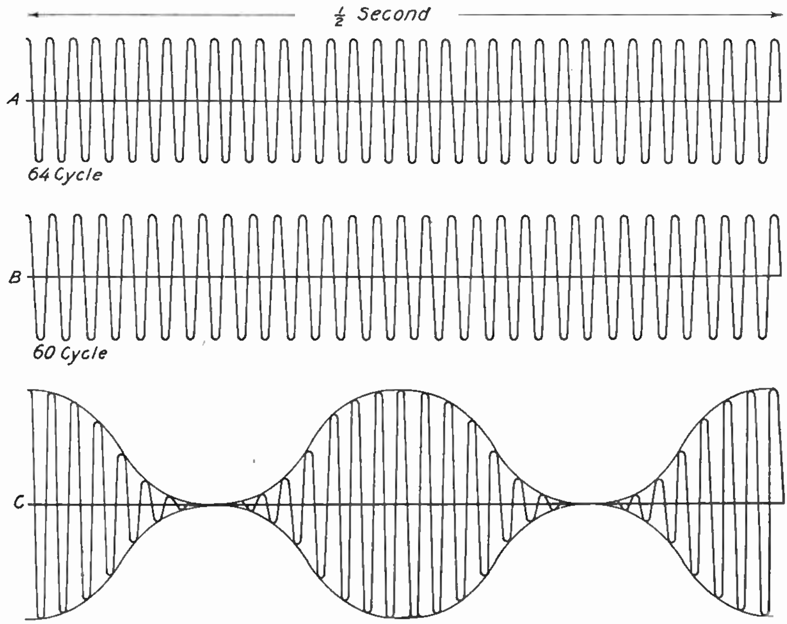

Fig. 1—Curves showing how two audio frequencies combine.

tween the two incoming frequencies. In other words, the detector will, from the 1,000,000 cycle voltage and the 1,001,000 cycle voltage present, produce a third alternating voltage having a frequency equal to the difference between these two, which is 1,000 cycles. The 1,000 cycle alternating voltage produced by the detector will then be amplified by the audio-frequency amplifier, passed through the head-set, or loud-speaker, and produce the very disturbing note which we have found.

It is of importance to note that the action of the detector is essential to the production of the beat frequency. This is a fact which is often but inadequately understood. If we were to amplify a 1,000,000 cycle voltage and a 1,001,000 cycle voltage by means of a perfect amplifier, the output of this amplifier would contain only the two frequencies with which we started. It is only by the aid of a detector that we can produce a frequency equal to the difference between the two. The fact that the two primary frequencies are well above the range of audibility does not in any way prevent the beat frequency produced by detector action from producing an audible sound when passed through a loud-speaker.

In addition to the beat frequency equal to the difference between the two incoming frequencies, there is produced by the detector another frequency which is equal to the sum of the two incoming frequencies. Thus, the combination of our 1000 kc and our 1001 kc frequencies produces in addition to the 1 kc (1000 cycle) beat note which is audible, another frequency of 2001 kc which is well above the range of audibility. This frequency has been used in certain types of receiving sets of an experimental character.

HETERODYNE RECEPTION OF CONTINUOUS WAVES

Let us now consider how the principles we have been discussing can be applied to the reception of radiotelegraph signals from a continuous wave transmitting station. As you have learned in previous lessons, continuous (CW) waves are produced by transmitting stations which produce pure sine waves, that is to say, the amplitudes of the succeeding oscillations are all the same. These waves may be produced by a vacuum tube oscillator, by a high-frequency generator, or by other methods. For telegraphic purposes, the waves are broken up into dots and dashes at the transmitting stations by means of a key. Referring to Fig. 2, curve (a) let us assume that this represents a dash as is made by closing the key for a given period of time and then lifting it as shown on the curve. Let us assume that we are located at some distance from the transmitting station at which this is done, and further that we are equipped with a radio receiving set, the circuit for which is shown in Fig. 3. The upper portion of Fig. 3 shows a conventional crystal receiving set, the operation of which we are already familiar with. In the lower portion of the figure, we have included a generating device for producing an undamped radio-frequency voltage, which voltage may also be applied to the crystal receiving circuit as is shown. We are not at this particular time concerned with the details of operation of this local generating circuit.

It might, however, very probably be a vacuum tube oscillator

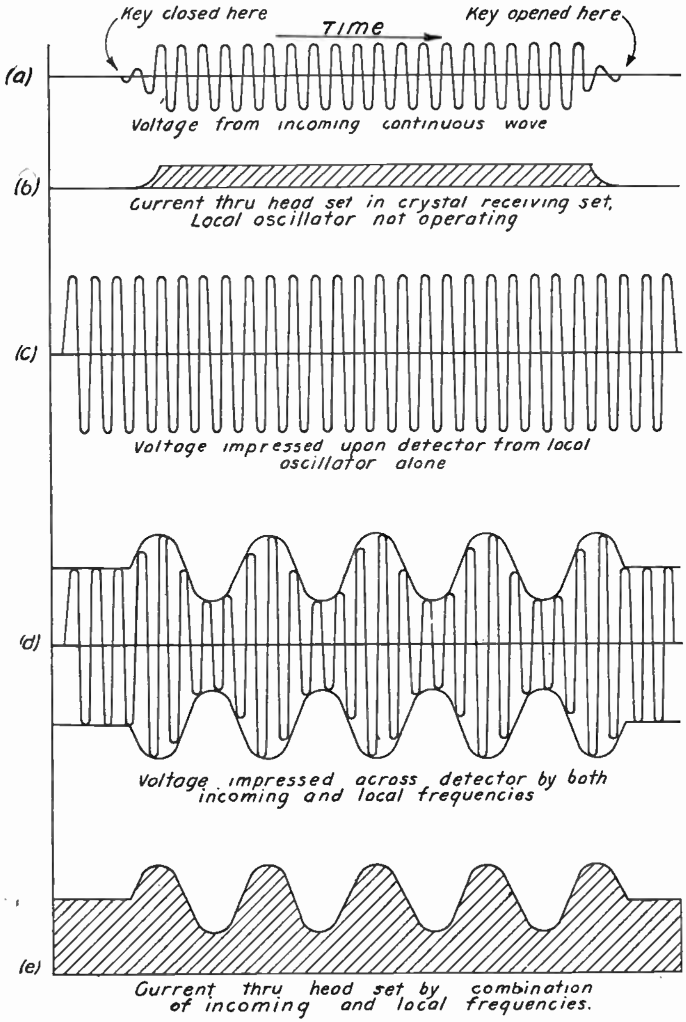

Fig. 2—Combination of incoming and local frequencies in heterodyne reception of continuous waves.

so constructed and so operated that the beat frequency produced by it could be varied at will.

For the purpose of our explanation, let us assume that the frequency produced at the distant transmitting station is 500,000 cycles (500 kc). This frequency is one which is very often used by radiotelegraph stations on ships or communicating with ships.

We have, therefore, selected a very suitable frequency for our illustration. Suppose now that before we start the local frequency generator shown in Fig. 3, we listen in the head-set of our crystal receiver while the operator at the distant transmitting station closes the key, transmits a dash and lifts the key to conclude the dash as shown in curve (a) Fig. 2. Before the incoming signal arrives, no current will, of course, flow through the head-set. When the signal does arrive, however, a voltage as is shown in curve (a) is applied to the crystal rectifier system and a steady current as is shown by curve (b) Fig. 2 will flow through the head-set.

When the key is closed at the transmitting station, a slight click will be heard in the head-set. This is due to the rise in the value of current through the head-set due to the application of the voltage as shown at the beginning of curve (b) Fig. 2. After the current through the head-set reaches this new value, it remains steady until the key is lifted at the end of the dash. This steady current will maintain tension upon the receiver diaphragm, but as the current and, therefore, the tension do not change, no sound will be heard until the key is lifted, when another click similar to the one heard at the beginning of the dash will be produced. If the operator at the transmitting station is transmitting dots and dashes in accordance with the continental code, then we will only hear a series of clicks at the beginnings and ends of the dots and dashes. Often due to the presence of other noises in the head-set, these clicks can not be readily identified.

From the above discussion, you can readily see that an ordinary crystal receiving set is not suitable for receiving radiotelegraph signals transmitted by a continuous wave transmitting station. This would also be true if a vacuum tube receiving set of the type ordinarily used for radiotelephone reception were under consideration. We must, therefore, include something else in our receiving set, if we are interested in receiving signals of the type shown in curve (a) Fig. 2.

Let us now throw into operation our local generator circuit and let us adjust the frequency produced by this generator to have a value fairly close to that produced by the distant transmitting station, say 501 kc. Curve (c) Fig. 2, shows the voltage which will be impressed upon the detector from this local oscillator alone. Since we can control the design of our generator, the voltage impressed upon the detector from it can readily be made considerably greater than will be that impressed by the incoming signal from the distant station.

Let us now assume that the operator at the distant telegraph station again transmits a dash by means of the key. We will now have present in the crystal detector circuit not only the voltage impressed by the local oscillator of 501 kc, but also the incoming voltage of 500 kc. These two voltages when added together will give a voltage such as is shown by curve (d) Fig. 2. Note the similarity between this curve and the one shown in one of our previous lessons describing the various types of waves. You will note that this is now a sine modulated wave. The varia-

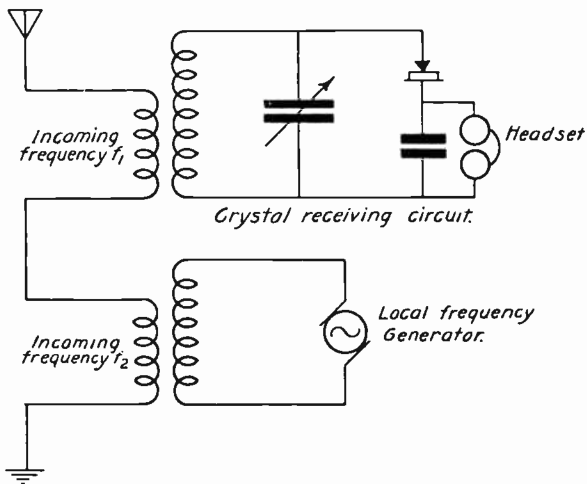

Fig. 3—Explanatory circuit to show principles of heterodyne reception of continuous waves.

tions in amplitude due to the combination of the two frequencies are of a frequency equal to the difference between the two frequencies, namely, 1 kc or 1000 cycles.

The application of a voltage to our crystal detector as is shown by curve (d) Fig. 2, produces a current through our head-set such as is shown by curve (e) Fig. 2. Note that until the key is closed at the transmitting station, the current through the head-set is steady and, therefore, the receiver diaphragm is under constant tension. This steady current is, of course, produced by the local oscillator. When the voltage impressed upon the detector begins to vary in amplitude due to the effect of the incoming voltage, then we have the current through the head-set varying as is shown in curve (e). These variations will take place at a frequency of 1000 cycles as we have described, and this will cause the head-set diaphragm to vibrate at this frequency. Since 1000 cycles is well within the range of audibility, a 1000 cycle tone will be produced in the head-set.

There are a number of important deductions which can be made from the curves shown in Fig. 2. In general, the amplitude of the incoming voltage will be quite low because the transmitting station is a long distance away. The amplitude of the local voltage can be made many times this. You will readily notice that the amplitude of the 1000 cycle tone produced in the head-set by heterodyne reception as shown by curve (e) is considerably greater than the amplitude of the clicks occurring at the beginning and end of the graph as shown by curve (b). This is due to the effect of the local frequency voltage. We discover here a very astonishing fact. *By the use of heterodyne reception, we can introduce great amplification into our signal.* The amplitude of the resulting signal in the head-set from the incoming voltage alone is usually assumed to be proportional to the *square* of this voltage. However, the amplitude of the signal produced in the head-set by the combination of the incoming voltage and the local voltage is proportional to the *product* of the two voltages. Since the local voltage may be many times greater than the incoming voltage, this *product* of the two voltages may be many times greater than the *square* of the incoming voltage. Heterodyne reception possesses this great advantage over other types of reception—*the process of heterodyning in itself introduces great amplification.*

The purpose of the circuit shown in Fig. 3 is to show the principles involved in heterodyne reception, and not to give a working diagram. The circuit for the local generator has therefore been omitted, and a crystal receiving circuit has been included in place of the more commonly used vacuum tube circuit because it is somewhat easier to explain the detector action involved. Until very recently the great majority of transmitters used on ships and in land stations operated for communication with ships have been of the damped wave type. However, the great amount of interference which transmitters of this type cause with other radio services and their inefficiency has led to their gradual abolition and to the use of modern continuous wave vacuum tube transmitters in their place. Some of these transmitters are of the pure continuous wave type while others radiate continuous waves modulated at audible frequency classified as Type A-2.

Continuous wave transmitters are now very extensively used in amateur stations. These stations range in power from a fraction of a watt up to about 500 watts and operate upon frequencies which are confined to narrow bands near 1,800, 3,750, 7,150, 13,000 and 28,000 kilocycles. The bands lying near the first four frequencies listed above are probably the most used by amateurs. In a later lesson we will discuss in considerably more detail the many interesting things which amateurs are doing. We are, in this lesson, only concerned with the fact that most amateur transmitting stations are of the continuous wave or modulated continuous wave type and, therefore,

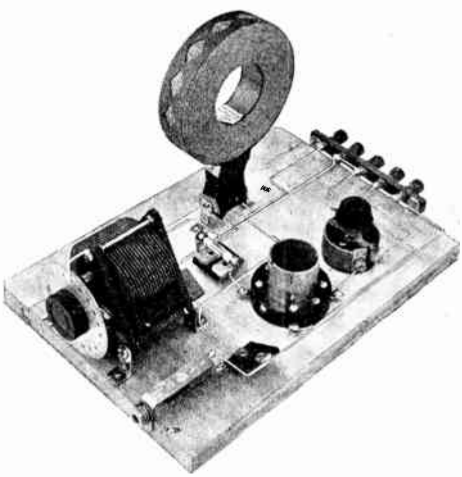

Fig. 4—A long wave receiving set for code practice.

amateur receiving sets are practically all such as to permit reception of signals from these stations by means of heterodyne reception.

A SIMPLE AUTODYNE RECEIVING SET

Most radio receiving sets used for heterodyne reception are, of course, of the vacuum tube type. In practically all such sets the same vacuum tube circuit used for detection is also used to produce the local frequency which is to be combined with the incoming frequency. This is done by using a regenerative circuit and by making the regeneration so great that the circuit actually produces oscillations. Since it is necessary only to retune the receiving set ever so slightly to make the local frequency different from the incoming frequency by an audible amount, say 500 or 1000 cycles, the fact that the receiving set is producing one frequency and receiving another does not to any appreciable extent impair its efficiency. When a particular vacuum tube circuit produces the local frequency and at the same time functions as a detector, reception is said to be by the "*autodyne*" method.

Circuits of this kind are open to one objection and this is the fact that inasmuch as they are producing oscillation they also act as small transmitters. They may, therefore, produce interference in other receiving sets trying to receive signals from the same transmitting station or from another station radiating nearly the same frequency. However, as heterodyne reception is today used most frequently in connection with commercial and Government radiotelegraph stations, the number

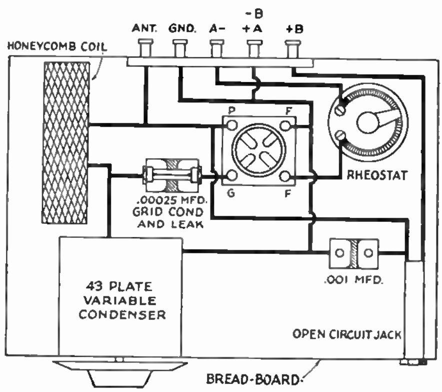

Fig. 5—Bread board mounting of a long wave receiving set.

of operators interested in this type of transmission is limited and the radiating properties of their receiving sets do not therefore ordinarily cause much trouble.

Fig. 4 shows a single circuit long wave receiving set which can be very easily constructed at small expense and which is very useful for listening to long wave stations for the purpose of learning the International Continental Code.* Trans-Atlantic radiotelegraph stations using continuous waves are continually sending on frequencies lying between 60 and 15 kilocycles (5000 and 20,000 meters). Many of them use tape transmission and therefore their sending is perfectly regular. These stations send at a speed depending upon receiving conditions at the time of transmission. It is usually possible to select a station going at about the desired speed for code practice.

* Figures 4 and 5 are taken from "The Radio Amateur's Handbook," published by American Radio Relay League at Hartford, Conn.

The following is a list of material necessary to construct a long wave radio receiver such as is shown in Fig. 4:

1 1500-turn honeycomb coil (5000 to 15000 meters).
1 standard single coil mounting (not pivoted).
1 good variable condenser having a maximum capacity of .001 microfarads.
4 brass angles to support the condenser.
1 good tube socket.
1 30-ohm rheostat.
1 .001-microfarad mica by-pass condenser.
1 .00025-microfarad mica grid condenser.
1 2-megohm grid leak.
10 feet No. 14 tinned bus wire.
1 single jack, open-circuit type.
1 terminal block, 2" x 4¾" x ¼" bakelite.
1 wood baseboard, 1" x 7½" x 12".
6 8/32 binding posts or machine screws with two hex nuts each.

Honeycomb coils and coil mountings can be obtained from radio parts dealers or from supply houses.

For the commercial ship and shore stations which operate upon 500 kilocycles and the frequencies which lie near this, a 150-turn honeycomb coil may be used. For the 250 to 115-kilocycle bands (1200 to 2600 meters), a 400-turn coil may be used. A 750-turn coil will bridge the gap between 115 and 60 kilocycles. These coils may be added as desired and by plugging them into the coil mounting, the wave-length range of the set may be changed. With the smaller coils, you can hear Arlington press as it is broadcast by telegraph for the use of the Navy as well as many low-powered ships and shore stations.

Figure 5 shows how the various parts may be mounted upon a plain pine board while Fig. 6 shows the wiring diagram, as well as the arrangement of apparatus. (The wiring diagram shown in Fig. 6 is somewhat different from that for the set pictured in Figs. 4 and 5 and will probably give somewhat better results. Note that it is necessary to tap the honeycomb coil.) If a 201-A type tube is used, then a 6-volt storage battery must be connected between the —A and +A terminals. The plate voltage should be supplied by one or two banks of 22½ volts each.

SUPER-HETERODYNE OR INTERMEDIATE AMPLIFIER RECEIVING SET

The same principles we have been discussing are used in a type of receiving set which is known to the great majority of radio listeners as the Super-Heterodyne. Briefly the theory of operation of this receiving set is as follows: Assume that it is desired to receive a radio broadcasting station which is operating on a carrier frequency of 1000 kc. In most receiving sets of this type, the signal energy is usually collected from the wave present at the receiving location with a coil antenna, such as is shown in Fig. 7. This signal is applied to a vacuum tube circuit which operates as the detector and to which we will refer as the *first detector*.

A voltage from a local oscillator is also produced in the coil antenna as shown in Fig. 7. This oscillator is ordinarily of the vacuum tube type and the frequency it produces can be varied at will by means of a tuning condenser. Now, instead of making the difference between the incoming frequency and the frequency produced by the *local oscillator* some frequency which is within the range of audibility, as was done in the receiving set we described for straight heterodyne reception of telegraph signals, the difference between the incoming frequency and the local frequency is made to possess some value considerably *above* the range of audibility. Let us assume that this difference is equal to 35 kc. If the incoming frequency were 1000 kc then the local frequency might be made 1035 kc. There would then be produced in the plate circuit of the first detector a beat frequency of 35 kc, together with upper and lower side bands extending to about 40 kc in one direction and down to 30 kc in the other direction.

The *intermediate frequency amplifier* shown to the right of the first detector unit in Fig. 7 will consist of two or more tubes together with associated apparatus so designed and adjusted that it will amplify frequencies lying between 30 and 40 kc much more readily than it will frequencies lying outside this band. You can readily see the reason why this amplifier is called an *intermediate frequency amplifier*. It is particularly designed to amplify a band of frequencies which lie *between* the *radio* frequencies ordinarily used for radio broadcasting and the *audible* frequencies present in speech and music. The intermediate frequency amplifier acts just exactly as it would in the event that the radiotelephone transmitter were operating at a carrier frequency of 35 kc (approximately 8571 meters) and the amplifier were connected up directly to a receiving antenna.

After the band of frequencies lying between 30 and 40 kc has passed through the intermediate frequency amplifier, the voltages are applied to the *second detector*. This functions as any detector circuit with the exception that its input will always consist of a carrier frequency of approximately 35 kc and side bands as produced by modulation extending up to approximately 40 kc and down to 30 kc. The fact that this range of frequencies is considerably lower than those lying in the broadcast band itself necessitates certain special considerations in connection with the design of this second detector circuit as we shall see in a later lesson.

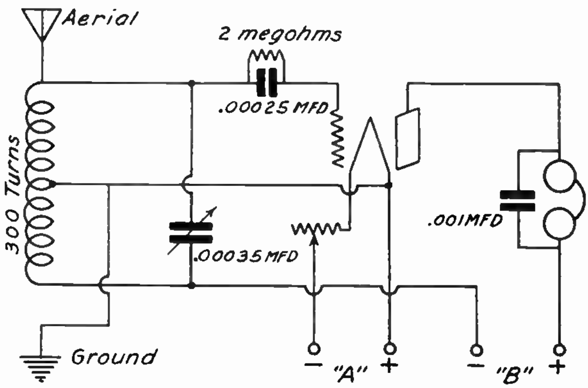

Fig. 6—Wiring diagram of a simple long wave receiving set.

The audio-frequency amplifier connected to the output of the second detector functions as would any such amplifier, its purpose being to raise the level of the speech and music frequencies to a point where they will satisfactorily operate the head-set or loud-speaker.

A Super-Heterodyne such as is shown in Fig. 7 would ordinarily use 8 tubes, one for the local oscillator, one for the first detector, three in the intermediate frequency amplifier, one for the second detector and two in the audio-frequency amplifier. In certain types of Super-Heterodynes, however, one or more tubes are made to do double duty thus reducing the total number required. To illustrate, the oscillator tube may be made to function as a detector or some other combination of functions may be made.

It should be understood that the circuit given above is not a practical one. There are, in fact, objections to coupling the local oscillator to the antenna system as is shown, inasmuch as the local oscillator will then produce energy in the antenna, which energy, when radiated, may cause interference with other receiving sets located in the immediate vicinity. The purpose of Fig. 7 is to show how the Super-Heterodyne works. We are not showing the circuit in so detailed a fashion as to distract your mind from the fundamental principles we are considering. Detailed information concerning specific Super-Heterodyne and intermediate frequency amplifier circuits will be given in a later lesson devoted specifically to this subject. We are concerned here only with the theory of operation.

There are a number of features in connection with Super-Heterodynes which you can readily appreciate after the very simple explanation we have just gone through. Regardless of the incoming frequencies, they can all be reduced to the band lying between 30 and 40 kc by the proper adjustment of the local oscillator. For instance, assume that the incoming frequency is 550 kc. If the frequency of the local oscillator is then made 585 kc or 515 kc, the beat frequency produced will still be 35 kc, and the side bands will lie to the sides of this frequency as before. The fact that the Super-Heterodyne can be made to reduce the signals from any station operating in the broadcast band to a 10 kc band of frequencies considerably lower but always the same makes it possible to design the intermediate frequency amplifier so as to operate most efficiently for all frequencies in this particular lower band. In other words, if tuned circuits are used in the intermediate frequency amplifier, they may be tuned by means of fixed inductances and condensers, and once tuned by the builder of the set, they do not need to be varied.

Only two tuning controls are necessary, the first is the variable condenser shown in Fig. 7, which must, of course, be tuned to the incoming signal. The second tuning control is the variable condenser which determines the frequency produced by the local oscillator. Receiving sets which have only two tuning controls are practically as good as those which have only one. In fact, there are those who believe that from a psychological standpoint, a receiving set with two controls is better than one possessing a single control. They argue that with a single control receiving set, one of the operator's hands has nothing to do and is, therefore, likely to be operating controls which should be left constant and not adjusted at all, such as, for instance, the filament control. However, whether or not there is any logic in this argument, no one can deny that it is practically as easy to operate a two-control receiver as a one-control receiver.

In our illustration we have assumed that the intermediate frequency amplifier is designed to handle a band of frequencies lying between 30 and 40 kc. The beat frequency produced by the combination of the signal from the local oscillator with that from the incoming signal will then be 35 kc. Such a receiving set would be referred to as a *35 kc Super-Heterodyne* and the intermediate frequency amplifier as a 35 kc amplifier. For radiotelephony it must, of course, handle a band of frequencies extending 5 kc each side of this. Different designers design their intermediate frequency amplifiers to handle different frequencies. The one we have selected for the purpose of

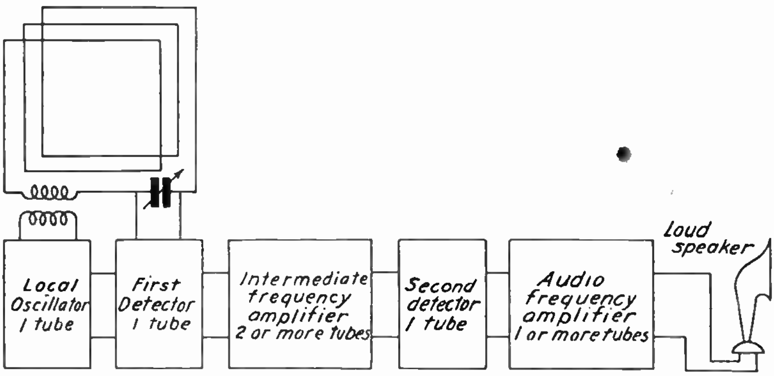

Fig. 7—Block diagram for a Super-Heterodyne or intermediate frequency amplifier type radio receiving set.

illustration is about as low as can be used without producing intermediate frequencies which will lie within the range of audibility. Some designers have built intermediate frequency amplifiers to operate when the beat frequency produced between carrier and local frequencies is as high as 340 kc. There is a distinct tendency now to use intermediate frequencies above 100 kc.

Let us note one or two peculiarities with respect to the operation of Super-Heterodynes. We will continue to assume that the intermediate frequency used in the Super-Heterodyne shown in Fig. 7 is 35 kc. If we are receiving a radio broadcast station whose carrier frequency is adjusted to 550 kc, then we can produce the intermediate frequency of 35 kc by adjusting the frequency of our local oscillator 35 kc below 550 kc; that is, 515 kc. Since the beat frequency produced is equal to the difference between the two frequencies we might also produce a 35 kc intermediate frequency by adjusting the local oscillator to produce a frequency of 585 kc. In other words, having tuned the antenna circuit by the aid of the condenser shown in Fig. 3 for 550 kc, we find that there are two places on the dial controlling the frequency produced by the local oscillator at which we can in general receive equally satisfactory signals. One of these is when the local oscillator is adjusted for 585 kc, the other when it is adjusted for 515 kc. This characteristic of the Super-Heterodyne is not possessed by any other type of receiver.

Let us assume that the station to which we are listening is transmitting on a carrier frequency of 550 kc, and is located at some distance from us. Let us, however, assume that much nearer to us is a broadcasting station whose carrier frequency is 620 kc. There will then be present in the coil antenna signals from two stations, one 550 kc, the other 620 kc. Were it not for the fact that our antenna system is tuned to 550 kc, the energy from the nearer 620 kc station would, of course, be many times that from the 550 kc station. However, in spite of tuning, it is quite possible that a considerable voltage will be produced at the input connections of the first detector circuit by the nearer 620 kc station. In addition to producing a 35 kc beat note with the incoming signal from the 550 kc station, the local oscillator will also produce a 35 kc beat note with the signal from the station transmitting a carrier frequency of 620 kc, since the difference between 585 kc and 620 kc is also 35 kc. We may, therefore, experience interference from the 620 kc station.

The phenomenon we have discussed is at times very troublesome in Super-Heterodyne receivers which are not so designed as to eliminate it, particularly in communities like Chicago and New York where there are many broadcasting stations. Less difficulty is experienced when a stage of tuned radio-frequency amplification is used between the coil antenna and the detector. The addition of this stage of tuned radio-frequency amplification and the introduction of the local signal after it has the added advantage of preventing the radiation of the local signal.

The interference we have described is also minimized by designing the intermediate frequency amplifier transformer for frequencies somewhat different than those we have used in our illustration. If our intermediate frequency amplifier is designed to handle a beat frequency of 37 kc and the two side bands as produced by an incoming signal and local oscillator, then the local oscillator would be tuned to 587 kc instead of 580 kc. The difference between 587 kc and 620 kc is 33 kc which is 4 kc lower than the 37 kc for which the amplifier is designed. However, this method of attempting to eliminate the interference is not as successful as might be supposed, due to the fact that the intermediate frequency amplifier cannot be highly selective, otherwise it will amplify the frequencies near the carrier frequency better than those removed 5 kc with the result that the signal will be distorted.

In view of the number of tubes necessary in Super-Heterodyne receivers, their circuits are often very complicated. Detailed information concerning these circuits and their operation will, as has been previously said, be given in a later lesson. The fundamental principles that we have discussed should make it comparatively easy for you to understand their operation.

Before closing our discussion, there is one principle which should be again emphasized. As you have already learned, *heterodyning in itself introduces great amplification.* In addition, since the frequencies handled by the intermediate frequency amplifier are comparatively low, it is possible to make this amplifier relatively efficient. As a result of the great amplification introduced by heterodyning and the high efficiency of the intermediate frequency amplifier, a Super-Heterodyne will operate satisfactorily even though the voltage delivered to the first detector by the signal collecting device is relatively low. In other words, Super-Heterodynes are very sensitive. They are, therefore, ordinarily used with coil antennas. Coil antennas do not deliver anywhere nearly as large voltages to the detector as do the larger antennas, but they are more selective and to some extent less subject to atmospheric disturbances.

HETERODYNE INTERFERENCE

It will be our object as we discuss the fundamental principles underlying various phases of radio communication to at the same time discuss the practical application of these principles. Thus in this lesson, after discussing in detail the production of beats, we have considered two practical applications of this phenomenon. We learned that the combination of two frequencies to produce a frequency equal to the difference between the two introduces great amplification. Two very useful applications of this principle are the use of heterodyne reception in receiving sets designed to receive continuous wave radiotelegraph signals and the use of the same principle in somewhat modified form in the Super-Heterodyne or intermediate frequency amplifier receiving set. In both of these cases, the fact that heterodyning introduces great amplification is a tremendous advantage. We are now going to consider in some detail a situation in which this amplification imposes a very serious limitation upon the use we can make of a radio station, particularly a radio broadcasting station.

As you are well aware, the range of a radio broadcasting station depends to some extent upon the power in use at the station. It also depends upon many other factors such as atmospheric conditions, the time of day or night, the season of the year, and the possible presence of disturbing influences at the receiving location. In general, however, it is possible to state figures with respect to the range of a radio broadcasting station in terms of power and miles which, while not accurate, do give a general idea of the results which can be expected.

Let us assume that a particular broadcasting station is operating upon a particular channel 10 kc wide, say the channel having its carrier frequency at 1000 kc. The approximate range of a 100-watt station is 15 miles, of a 500-watt station 30 miles, of a 5,000-watt station 100 miles and of a 50,000-watt station 300 miles. We do not, of course, mean that a 5,000-watt station will never be heard if the receiving set is located more than one hundred miles away from it. We mean that the average range of this station under normal day and night conditions throughout the year will probably run around one hundred miles. It is, of course, true that under very favorable conditions at night, a 5,000-watt station may be heard one, two or even three thousand miles away, but it is also true that under certain conditions the station cannot be satisfactorily heard at a distance of forty or fifty miles, so we will take the figure 100 miles for the 5,000-watt station as being its average good broadcast range. In other words, the radio listeners who will receive good reliable service from the 5,000-watt station under consideration will in general reside within a circle of 200 miles diameter having the station in question at the center of the circle.

An inexperienced listener might think that if the people receiving good service lie within the above described circle drawn around a station operating on 1,000 kc, a second broadcasting station operating on 1,000 kc could be located at a city two, or possibly three hundred miles distant from the first city, and that the power in use by this station might also be made 5,000 watts. If you have had any experience at all with radio receiving apparatus you know that such is certainly not the case. Even though you might be only 10 or 15 miles from the first 5,000-watt station, the operation of a second 5,000-watt station on the same carrier frequency assignment located two or three hundred miles distant from the first would completely destroy your reception from the nearer station. You would, as you well know, have a very strong heterodyne beat note produced in your receiving set which would result from the fact that without special equipment the carrier frequencies in use at the two stations would not be exactly the same, but would differ by an amount which would lie within the audible range. In fact, it is quite possible that even though the two stations in question were separated by much greater distances, you would still experience excessive interference. We might state our conclusions as follows: *While the service range of a 5,000-watt station is of the order of 100 miles, its interference range, due to the limitations imposed by heterodyning, is far greater, probably about two or three thousand miles.*

The fact that the interference range of a station is so much greater than its service range imposes some very peculiar limitations. In general, one 5,000-watt station cannot be located upon the same channel as another 5,000-watt station with a separation of less than three or four thousand miles if we are to prevent serious heterodyne interference occurring in the normal service area of either station. This means that in general it is impossible to assign the same channel in the United States to more than one station of 5,000 watts without introducing the possibility of serious interference.

Some figures have been compiled to show the maximum number of stations of given powers which can be operated simultaneously upon the same channel in the United States without serious interference due to heterodyning. These figures are as follows:—if the station is of 5,000-watt power or more, not more than one station can be operated per channel in the United States—two or three stations separated from each other by eighteen hundred miles can probably be operated simultaneously without excessive interference if the power does not exceed 1,000 watts—five or six stations separated from each other by twelve hundred miles can be operated simultaneously without excessive interference if the power does not exceed 500 watts per station—nine or ten stations separated by six hundred miles can be operated simultaneously without excessive interference if the power does not exceed 100 watts per station.

It is possible to draw a number of rather interesting conclusions from the figures which have been given. Table 1 contains approximate figures for the service radius of stations of given powers, and the number which can be operated simultaneously upon the same channel without excessive interference. These figures are, of course, only approximate and will undoubtedly vary from time to time as conditions change. Let us calculate, for the purposes of discussion, the number of square miles served by stations of various powers. These figures resulting are also shown in Table 1.

TABLE 1

Areas served upon a given broadcast channel assuming the simultaneous operation of the maximum possible number of stations of given power without excessive heterodyne interference.

Power watts	Service radius miles	Service area square miles	Maximum number simultaneous operation	Total area served by simultaneous operation square miles
100	15	707	10	7,070
500	30	2,827	6	16,964
1,000	45	6,361	3	19,085
5,000	100	31,416	1	31,416
50,000	950	2,827,440	1	2,827,440

If we assume the figures giving the ranges of broadcasting stations are correct, and that the figures showing the maximum number of stations which can be simultaneously operated upon a given channel without excessive interference are also correct, then there are certain logical conclusions which it is difficult to escape. Table 1 shows that more than twice as many square miles of area are given service by the operation of six 500-watt stations properly placed throughout the United States than by the operation of ten 100-watt stations. The table also shows that a slightly greater number of square miles are served by three 1,000-watt stations than by six 500-watt stations. However, we can serve approximately fifty per cent more square miles by the operation of one 5,000-watt station than by the operation of three 1,000 stations. The most astonishing fact, however, is that one 50,000-watt station will serve nearly three million square miles, while one 5,000-watt station will serve only thirty-one thousand square miles. In other words, the area served by the one 50,000-watt station is nearly one hundred times as great as that served by one 5,000-watt station, although the increase in power has only been ten times.

The reason for the larger area served here by an increase in power, is, of course, the fact that while it is possible to operate only one 50,000-watt station in the United States without interference, it is still not possible to operate more than one station without interference even though the power is only 5,000 watts. The obvious conclusion is that if the power is 5,000 watts at a particular broadcasting station, there is no reason why that power should not be increased to as large a value as is practicable. Since the interference range already extends beyond the United States, this increase in power will not materially produce more interference, although it will, of course, produce some difficulties in the receiving sets of those who desire to receive distant stations located at frequencies near that of the 50,000-watt station and who reside close to the 50,000-watt station.

The figures contained in Table 1 are worthy of a great deal of study. They are excellent illustrations of data such as the radio man is continually being called upon to produce. Such data are not strictly accurate mathematical calculations resulting in strictly accurate and irreputable conclusions. A great many of the phenomena with which we must deal in the field of radio communication are difficult of analysis. The factors affecting the transmitting range of radio broadcasting stations are many and varied. Let us, therefore, examine the conclusions we have drawn in the preceding paragraph and see if there are any factors which we have neglected or if there are others which we have over-emphasized.

In the first place, we must admit that our figures showing service range as a function of distance are distinctly approximate and that they depend upon the type of radio broadcast service in which we are interested. You might very properly point to instances where radio receiving sets located three hundred miles from a 5,000-watt broadcasting station had received almost daily service from that station. You might likewise indicate one or two instances where receiving sets located closer than one hundred miles, say fifty miles, from a 5,000-watt station found it impossible to secure satisfactory reception from that station. Our figures are, therefore, merely average figures. Assuming these to be correct, however, our calculations of service area immediately follow since all we have had to do is to compute the areas of circles of known diameter.

We now come to the fourth column in our table which shows the maximum possible number of transmitting sets which can be simultaneously operated assuming the transmitting stations to be of a given power. If we attempted to so place our stations through the United States that the maximum number is possible, we would probably find that at some locations where we desired to place our stations there would be no cities and probably no sources of program material available. Because of this we can probably only operate a smaller number of stations of a given power on a given channel than is shown by our table. On the other hand, we might find that transmission across mountain ranges or in particular directions is not as good as it is in other directions with the result that we might not need as great a separation between stations as we have previously decided. Taken as a whole, therefore, the figures we have given in the fourth column may be considered as good enough for our purposes. The figures in the fifth column, of course, follow from those in the previous column.

Now, if you have been thinking intently upon the subject matter we have been discussing you have already put your finger upon the weakest point in the argument presented. It is as follows: We are not interested primarily in broadcast service to *areas*. We are primarily interested in building up a broadcasting structure which will serve the *maximum number of people*. Our figures might be unimpeachable if every square mile in the United States possessed the same density of population. Such, however, is not the case. It might, therefore, be possible to place a 1,000-watt station near a large city and then to place another 1,000-watt station some distance away on the same channel near another large city and have the total number of radio listeners served by the two stations greater than could possibly be served by the operation of one 5,000-watt station at either location. This, of course, would be due to the concentration of population at these two points. While we have taken into account several of the factors involved in the delivery of good broadcast service on a particular channel, we have not taken into account all of them.

The above discussions should be sufficient proof of the necessity of carefully scrutinizing all of the factors involved in the deduction of any set of conclusions from a given accumulation of data, particularly where the data are approximate in nature and in some instances open to question. Coincidence is very often taken for connection, let us illustrate—last Monday night radio receiving conditions were very poor. Last Monday night the wind was from the East. Therefore, when the wind is from the East we can expect that radio reception will be poor!—perhaps the wind had something to do with receiving conditions but the chances are that it had nothing at all to do with them. It was merely a coincidence that the wind was at the East at the same night receiving conditions were poor. As you become more and more acquainted with the radio field, you will find that there are more superstitions about radio reception and radio operation in general than almost any other science. This is due to the fact that there are so many factors involved which are exceedingly difficult to analyze. We must, therefore, be very careful not to draw conclusions from too little data.

INTERFERENCE FROM RADIATING RECEIVING SETS

In the early days of radio broadcasting, a certain type of interference was very prevalent which fortunately has now practically ceased to exist. This type of interference also owes its existence to the principles we have been discussing in this lesson and is known as interference from radiating receiving sets. In the early days of broadcasting, a great majority of radio receiving sets were of the single circuit regenerative type. In tuning such a receiving set, the operator manipulates a tuning control and a regeneration control. The greatest sensitivity exists when regeneration is brought almost to the point where oscillations are produced. In attempting to adjust a set for weak signals, it is a very common occurrence for the operator to increase the regeneration beyond the point where oscillations are produced with the result that during the time when the operator is tuning, his set itself will be radiating high-frequency energy. The frequency of these radiations will be that for which the set happens to be tuned at the particular instant in question. Since the operator is invariably looking for stations when his set is producing oscillations, this frequency will not be constant but will be continually varying.

The high-frequency alternating current produced in the receiving antenna of the regenerative set will produce voltages in other receiving sets located nearby. Sometimes the interference may exist one-half to one mile or more away. If the frequency radiated by the receiving set is sufficiently close to that of the carrier from the distant transmitting stations to which nearby operators are listening, then the two frequencies will combine and a heterodyne beat note will be produced equal to the difference between the two. Inasmuch as the transmitting station desired is usually a long distance away, while the interfering receiving set is nearby, the electric field intensities from the two sources will be of the same order of magnitude. The beat note or "squeal" which results is very objectionable.

Many radio listeners have difficulty in differentiating between heterodyne beat notes as produced by the simultaneous operation of two broadcasting stations upon carrier frequencies too close together and the operation of a regenerative receiver on a frequency too close to the transmitting station to which they are endeavoring to listen. It is very easy to differentiate between these two types of interference. Since the frequencies used by broadcasting stations remain fairly constant, the beat note produced by the operation of two broadcasting stations on carrier frequencies too close together is practically always fairly constant in frequency. On the other hand, since a regenerative receiving set operator is usually engaged in tuning his set during the time when it is producing oscillations, the beat note produced by a combination of his signal with that of a distant transmitting station will be varying continuously.

Interference from the operation of regenerative receiving sets was very serious in the early days of broadcasting when the great majority of sets were of this type. However, the increasing use of tuned radio-frequency sets and more modern sets of other types has practically driven the regenerative sets out of existence. The situation was somewhat aggravated by the fact that in tuning for a distant station, it is somewhat easier to do so with a regenerative receiving set when the set is producing oscillations, although after the station has been found, regeneration must be decreased below the oscillation point, otherwise satisfactory reception of the speech and music cannot be obtained.

Some very humorous situations used to arise in the old days as a result of a lack of understanding on the part of the public of this peculiar phenomenon which we call fading, particularly when a large number of people in a given city were listening to signals from a fairly distant broadcasting station. Due to fading the signal would probably be changing somewhat in intensity. It would first be very strong for three or four minutes and then slowly fade out until the station could not be heard at all or was very weak. In a few minutes it would again be as strong as ever. During the period of time when the signal was strong all would be well. Large numbers of people would be listening to the station and enjoying its program. As the signal began to fade out, those unfamiliar with the phenomenon assumed that something had gone wrong with their receiving sets and they immediately began to retune. The wise listener, however, knew that the signal was fading and that nothing he could do to his receiving set would change the situation but he also knew that if he would be patient and wait a minute or two the intensity would rise to its former value.

The actions of the large number of listeners who became alarmed at the decrease in intensity of the signal and their attempts to find the station again with their receiving sets producing oscillations produced a very amusing effect. The oscillations produced by their receiving sets would, of course, beat with the frequency from the incoming station although that signal might be so weak as to prevent satisfactory reception of the speech or music. The whole effect as produced in the receiving set of the listener who did not change his set was that of listening to a swarm of bees which had been suddenly disturbed by poking a stick into the hive. This state of affairs would exist until the signal began to increase in intensity again and then one by one the listeners who had been so seriously disturbed by fading would find the station again and would for a few minutes more settle down to listen to the program. The effect of this settling down was very much as though the swarm of bees had again gradually settled down into a new hive. In a few minutes, however, the signal would begin to fade out again and numerous listeners would again become disturbed and the whole story would be repeated. While this state of affairs did not make for the best reception for the man who knew what was going on and who knew enough to leave his receiving set alone, it did undoubtedly furnish him with a great deal of amusement.

INTERFERENCE FROM HARMONICS FROM RADIO TRANSMITTING STATIONS

We have discussed two types of heterodyne interference, namely, heterodyne interference produced by the operation of two broadcasting stations upon frequency assignments which are too close together and heterodyne interference due to the operation of regenerative receiving sets. Before leaving this subject, we must consider a type of heterodyne interference which is identical in characteristics with that produced by the operation of radio transmitting stations on assignments too close together, except that it is produced by the harmonics of one or both of these stations. We must, therefore, briefly consider the production of harmonics by radio stations.

As you already know from previous lessons, *harmonics* are frequencies which are *multiples* of a frequency known as the fundamental. You will remember that in describing the production of musical sound, you learned that associated with a fundamental musical tone there were certain harmonics which gave to the tone its quality or timbre. Thus a musical tone having a fundamental of 1,000 cycles would have associated with it harmonics having frequencies of 2,000, 3,000, 4,000, 5,000 cycles, etc. Harmonics may also be produced in radio transmitters. Thus if a continuous wave transmitter is operating upon, let us say, 250 kc, it may also produce and radiate energy at frequencies of 500, 750, 1,000, 1,250, 1,500, 1,750, etc., kc. However, while musical instruments may produce as many as ten or more harmonics and while the energy content of these harmonics may be greater than that of the fundamental, fortunately with radio stations not so many harmonics are produced nor is the energy in them nearly so great in proportion to that in the fundamental. Were this not the case the type of interference we are about to discuss would present a problem far greater than is the case.

It is possible for a radio broadcasting station operating on a carrier frequency of 600 kc to radiate a second harmonic on 1,200 kc of such amplitude as to cause a serious heterodyne beat note with the signal from a broadcasting station whose carrier frequency is assigned to 1,200 kc. If a radio listener is located fairly close to the 600 kc broadcasting station and is some distance removed from the 1,200 kc broadcasting station, he may find it impossible to obtain satisfactory reception from the more distant 1,200 kc station due to the presence of energy at approximately 1,200 kc produced by the second harmonic of the signal radiated from the nearby station which should properly confine all of its energy to the 10 kc band having its carrier frequency at 600 kc. Interference may also be produced between the higher harmonics of an interfering and the fundamental of a desired station.

You can readily see that it is only those broadcasting stations whose carrier frequency assignments lie on or below 750 kc which can produce second harmonics lying within the broadcast band and only those stations having assignments lying between 1,100 and 1,500 kc, inclusive, are liable to receive interference of this sort. Fortunately, however, interference of this type within the broadcast band is not particularly troublesome due to the fact that the more modern transmitters have apparatus incorporated in them for the suppression of harmonics, and to the fact that energy radiated on broadcast frequencies is fairly rapidly damped out as it travels over the earth. Harmonics from broadcasting and other stations can, however, produce serious interference with communication on the higher frequencies unless the transmitters in question are carefully designed and correctly operated. Consider for instance the operation of a radio broadcasting transmitter in which the harmonics have not been suppressed upon a carrier frequency assignment of 900 kc. Unless this transmitter is properly equipped with apparatus for suppressing harmonics, and unless it is properly operated, a second harmonic will exist at 1800 kc, a third at 2700 kc, a fourth at 3600 kc, a fifth at 4500, a sixth at 5400, a seventh at 6300 and an eighth harmonic will exist at 7200 kc. Now, due to the fact that the higher frequency waves usually travel over the earth's surface with much less attenuation or damping than do the longer ones, these harmonics may cause very serious disturbance with the operation of other radio services in no way associated with radio broadcasting. The second harmonic lies within a band now assigned to amateurs and used by them for radiotelephone. The seventh harmonic (6300 kc) lies within a band assigned to mobile services. It is quite probable, for instance, that this band might be utilized for communication with aircrafts. The eighth harmonic lies within the amateur band which is most used for international communication. The presence of harmonic signals from broadcasting stations in this band will be almost certain to cause serious interference with the operation of amateur stations.

I think you can see from the above discussion why it is essential that radio stations be required to suppress the harmonics which are produced by the normal operation of their transmitters. It is, of course, possible for other transmitters to produce harmonics. One of the most prolific sources of interference of this type is the arc transmitter often used for high-power long-distance communication on low frequencies. Arc transmitters are prolific producers of harmonics, and those who use such transmitters have had to devote a good deal of time and attention to the elimination of these troublesome sources of interference.

Before we finish this text there is one matter which you should thoroughly understand. Harmonics are always frequencies which are *higher* than the fundamental. Thus a station operating on 500 kc cannot produce a harmonic of 250 kc. If the station were radiating energy at 250 kc, then its *fundamental* would be 250 kc and 500 kc would be the second harmonic. You may have heard a listener complain, perhaps, that when his receiving set was tuned for a frequency of, let us say, 600 kc, he heard a station which was supposed to be transmitting on 1200 kc. He, therefore, maintained that the transmitting station is radiating energy upon a frequency one-half of that which it was assigned. This is not possible. The transmitting station cannot, if its fundamental is 1200 kc, radiate energy at 600 kc. However, when a receiving set is tuned to 600 kc, it may receive some energy at 1200 kc.

If you are operating a short-wave radio receiving set for amateur purposes, you may find it interesting to explore the waves above 1500 kc to see how many broadcasting stations you can listen to on their harmonics. You may at times, due to the peculiarities of transmitting conditions at the higher frequencies, receive certain stations better on their harmonics than you can on their fundamentals.

TEST QUESTIONS

Number your answers 19—2 and add your Student Number.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. If one broadcasting station is operating on a carrier frequency of 600 kc and another several hundred miles away is operating upon a frequency of 597 kc, what will be the frequency of the beat note produced in a receiving set which is receiving signals from both stations simultaneously?
2. Why is it advantageous to use heterodyne reception for continuous wave radiotelegraphy?
3. A Super-Heterodyne radio receiving set uses an intermediate frequency amplifier designed to amplify a frequency of 45 kc. At what two frequencies can the local oscillator be set for receiving signals from a broadcasting station transmitting with a carrier frequency of 700 kc?
4. What is meant by autodyne reception?
5. Name two types of interference of the heterodyne type.
6. Give five harmonics such as might be radiated from a transmitting station improperly constructed or operated whose fundamental frequency is 730 kc.
7. Why is it not possible for broadcast stations operating on carrier frequencies lower than 1100 kc to have their reception subject to interference from harmonics produced by other stations operating in the broadcast band which extends from 550 to 1500 kc inclusive?
8. Why is it not possible for broadcast stations operating upon carrier frequency assignments higher than 750 kc to generate harmonics which will cause interference with the reception of programs from other broadcasting stations operating within the broadcast band?
9. Why are coil antennas usually used with Super-Heterodyne receiving sets?
10. Can a station operating on a certain frequency in Kcs produce a harmonic of a frequency lower than its fundamental frequency?

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TEMPERATURE AND LIGHT

A Personal Message from J. E. Smith

Everyone needs a suitable temperature. Most Americans keep rooms too warm in winter for the best mental activity. A temperature slightly under 70° Fahrenheit with a normal amount of moisture in the air, is most conducive to study.

Also, everyone needs proper light. Indirect lighting—that is, lighting reflected upon one's work from a ceiling or other surface, or direct diffused lighting is best. Glare on books and papers does not constitute good lighting.

The light, of course, should come from behind and somewhat above. If one is doing any writing in connection with his study, the light should fall across his left shoulder, unless he is left-handed, when it should fall across the right shoulder.

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

The Neutrodyne Circuit

One of the most popular Radio Receiving circuits ever designed is the Neutrodyne which employs a system of neutralizing oscillations in the radio-frequency amplifier developed by Prof. L. A. Hazeltine. This development was without doubt a distinct improvement in the art of radio reception in that it completely overcomes one of the most annoying causes of failure in tuned radio-frequency amplification, namely, it eliminates the tendency of tuned amplifiers to oscillate. In order to thoroughly appreciate and understand what the neutrodyne accomplishes, it is necessary to examine the conditions which led to its development.

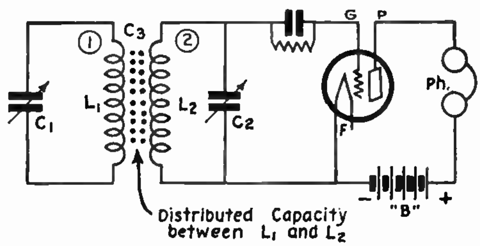

Fig. 1—Capacity Effect Between Inductively Coupled Coils.

One of the principal sources of trouble in radio-frequency circuits is the existence of small stray or distributed capacity between different parts of the circuits. Such small capacities are especially harmful at the low wave-lengths or high frequencies. For at the high frequencies the reactance of this small stray capacity becomes very small and so passes high-frequency currents when it is not intended that current should pass.

Thus suppose we have, as in Fig. 1, two radio-frequency circuits which are magnetically coupled to each other by the coils L_1 and L_2. Energy then passes from circuit ① to circuit ② by way of magnetic induction. But since both coils

L_1 and L_2 are conductors and are separated by an insulating medium they constitute a small condenser, or, in other words, there is distributed capacity between them. This distributed capacity behaves like any condenser and will therefore let radio-frequency currents flow through it. Thus high-frequency currents would flow from circuit ① to circuit ② by way of the small stray capacity rather than by way of the transformer coils and induction, thus defeating the purpose of the transformer. These capacity currents, called parastic currents, represent a loss of energy, and are, therefore, an undesirable feature of any circuit. Not only does this small stray capacity introduce harmful effects by by-passing from their legitimate paths currents to which the circuits are tuned, but it also creates trouble by introducing into the circuits undesirable, extraneous currents to which the circuits are not tuned.

Consider again Fig. 1, which represents two radio-frequency circuits inductively coupled, the secondary of which feeds the grid of a detector tube, and suppose C_3 represents the small distributed capacity existing between the two coils. Let us furthermore assume that the circuits represent the primary and secondary of a receiver which is designed to receive over a band of wave-lengths from 200 to 600 meters. In the first place, we would have present the harmful effects described above, namely, at the low wave-lengths around 200 meters, the distributed capacity will by-pass some of the received current, preventing the coupling coils from performing their proper function. In the second place, when reception is taking place at the higher wave-lengths, interference from low wave signals will be introduced by the distributed capacity. Any low wave signal which may get into the primary circuit in any way, as for example, via the aerial, will be transmitted to the secondary through the capacity which exists between primary and secondary, and thus will get on the grid of the detector tube and produce an interfering signal. This occurs irrespective of the tuning of the circuits, since capacity parastic currents do not depend on the tuning of circuits but simply flow through the capacity coupling.

When we consider the vacuum tube, we are again confronted with very small capacities which considerably influence the action of the tube. The plate and grid together form the two plates of a tiny condenser. In the average tube this capacity is of the order of 3 to 5 micro-microfarads. This is, of course, very minute but is capable of spoiling reception if not properly controlled.

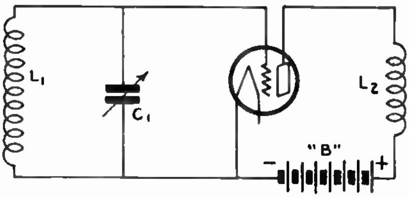

Fig. 2—Conventional Amplifier Circuit.

Figure 2 represents a conventional type of circuit frequently employed in radio reception, as for example one stage of a transformer, coupled R.F. amplifier with one tuned circuit. L_2 is not coupled to L_1, and it might therefore be thought that such an amplifier would be stable. This is not necessarily the case as will be seen when we simplify this circuit as in Fig. 3 where we have inserted CP in place of the tube. CP represents the capacity between plate and grid. This small capacity is in reality a coupling condenser, for one plate is in the grid or input circuit while the other is in the plate

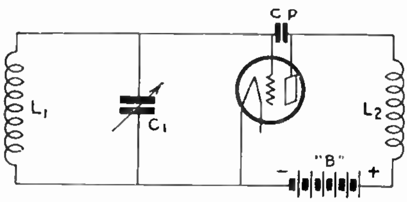

Fig. 3—Tube Capacity Effect in Circuit of Fig. 2.

or output circuit. As a result, even if there is zero coupling between coils L_1 and L_2, it will be seen that there is capacity coupling through CP between the output and input. Any current flowing in the plate circuit of the tube will therefore feed back into the input circuit, thus rendering the circuit unstable. This explains the reason for regeneration in circuits where there is no apparent feed-back coupling between input and output. The higher the frequency, the greater is this capacitive feed-back, for the reactance of the small coupling condenser decreases and makes feed-back all the easier.

It is for this reason that radio-frequency amplification at the low waves—600 meters and under—was very unsuccessful for a long time, for the capacity coupling and feed-back was so great that circuits were rendered unstable at the slightest provocation and would oscillate, thus ruining any amplification.

Methods of Neutralizing.

A number of methods have been advanced for overcoming this undesirable capacity effect, as for example, the well known device of a stabilizer potentiometer. This does not eliminate the regenerating effect of the tube capacity, but simply introduces such losses into the grid circuit that the amount of regeneration is reduced. One of the solutions to this problem of stable radio-frequency amplification was the development of the super-heterodyne receiver, which will be

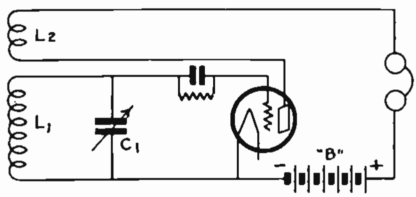

Fig. 4—Two Magnetically Coupled Circuits.

taken up in a later book. Another solution is the neutrodyne circuit as advanced by Prof. L. A. Hazeltine.

The principle on which the neutrodyne system is based is that of neutralizing the effect of one voltage by an equal and opposite voltage. In this particular case, neutralizing the capacity feed-back of the tube by an equal and opposite capacity feed-back introduced externally, the two feed-backs neutralize each other.

To understand the principle, let us consider the simple case of two magnetically coupled circuits which is more easily understood (see Fig. 4). Here we have inductive coupling and coil L_2 induces in coil L_1 a voltage which has a certain value and phase. Suppose that we are able to couple another coil L_3 to coil L_1, as shown in Fig. 5 and the direction of the coupling is such that the voltage induced in L_1 by L_3 is equal and opposite to the voltage induced in L_1 by L_2. Then these two voltages neutralize and balance each other in L_1, and no effect is produced by either.

This principle is applied in neutralizing the feed-back effect of tube *capacity*. Since the feed-back however is capaci-

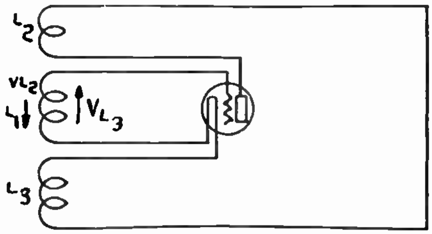

Fig. 5—Neutralized Inductive Coupling.

tive, it is necessary to employ a condenser to balance it. Furthermore, in order to obtain a voltage of opposite phase to an existing voltage it is necesary to employ two opposing coils as explained in the preceding paragraph. The neutrodyne method then is as follows:

Figure 6 represents one stage of a multi-stage radio-frequency amplifier in which the plate circuit is the tuned cir-

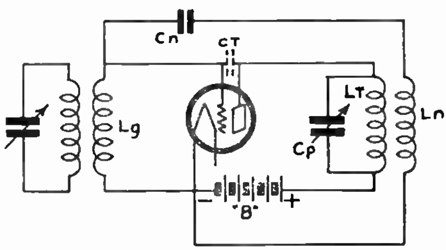

Fig. 6—One Stage of Tuned R. F. with Tuned Plate Circuit.

cuit. The dotted capacity CT represents the small but disturbing capacity which always exists between the plate and grid of the tube. L_g, LT and L_n represent inductance coils, of which L_n is the neutralizing inductance. C_n is a small fixed capacity external to the tube which is used as the neutralizing condenser. Assume for the moment that the neutralizing inductance L_n and the neutralizing capacity C_n are not present. When the amplified currents flow through the tuned plate circuit LT, C_p, a regenerative action is set up through the medium of the tube capacity CT and a feed-back current flows from the plate circuit through the capacity coupling CT and through L_g. This feed-back current flowing through L_g sets up a voltage across it which is applied to the grid and re-amplified by the tube, in this way producing the well-known regenerative effect as explained in a previous paragraph. To neutralize this effect, the coil L_n is coupled to LT; the voltage induced in it is opposite in phase to that in coil LT. This is obtained by using reverse coupling to that normally employed. In addition, the external neutralizing capacity C_n is adjustable and the current through it may be controlled. By adjusting the neutralizing condenser C_n, the current through it due to the reversed voltage of L_n may be brought to such

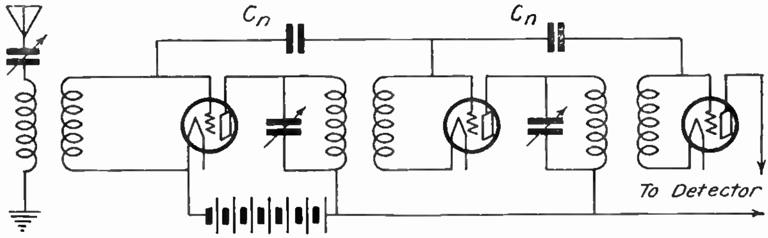

Fig. 7—Condenser Connections in Multi-Stage Neutrodyne Using Tuned Plate Circuits.

a value that it sets up a voltage in L_g equal to that set up by the feed-back current through CT. But since these voltages are opposite in phase, due to the reversed coupling of LT and L_n, they just neutralize each other and the regenerative effect is thus destroyed.

However, in coupling from the plate circuit of Fig. 6 to a succeeding tube, another coil is needed. If L_n is utilized solely as the neutralizing inductance, it will be seen that three coils will be required; one in the plate circuit of the tube, which acts as the primary of the radio-frequency transformer, a coil coupling this to the grid of the succeeding tube, *i. e.*, the secondary of the radio-frequency transformer, and thirdly a neutralizing coil. Such an arrangement is obviously cumbersome. As a result in commercial neutrodyne receivers, the neutralizing inductance acts also as the secondary of the radio-frequency interstage transformer.

The neutralizing coil and the plate inductance must be designed to behave efficiently as a radio-frequency transformer, and hence the ratio of the number of turns in each coil is limited. If the coils have the same number of turns, then the neutralizing condenser must equal the capacity of the tube CT. In practice this capacity is determined by trial and when the exact suitable value is found the capacity is fixed and sealed.

It will be apparent that the neutralizing condenser is extremely small, about a few micro-microfarads. In order to secure such small capacities which are adjustable, a small metal sleeve is used in some types about 2 inches long. This slides over the ends of two insulated wires as shown in Fig. 7-A. The capacity between the ends of these two wires is extremely small and varies with the extent to which they are

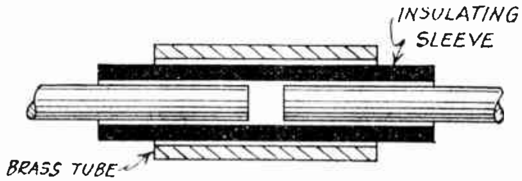

Fig. 7-A—Cross-Section of Early Neutralizing Condenser.

covered by the metal sleeve. The adjustment is made by moving the metal sleeve and when the proper conditions are obtained the sleeve is sealed in that position.

Figure 7 illustrates how the neutralizing condensers are connected in a multi-stage neutrodyne, namely, between the grids of succeeding tubes. Under ideal conditions, the neutralizing condenser should be constant at all wave-lengths. On account of leakage in the radio-frequency transformers this is not actually the case. Over a narrow band of wave-lengths, a fixed value of the neutralizing condenser is satisfactory. Even in cases where the neutralizing capacity is not exactly of the right value it effects a reduction in the feed-back coupling through the tube capacity and avoids oscillations due to regeneration. Figure 8 shows the complete wiring diagram of two R. F. stages and detector of a three tube neutrodyne set.

The .006 mfd. and .001 mfd. condensers are for by-passing the radio-frequency currents across battery and head-phones.

Figure 9 pictures the actual apparatus illustrated by the diagram in Fig. 8 and shows both the arrangement of the parts and how they are wired to one another.

Figure 10 shows a circuit of this type which is much used in commercial sets. The circuits shows two stages of radio-frequency amplification and detector. A complete commercial set would ordinarily require 5 tubes as it would contain in

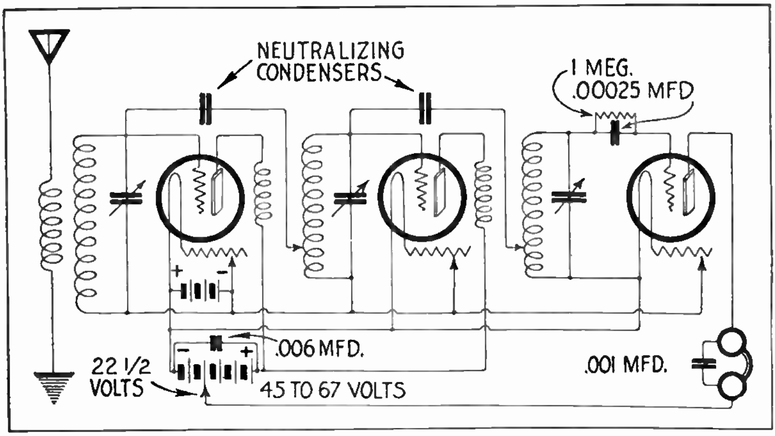

Fig. 8—Circuit Diagram of a Neutrodyne Receiver Using Two Stages of R. F. Amplification and Detector.

addition two stages of audio-frequency amplification. L_1 and L_2 constitute a radio-frequency transformer.

The neutralizing condensers C_N are connected to the secondaries of the radio-frequency transformers (L_1, L_2) and

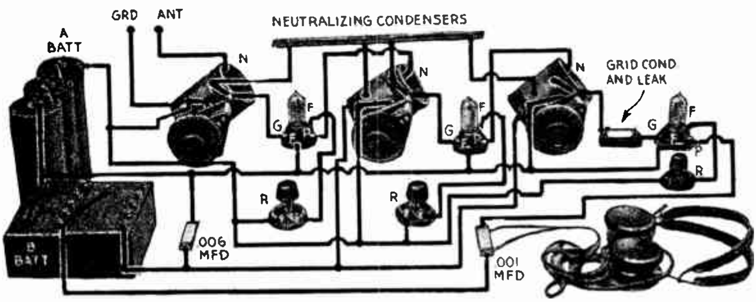

Fig. 9—Pictorial View of Hook-up Shown in Fig. 8.

(L_3, L_4) which are wound in such a direction that the radio-frequency voltage produced across C_N will be 180 degrees out of phase with that of the radio-frequency voltage across the plate grid capacitance of the tube. The small neutralizing condensers the capacity of which is made variable so that when the correct capacity is obtained, the adjustment can be locked.

Two methods of adjusting C_N will be discussed here. An article by Professor Hazeltine on "Tuned Radio-Frequency Amplification with Neutralization of Capacity Coupling" states: "The adjustment of each neutralizing capacity is made experimentally by tuning in a strong signal and then turning out the filament of the tube whose capacity is to be adjusted, but leaving the tube in the socket. If the neutralizing capacity is not correct, the circuits on each side of the tube will have capacity coupling which will transmit the signal. The neutralizing capacity is then adjusted until the signal disappears."

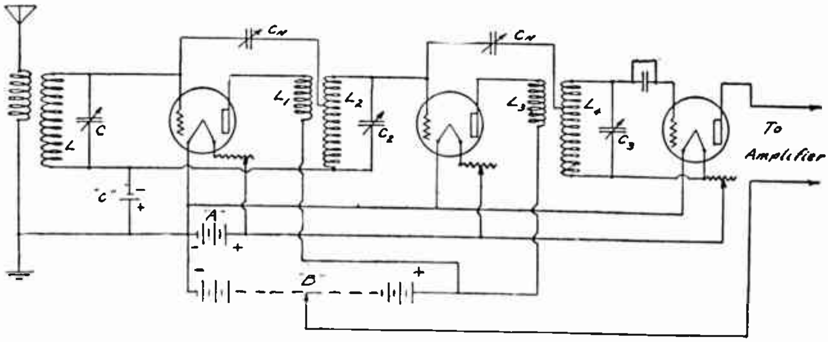

Fig. 10—Circuit Diagram of Neutrodyne Receiver.

This method of adjustment was developed by Mr. Harold A. Wheeler and will be carefully taken up later. It is quite evident that if a radio-frequency amplifier circuit is adjusted by this method, no regeneration exists, as variations of plate potential do not cause variations of grid potential to any appreciable degree, and thus, for all practical purposes there is no feed-back. If the capacitance of the condenser C_N is increased beyond the point necessary to completely eliminate the incoming signal, the voltage induced on the grid will tend to destroy any amplification resulting from the use of a tube.

It is not necessarily desirable to completely neutralize the effect of regeneration as has been described above. Stronger signals will be obtained with the same number of tubes if the capacitance of C_N is increased only to the point where the amplifier ceases to produce radio-frequency oscillations.

The regeneration remaining will also tend to increase the selectivity of the system. If too much regeneration remains, distortion may result from excessive selectivity or other reasons. We are not concerned with the debatable question as to whether or not the manufacture or sale of radio-frequency amplifiers in which the effects of regeneration are not completely eliminated is covered by patents which control regeneration, but only with questions as to the relative advantages of amplifiers in which regenerative effects are completely eliminated and those in which regenerative effects exist.

The statement has been made that it takes about one and one-half stages of non-regenerative radio-frequency amplification to deliver as strong a signal to a detector tube as can be obtained by the use of a regenerative detector circuit connected directly to the aerial. Such a statement is only a rough approximation, but expresses the fact that if non-regenerative radio-frequency amplication is used as a substitute for regeneration, more than one stage must be used if any increase in signal strength is to be expected. The results may not then be what the experimenter expects from the cost of the additional equipment necessary to add the radio-frequency amplification. If the radio-frequency circuits are carefully designed and the limitation of regeneration is carried only to the point where oscillations are not produced, there is no reason why a tube detector with one or two stages of radio-frequency amplification ahead of it should not deliver a much stronger audio-frequency signal than could be obtained by the use of only a regenerative tube detector circuit connected directly to the aerial.

Theoretically, after the neutralizing condensers are correctly adjusted for the prevention of oscillations for one adjustment of the tuning controls, this adjustment should be correct for all adjustments of the tuned circuits providing the tubes in the set are not changed. In general practice, this is not always the case and it may be found that when the neutralizing condensers are adjusted to the point where oscillations are prevented at a particular tuning adjustment, the set will begin to produce oscillations if the tuning adjustment is changed. It would seem, therefore, that the experimenter, thoroughly acquainted with the operation of his set, might obtain better results if the setting of the neutralizing condensers could be easily varied. The operator could then control the regeneration in the radio-frequency stages at will and operate the receiver at maximum selectivity and sensitivity at all wave-lengths. Manufactured sets are usually permanently adjusted at the factory in such a manner that in general radio-frequency oscillations will not be produced regardless of the wave-length to which the set is adjusted. This may mean that slightly better amplification is obtained at one wave-length than at others.

It will be seen by referring to Fig. 10 that a tuned radio-frequency amplifier having two stages of radio-frequency amplification has three tuned circuits and three tuning controls. For the reception of distant stations, all three of these circuits must be tuned to the wave-length to be received. Until the operator has made a chart showing the three settings which must be used to adjust the set for any particular station, the adjustment of the three circuits to the same wave-length is rather difficult. After such a chart has been made it is a simple matter to find any station by referring to the chart and adjusting the set accordingly.

Calibration of Set.

The original calibration of a three-dial set is best accomplished on a night when static or induction disturbances are fairly strong. When the dials are so adjusted that the noises resulting from static or induction are loudest, the three tuned circuits are adjusted to the same wave-length. By varying one of the dials a little at a time and then adjusting the other two until the noises again are at a maximum, the entire wave band covered by the receiver can be searched and all stations in operation giving a sufficiently loud signal to be heard can be logged for future reference.

It is common practice to use from 90 to 120 volts on the plates of both the audio and radio-frequency stages of a set using tuned radio-frequency such as is shown in Fig. 10. Unless a correct negative bias is used with amplifiers operating at such high plate voltages, heavy plate currents will flow and grid circuit losses will result due to the flow of current to the grids when they are positive with respect to the filament. The flow of grid current may not be important in the radio-frequency stages where the alternating currents and voltages are relatively small, but will cause distortion and loss of efficiency in the audio-frequency stages. Distortion will also result due to the fact that the tube is not operated on the central portion of the characteristic curve. We mention the fact as but few manufacturers and experimenters appear to recognize the importance of a correct negative bias when high plate voltages are used, and many sets do not provide for any negative voltage on the up-to-date grids of the amplifier tubes.

Figure 11 shows a very satisfactory comparatively simple three-tube receiving set using one stage of radio-frequency amplification, detector and one stage of audio-frequency amplification. If loud-speaker reproduction is desired, additional stages of audio-frequency amplification can be added. Certain features of this circuit are worthy of note. Only two tuning controls are used which make the set somewhat easier to tune than the one shown in Fig. 10. A negative bias is used on the radio-frequency amplifier tube for the reasons just brought out. The same "C" battery can be used for the audio and radio-frequency amplifier tubes if desired.

Instead of building a radio-frequency transformer using two closely coupled coils to provide a means of feeding back voltage to the grid which will limit regeneration, use is made of auto transformer action in a single coil. Exact physical dimensions of this coil L_2 will depend upon the wave-length band it is desired to cover. Approximately 60 turns on a 3-inch tube are suggested for use with the average condenser for broadcast waves. Approximately one-sixth the total number of turns should be included between the base of the coil and the "B" battery tap and another sixth between the "B" battery tap and the tap which goes to the plate of the radio-frequency amplifier tube. The neutralizing or regeneration limiting condenser C_N is connected to the base of this coil. It is necessary to connect the grid leak directly to the positive side of the detector tube filament. If it were across the grid condenser, as is common practice, the full voltage of the "B" battery would be applied to the grid of the detector. It is also necessary to use a grid condenser capable of standing this "B" battery voltage without leakage.

Regeneration is provided in the detector circuit by the insertion of the variometer V. A tickler coil in the plate circuit of the detector tube coupled to L_2 might be used in place of the variometer for the same purpose. Regeneration in the radio-frequency amplifier circuit can be controlled by varying the capacitance of the small condenser C_N. As has been explained, only a little of this adjustment is necessary beyond that originally made to prevent the production of oscillations or completely eliminate regeneration.

A valuable feature of a set which provides for regeneration in the detector circuit is the fact that regeneration can be carried to the point where oscillations are produced

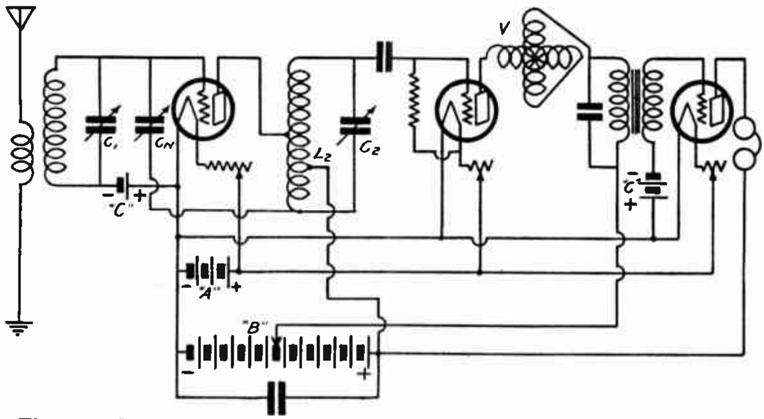

Fig. 11—One-Stage R. F. Amplifier with Regenerative Detector and One-Stage A. F. Amplifier.

and the beat note which results when the circuit L_2C_2 is tuned to a frequency near that of an incoming signal may be used as a means of tuning for weak signals. As the oscillations produced in the set are not produced in a circuit coupled to the antenna, the receiver does not radiate and thereby cause objectionable disturbance to nearby listeners. The setting of the dial controlling C_2 at which its circuit is tuned to various stations can be logged on a chart and this chart used for future reference. The variometer method of regeneration in the detector circuit is recommended because in general the effect of the variation of regeneration by this method on the tuning of the detector circuit will not be great. A circuit similar to the one just described has been used with very satisfactory results in sets designed for the United States Signal Corps by the Radio Laboratories at Camp Alfred Vail.

Commonly Used Neutrodyne Circuits.

The conventional Neutrodyne receiver usually employs four or five tubes, two radio-frequency amplifiers, detector, and two audio-frequency amplifiers. The circuit of a five-tube receiver is illustrated in Figure 12. Three separate rheostats are provided, one for controlling the filament temperature of the radio-frequency tubes, one for the detector and one for the audio-frequency. The radio-frequency rheostat provides a volume control for cutting down the strength of the signal, which is advisable when the receiver is located near one of the more powerful broadcasting stations. The other two rheostats are used in the ordinary way.

The two radio-frequency amplifiers (employing the Neutrodyne principle) are different from the one illustrated in Fig. 11 in that instead of tuning the plate circuit, a secondary coil closely coupled to the primary or plate coil is tuned. This allows a step-up ratio to be employed which gives greater amplification and selectivity. If the two coils are connected properly—that is, with the plate of one at the opposite polarity to the grid of the succeeding tube, then a portion of the secondary coil may be used in place of a third or neutralizing coil. Referring to Fig. 12, the neutralizing condenser C_{n-1} R. F. is connected from the grid of tube No. 1 to a tap on the secondary of the transformer unit B. The neutralizing condenser C_{n-2} for the second tube is connected in a similar manner from the grid of that tube to a tap on the secondary of the R. F. transformer unit C. The correct location of these taps depends on the value and range of the neutralizing condensers used; that is, if the tap on coil L_2 is moved up so as to include twice as many turns between it and the ground potential end of the secondary coil, then the capacity required at C_{n-1} will be only one-half (approximately) as large as before. In this connection it should be pointed out that many receivers constructed from parts, but not provided with a proper panel shield, are very difficult to balance due to their inherent capacities. Referring again to Fig. 12, any capacity between adjacent grids tends to neutralize the tube capacity even more effectively than does capacity at C_{n-1}. This capacity will always be appreciable because the fixed plates of the variable condensers C_1, C_2, and C_3 are connected to the grids of the tubes and the variable plates grounded which present large surfaces thus introducing the capacity between them. As mentioned above, it is possible for these capacities to more than neutralize the tube capacities. If this is so, it is impossible to obtain a balance by a further addition of neutralizing capacity. This condition may be eliminated by minimizing the inherent capacities by shielding. A grounded metal shield properly mounted on the panel cuts down the external field of the condensers sufficiently to make a balance possible.

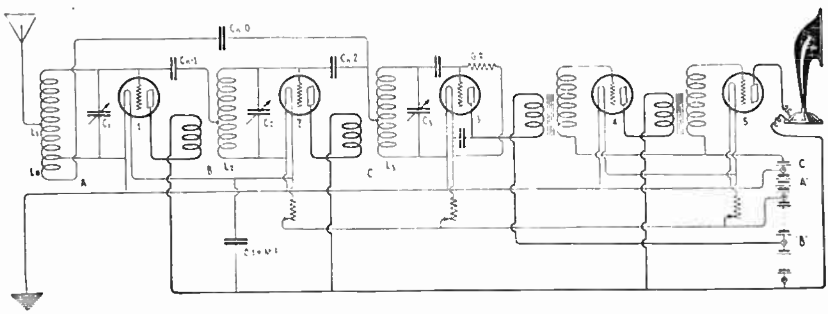

Fig. 12—Circuit of a Five-Tube Neutrodyne, Showing the Method of Neutralizing the Over-all Capacity.

Adjusting the Neutralizing Capacity.

The actual adjustment of the neutralizing condensers C_{n-1} and C_{n-2} is accomplished as follows: A strong signal either from a nearby broadcasting station or from a local oscillator is impressed on the antenna coil. The condensers C_1, C_2, and C_3 are then tuned to this signal with the filaments of all tubes lighted. At this time the receiver will probably oscillate. The filament of tube No. 1 is then extinguished, usually by placing a piece of paper under one of the filament prongs. The dials can then be retuned for maximum signal. This signal is present only because of the coupling between circuits A and B introduced by the grid-plate capacity in the tubes. If the capacity of the neutralizing condenser C_{n-1} is increased, the signal will grow weaker and weaker and finally will disappear entirely. If the capacity of C_{n-1} is still further increased, the signal will again become stronger. The circuit is then said to be over-neutralized. An over-neutralized receiver will oscillate when all tubes are operating.

If the tube capacity is exactly balanced while the filament is not lighted and still cold, no signal will be transmitted through the succeeding tubes. The explanation of this is as follows: Referring to Fig. 12, the voltage present in circuit A causes a current to flow through the grid-plate capacity of tube No. 1, but at the same time another current flows through the neutralizing condenser C_{n-1}. These currents in passing through the primary and tapped portion of the secondary of circuit B, respectively, produce equal and opposite magnetic fields in circuit B which cancel out and produce no resultant voltage.

The neutralizing condenser C_{n-2} is adjusted in a similar manner. For a final check repeat the process over again for both tubes.

Buzzer Circuit for Neutralizing.

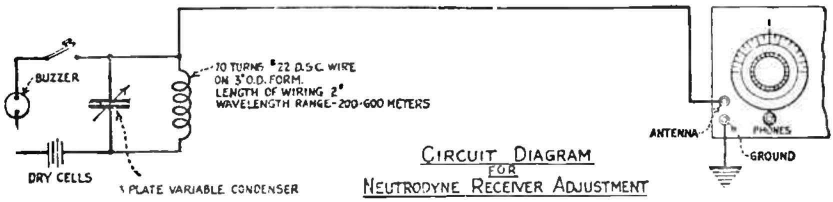

Fig. 13—Buzzer Circuit Attached to Receiver for Neutralizing Purposes.

A third neutralizing condenser is sometimes used for the purpose of neutralizing the very small capacity existing between circuits A and C. This will be discussed in detail later. It should be noted in Fig. 12 that primaries of the audio-frequency transformers are reversed relative to the secondaries in a manner similar to that employed in the radio-frequency circuits. This very often prevents "singing or howling" at audio-frequency. It might even be worthwhile for the purpose of improving the quality of reproduction to completely neutralize the audio-frequency tube capacities. This could be done by the introduction of very small capacities between adjacent grids.

The buzzer circuit, illustrated by Fig. 13, may be conveniently used when neutralizing a receiver. The buzzer is of the high-frequency type. The circuit may be tuned by the variable condenser to cover a wave-band between 200 and 600 meters. The method of attaching it to the receiver is clearly shown in Figure 13.

The use of a circuit of this type makes the operator independent of broadcast reception while neutralizing the set. The procedure for neutralizing is the same as already explained.

The final test to be applied to a receiving set is its actual operation. When the receiver is perfectly balanced out or neutralized, according to the Neutrodyne principle of circuit and tube capacity neutralization, as outlined, this adjustment will hold over its entire wave-length range. If this is not the case, the neutralizing condensers should be carefully readjusted.

Other Causes of Regeneration.

It is necessary in a Neutrodyne set to more than merely neutralize the tube capacities. In the conventional type which employs three sharply tuned circuits, it is necessary to remove all couplings that may exist between these circuits except mutually conductive or one-way coupling of the tubes. In fact if in any way radio-frequency energy may be transferred from one circuit to a preceding one, regeneration will usually occur. This is always undesirable since it has the effect of sharpening the tuning to too great an extent and thus ruining the quality of reproduction. The capacity couplings due to the tubes may be neutralized by the method already described. *The other undesirable couplings between circuits in a Neutrodyne set which should be eliminated are:*

(1) Inductive coupling between adjacent stages (coils L_1-L_2-L_2-L_3); (2) coupling from the second to the first stage due to the impedance of the leads to the "B" battery; (3) coupling from the third to the first and second stages due to improper connection of the telephone condenser; (4) coupling introduced by a common "C" battery or due to improper connection of grid-returns; (5) coupling between stages introduced by inductive loops in the wiring; (6) coupling between first and last stages due to inherent capacity between high-potential surfaces of these stages.

Arrangement of Neutroformers.

The first of these, inductive coupling between coils of the different stages, may be eliminated by properly placing the coils. As is well-known, three coils may be placed mutually at right angles, making the magnetic flux of any one to have no resultant linkage with the turns of the others. A neater and more symmetrical arrangement was devised by Professor Hazeltine. He discovered mathematically that a number of coils might be placed on a common line of centers and if their axes were inclined at an angle of 54.57 degrees to this line of centers, no magnetic coupling would exist. That this is physically possible is rather hard to visualize at first. In Fig. 14 two coils are shown inclined at the theoretically correct angle. Magnetic flux of coil XY will pass through coil AB roughly as shown. Some of this flux, as represented by the middle line, passes through coil AB in a direction perpendicular to the axis of that coil and does not link with the turns at all. Other portions of this magnetic flux will link

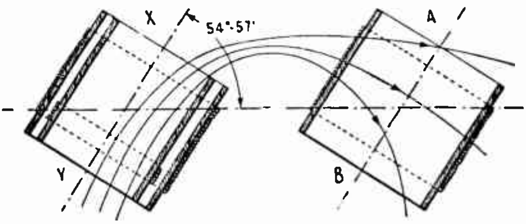

Fig. 14—How the Angles of the Coils Used in the Neutrodyne Receiver May be Used to Give Zero Magnetic Coupling.

with turns on AB. Some of it passes up and some down through the coil. There are flux linkage in both senses. It seems reasonable that if the coils are set at some such angles as these, zero coupling may be obtained. This is true, but the angle varies slightly from the theoretically correct one, due to conditions not being ideal. The most conspicuous reason for variation is the fact that the leads which carry the coil current to the condenser form a single turn in an entirely different plane from the turns on the coil itself. The exact angle may be determined in any given receiver whose coils are first set approximately correct and the neutralizing condensers adjusted for a high broadcast frequency. The settings of the two neutralizing condensers C_{n-1} and C_{n-2}, Fig. 12, are then noted and the process repeated at a low broadcast frequency. In general the settings will be different. This is due to the fact that if inductive coupling is present between adjacent coils, the neutralizing condenser counteracts this as well as the coupling due to the tube capacities. This neutralization will be exact for only one frequency, because with varying frequency, the coupling effect due to the mutual inductance between coils varies at a different rate than the negative coupling effect due to the neutralizing capacity. If the settings are different, the coil angles are shifted a slight amount and the process repeated. When the neutralization is correct at both high and low-frequency ends of the scale, the coil angle is correct. It has been found to vary from 54 to 58° by this method in different receivers.

INTER-CIRCUIT COUPLING IS OBJECTIONABLE.

Objectionable coupling between circuits due to the use of a common "C" battery has proven very troublesome, but not objectionable if proper precautions are taken. The coupling introduced by the battery is analogous to that introduced in the theoretical circuit shown at the top of Fig. 15 by the impedance Z. Here the current of circuit C_1L_1 flows through the impedance Z which is common to circuit C_2L_2. It is evident that the current of one circuit will induce a voltage in the other, or it may be stated that if any portion of the current of one circuit flows through an impedance in common with any portion of the current of another, then these circuits will be coupled. The lower portion of Fig. 15 illustrates several ways in which this sort of coupling may be introduced (batteries, rheostats, and non-essential wiring are omitted to avoid confusing the figure). The plate circuits of tubes 1 and 2 carry radio-frequency currents which, like all other electric currents, must flow in closed paths.

Let us trace the probable path of the electron current produced by tube No. 1. Starting at the plate the electrons pass through the primary of unit "B" and thence to the "B" battery, through the battery, and back to the filament, where the electron stream completes the circuit to the plate. As it takes this path, the batteries and, more important, the leads to the batteries, form an impedance through which a similar current from tube No. 2 must also flow. The common impedance introduces coupling. A large condenser placed as shown between the + B and the — A leads has the effect of by-passing these currents and preventing their passage along common leads. To be effective, this condenser should be of at least 0.1 microfarad capacity. It should be carefully placed at the point which provides the minimum of common wiring for the currents in the separate circuits. It would be less effective if placed at the right, as shown by the dotted connections.

The detector plate circuit carries radio-frequency current for which a reasonably low impedance path must be provided. If this path is not provided the signal will be considerably weakened. In regenerative circuits it is common practice to shunt the high impedances of the telephones or audio-frequency transformers by a condenser of about 0.001 microfarad capacity. This must be done in the Neutrodyne circuit, but care must be taken to connect this condenser from the plate of the detector *directly to its filament.* Otherwise if connected as shown alternatively in Fig. 15, a large radio-frequency current must pass through the "B" battery leads in order to complete its circuit. This might readily cause trouble.

Preventing Coupling Prevents Oscillation.

Coupling sufficient to cause oscillation has been found when either a "C" battery or a common filament rheostat has been used to introduce a negative bias on the grids of the radio-frequency tubes. (See Fig. 15.) This is analogous to the coupling introduced by the common "B" battery, since the currents which pass through the grid filament capacities for the first two tubes must return to their starting points by way of this rheostat or "C" battery. If such a device is used, it should be by-passed with a large condenser which is located in the most desirable place, namely, the one which provides the least common wiring for the different currents. It has not been found necessary to use a bias on the radio-frequency tubes and the grid-returns are usually connected directly to the negative filaments of the separate tubes as illustrated in Figure 12.

Inductive loops in the low potential wiring cause a great deal of trouble and are present in a great many "home-made" receivers. If, for instance, the negative and positive battery leads are far apart, a loop closed at the ends by the filaments of the tubes is formed. This loop has mutual inductance to all coils in the receiver and provides a path for the feed-back of energy which is often sufficient to cause oscillation. The remedy for this is obvious and simple. All wires which carry the "A" or "B" battery currents should be bunched together and thus minimize the area of possible loops.

It was found in certain receivers that after all other possible sources of coupling had been eliminated that energy was fed back through the extremely small capacity usually present between circuits C and A. This capacity may be eliminated by shielding, but because this is expensive, several types of receivers have been equipped with a third arrangement which serves to neutralize this last form of coupling. The effect of this coupling capacity is only noticeable in receivers

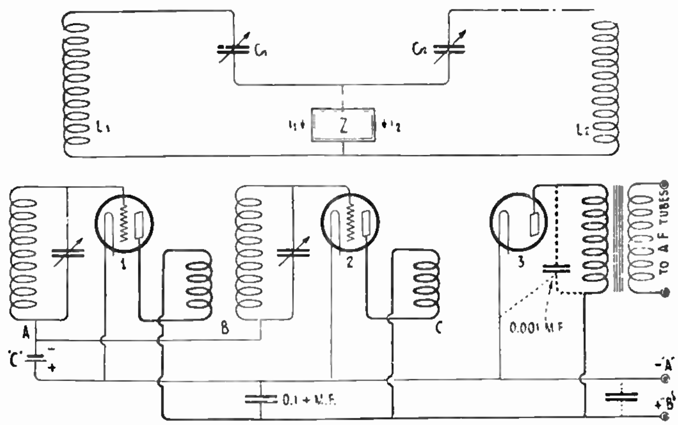

Fig. 15—How Coupling Other Than that Due to Tube Capacity May be Eliminated.

having very low resistance circuits and having, therefore, very high amplification. It is accentuated by the presence in the neighborhood of the receiver of a piece of ungrounded metal, such as a long piano hinge on the cabinet. If the antenna is connected in such a way that it passes behind the receiver close to the last circuit, the effective capacity between the first and last circuits is increased. The antenna lead may be shielded with a grounded metal tube or Belden braid, and the metal hinge may also be grounded. If these precautions fail to remove the trouble, complete shielding or neutralization must be resorted to. Neutralization of over-all capacity may be accomplished with the arrangement of Fig. 12 already referred to. When adjusted, the action is as follows: a very small current passes through the space from the high potential parts of circuit C to circuit A. Another larger current flows through the third neutralizing condenser C_n-O. This current, in passing through the extra coil L_o which is coupled closely to L_1, produces a magnetic effect in circuit A exactly equal and opposite to that produced by the first current in flowing through L_1. The net regenerative effect is then zero. It is interesting to note the relative size of the coils and capacities involved in this action. In a certain receiver L_1, L_2, and L_3 are of 65 turns each. A tap on L_3 used for two neutralizing condensers is located 8 turns distant from the grounded side of that coil. L_o has but one turn. The neutralizing condenser C_n-O is of the usual form and when adjusted has a capacity of about 10 micro-microfarads.

The adjustment of the over-all C_{n-o} third neutralizing condenser is accomplished by first encouraging the receiver to oscillate. This is done by tuning the circuits to the highest possible frequency and by adjusting the plate and filament voltages to produce the greatest amplification. If the receiver oscillates under these conditions, the condenser C_n-O is increased until oscillation ceases. If increased too far, oscillation will again commence. The correct setting of this over-all condenser is, of course, at the center of the range of non-oscillation. If no oscillation or regeneration is noticeable when these steps are taken, over-all neutralization is unnecessary and may be omitted.

Another cause of unsatisfactory operation on the part of Neutrodyne receivers is that introduced by local conditions. High impedance ground leads may be the cause of oscillation for reasons which are not very clear. The trouble may usually be eliminated by replacing the long lead with a short one to the nearest piping system, such as the radiator or water pipe. If the "A" battery is located at some distance from the receiver and is wired to it with long leads, trouble again may occur. This form of oscillation trouble usually appears over only a limited frequency range and is probably due to an action which occurs at the natural period of the ground or battery system.

Figure 16 shows the wiring diagram of a 5-tube Fada Neutrodyne receiver, employing two stages of radio-frequency

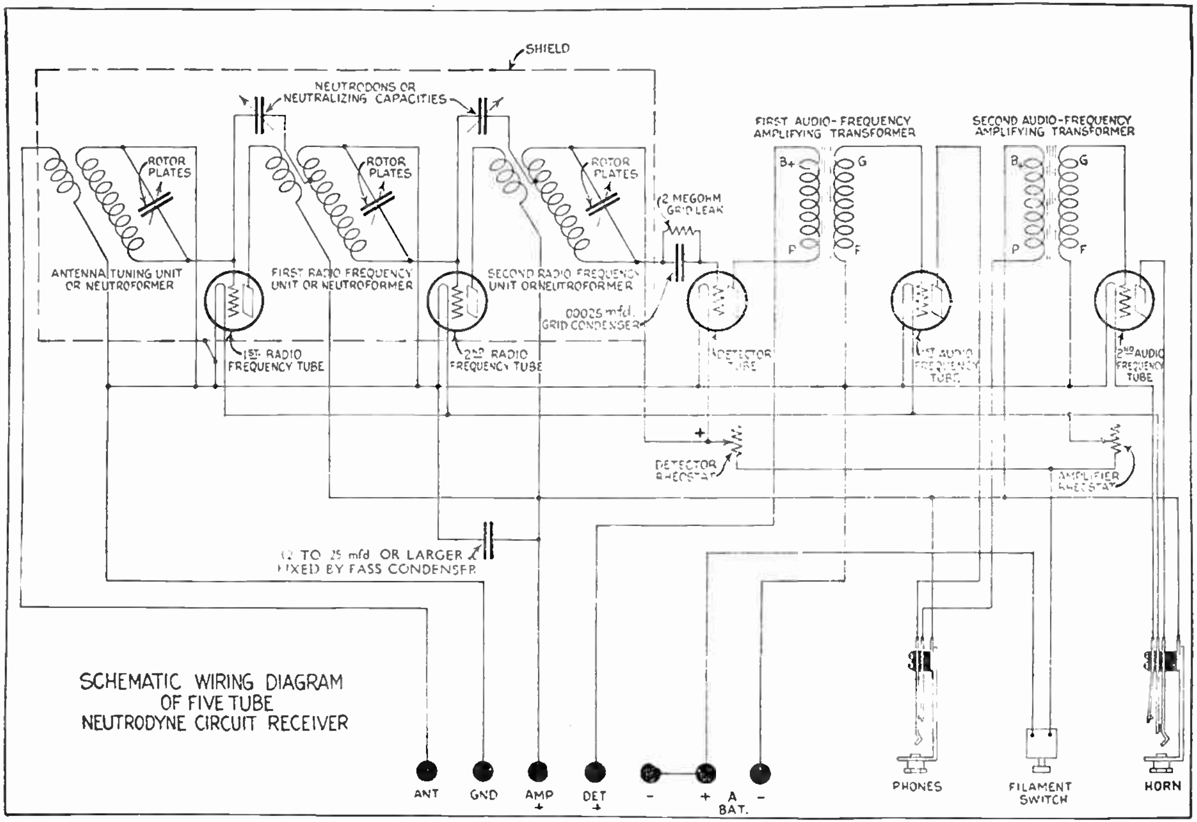

Fig. 16—Wiring Diagram of Fada Neutrodyne Receiver.

amplification, detector and two stages of audio-frequency amplification. This receiver is supplied with the necessary jacks, in order that either one or two stages of audio-frequency amplification may be used.

The transformers of Neutrodyne sets are of the air-core type, wound over a piece of tubing and mounted on the condenser as shown in Figure 17.

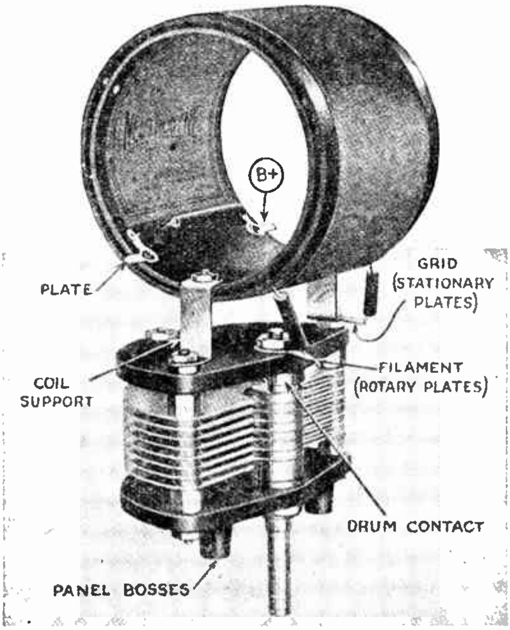

Fig. 17—A Neutroformer, Showing Construction and Terminals.

The Neutrodyne receiver employs an aperiodic, or untuned primary, for the coupling between the antenna and the first stage. The tuning is accomplished by means of the variable condenser only. The tuning of the secondary circuit by means of the condenser, affects the wave-length of the primary, due to the mutual induction of the two coils. The primary coil, being of only a small number of turns of wire, and having no variable contact in any way, means that the antenna system is used at approximately its fundamental wave-length.

This makes the apparatus of limited wave-length; such sets being usually designed for broadcast reception only. In tuning, it is usually found that the condenser dials will be at

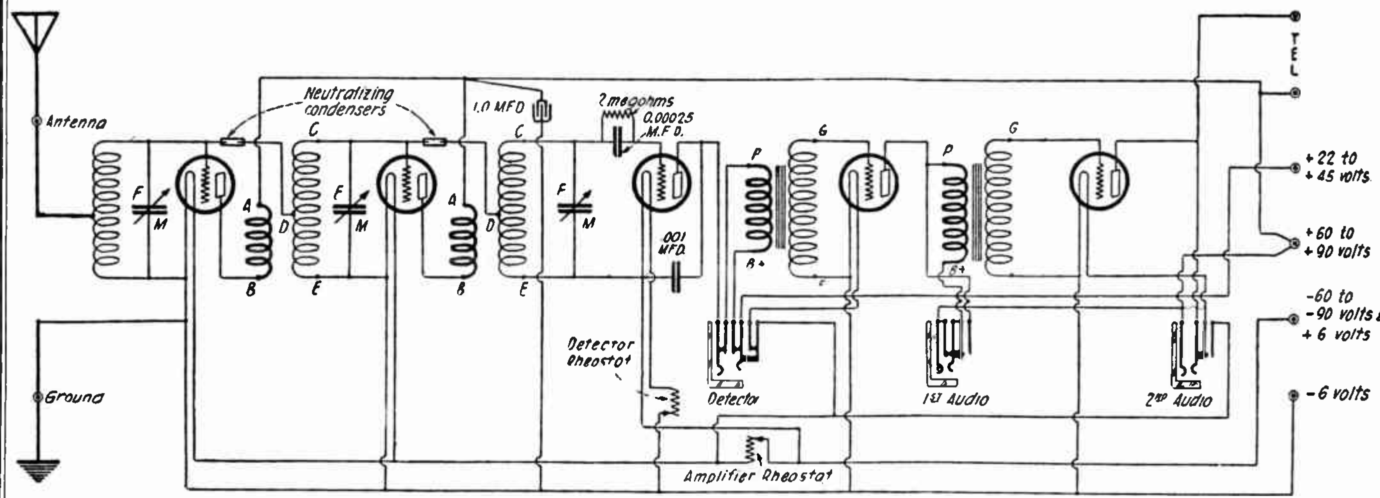

Fig. 18—The Freed-Eisemann 5-Tube Neutrodyne.

the same adjustment for all three neutroformers. In some cases, a geared control is employed, which turns the rotating plates of all three condensers at the same time. This is convenient for people who do not care to bother with much tuning. As it is difficult to obtain condensers and coils which have the exactly same characteristics, it is often found that they will not all be tuned in exactly the same manner to get the best results.

The coil in the antenna circuit frequently tunes a little differently from the others.

Figure 18 shows the circuit diagram of a Freed-Eisemann 5-tube Neutrodyne receiver. The neutroformers are represented by the inductance winding, AB, and CDE; the three variable condensers are represented by FM. The audio-frequency transformers are indicated by the windings, P, B plus and G, F. Otherwise, the diagram is self-explanatory.

Figure 19 shows the circuit diagram of the Fada 7 tube Neutrodyne receiver. This set employs four stages of radio-frequency amplification, detector and two stages of audio-frequency amplification. It can be operated either by the loop aerial or outside antenna. This receiver uses individual stage shielding on coils and condensers operated by dual control. The on and off switch and volume control are combined in one.

The circuit diagram of the Philco Electric Radio Receiver Model 87 is shown in Fig. 20. This receiver is of the Neutrodyne type, employing three stages of tuned radio-frequency amplification, detector, and two stages of transformer coupled audio-frequency amplification. The second audio-frequency stage is a push-pull arrangement. The plate supply is obtained from a full-wave rectifier tube.

Four variable condensers are used to tune the three radio-frequency circuits and detector circuit. To increase the selectivity, a small variable condenser is used with the tuning condenser in the grid circuit of the first radio-frequency tube.

The other three variable condensers each have a compensating condenser shunted across them. The capacity of the compensating condensers can be varied by adjusting with a wrench. This provides a method for equalizing or matching all the tuned circuits.

The push-pull amplifier uses two CX-345 or UX-245 power tubes to handle great volume of signals and fidelity of tone.

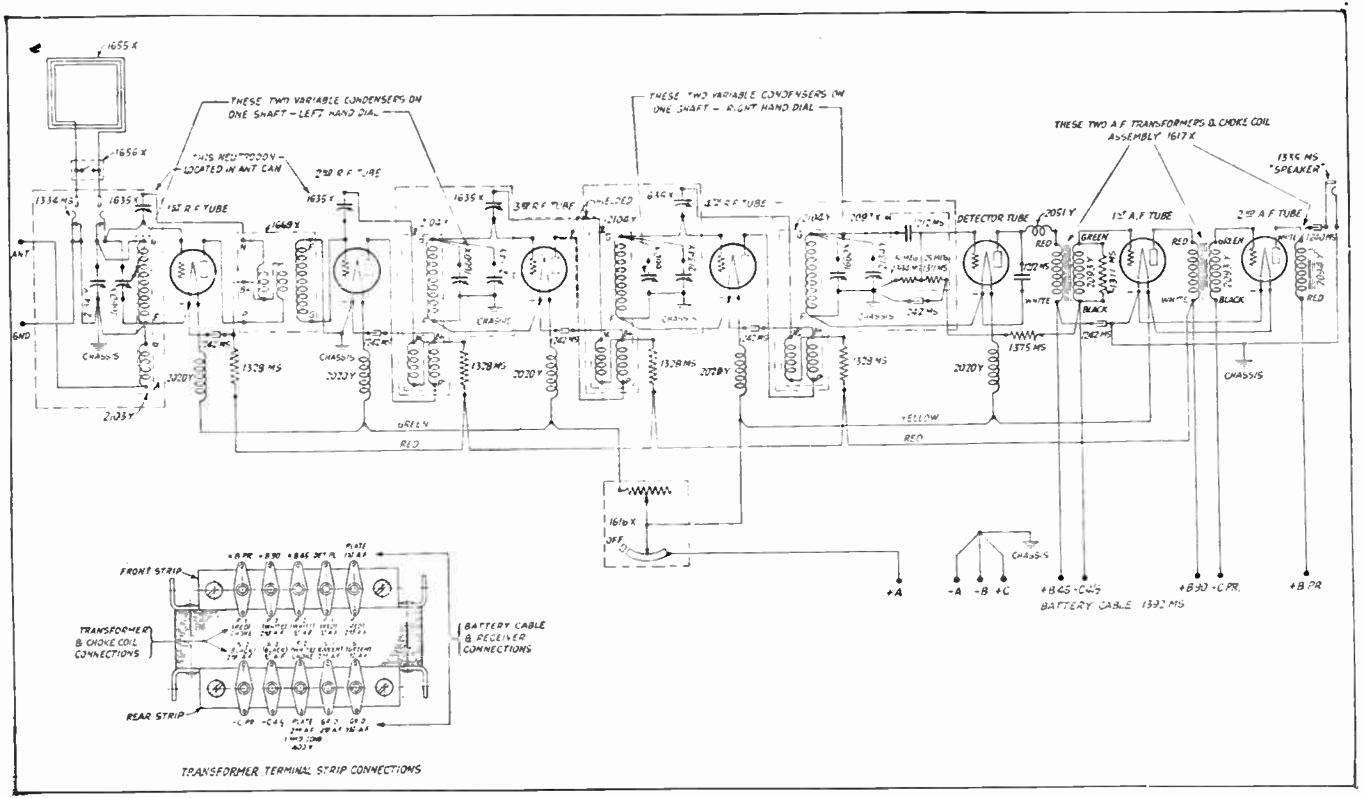

Fig. 19—Circuit Diagram for Fada 7-Tube Neutrodyne Receiver.

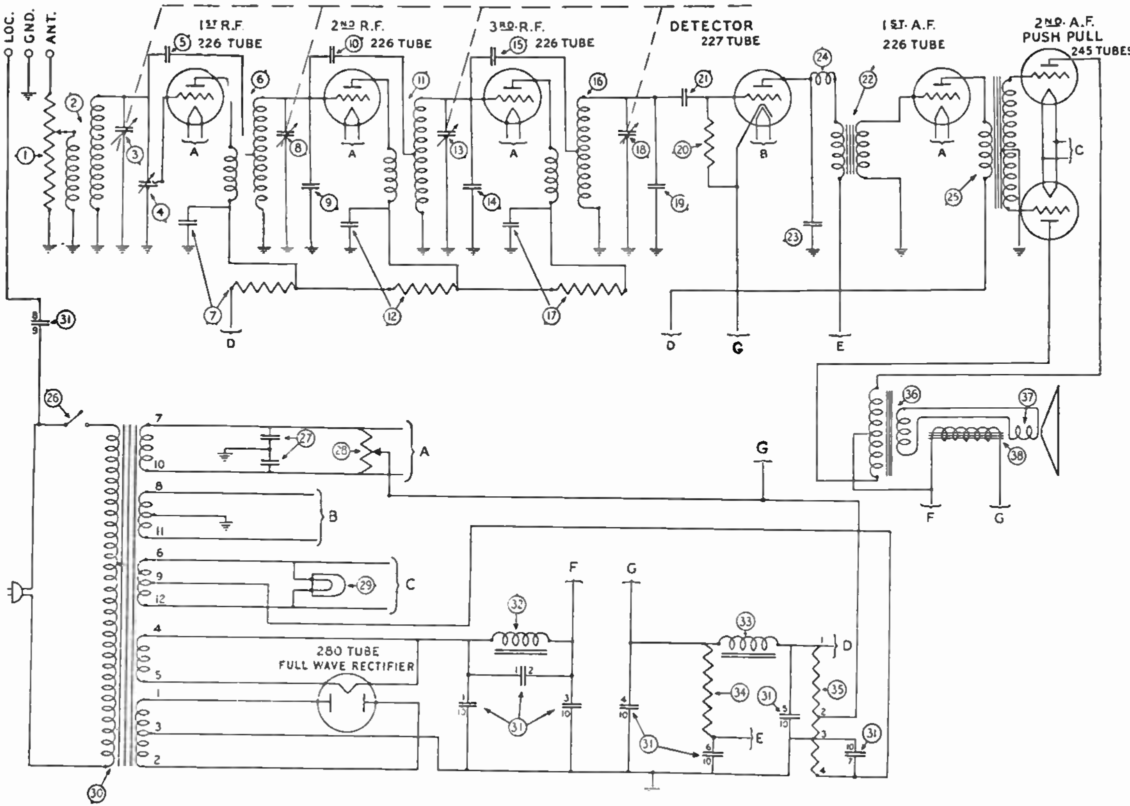

Fig. 20—Schematic Wiring Diagram of the Philco Electric Radio Set, Model 87.

The main volume control is a potentiometer resistance of 10,000 ohms connected from antenna to ground. The input to the set is connected to this resistance by means of a sliding contact, thereby allowing more or less of the signal strength to pass directly to the ground.

In the previous pages, the student has been given a complete explanation of the theory of the Neutrodyne set, the working principles of each part, with special methods for preventing oscillations. Various diagrams and essential features of different types of Neutrodyne circuits, along with the most important points of consideration which should be taken in the selection of a successful design, either for home-made receivers or factory built sets, have been presented.

A student should now have sufficient knowledge of the Neutrodyne receiving sets to proceed in a practical way in the construction, testing and operating of the various circuits involved in these receiving sets.

TEST QUESTIONS

Number your answer sheet 20 and add your **student number.**

1. What is the principal source of trouble in radio-frequency circuits?
2. How does the Neutrodyne system overcome these troubles?
3. Tell the difference between Figures 7 and 8.
4. Name several undesirable couplings between the circuits of a Neutrodyne receiver.
5. How is the over-all neutralization adjustment made for the third condenser C_{n}-O in Fig. 12?
6. What final test can be applied to the receiver to prove that the circuit is complete?
7. What precaution must be taken in placing the neutroformers on the panel?
8. Show by diagram how a buzzer circuit may be used for neutralization of the receiver.
9. How many rheostats are used in Fig. 12 and what tubes does each rheostat control?
10. Draw a diagram of a 5-tube Neutrodyne Circuit and mark the parts with the proper names.

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LESSON TEXT No. 21

THE SUPER-HETERODYNE RECEIVER DEVELOPMENT, DESIGN AND OPERATION

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SOME GOOD STUDY HABITS

A Personal Message from J. E. Smith

Pausing for Thought. Concentration in study, as I use the term does not mean a steady reading without pause. One ought to stop and turn over in his mind what he has been reading. That is the only way to insure that the ideas you have gained, or think you have gained, are really clear to you. It is the only way, too, in which you can make them genuinely your own and be able in the future to apply them to circumstances in which you may be placed.

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THE SUPER-HETERODYNE RECEIVER

In previous lessons, you learned about the two general types of amplification used in radio reception, namely, radio-frequency amplification and audio-frequency amplification.

Audio-frequency amplification is used to build up volume after the signal has been received and rectified by the detector. It is possible to take a weak signal from the detector and pass it through several stages of audio amplification so that it can be heard several blocks away. However, two or three stages are about all that may be used successfuly in a radio receiver. When more than this is used, the amplifier itself becomes noisy and the quality of signals is destroyed unless special precautions are taken.

If there is no signal in the detector, no amount of audio-frequency amplification will bring it out. The incoming signal has to be of a certain minimum intensity before detector action takes place. In other words, there is a certain entrance value that signals must attain before they can be heard in the detector. Here is where radio-frequency amplification becomes very useful.

This type of amplification is used ahead of the detector tube, between it and the aerial or loop, as the case may be. The function of radio-frequency amplification is to amplify and bring out the weak signals that otherwise might not affect the detector tube and accordingly would be too weak to be received. Radio-frequency amplification will build up and amplify radio-frequency impulses regardless of their strength. Therefore, it becomes very valuable in long distance radio reception.

However, we are dealing here with a much more difficult type of current. An extremely weak current of very high-frequency is a difficult thing to handle. It delights in jumping about from one wire to another, if the slightest opportunity is given it, and very often is dissipated throughout parts of the receiving set, where it is of no use whatever. It must be handled with extreme care and the higher the frequency of the signal—that is the lower the wave-length, the harder it becomes to amplify at radio frequencies. Therefore, while this system is theoretically ideal, it has been very difficult to work out a satisfactory system for accomplishing this radio-frequency amplification on wave-lengths much below 600 meters.

The lower these wave-lengths became, the greater were the difficulties encountered. These difficulties can be attributed chiefly to the capacity effects in the vacuum tubes themselves as well as in the wiring and between the various instruments that make up the receiver. As the wave-length decrease the frequency increases, and the higher the frequency, the greater is the tendency for the weak radio impulses which we are trying to conserve and build up, to leave their proper path and jump to some nearby point from which they may pass to ground or otherwise become lost.

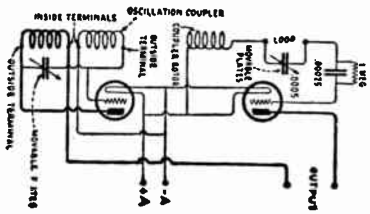

Fig. 1—Circuit Diagram of an Oscillator and Frequency Changer.

Indeed, at these high frequencies even small capacities between wires are nearly as bad as having these wires directly short-circuited, for the higher the frequency, the less capacity is needed to by-pass it.

The principal methods for amplifying broadcast wave-lengths at radio-frequency are *tuned radio-frequency amplification, untuned transformer-coupled amplification* and *resistance coupled amplification.* Fig. 2 illustrates the first plan, namely, tuned radio-frequency amplification. Two stages are shown before the detector. However, two or three stages of such a method offer sufficient difficulties. Such an amplifier is extremely selective. If any one of the tuned circuits is not exactly in resonance, amplification will be destroyed and, in fact, the signal may be completely lost.

However, when each of these circuits is tuned and the full amplification from each tube is realized, there is another difficulty in the way. The internal capacity of the tube produces feed-back between the plate and grid circuits which is sufficient to produce radio-frequency howling. It is almost impossible to avoid regeneration at such high frequencies without introducing some neutralizing force. Regeneration results in oscillations which spoil quality of signals and reduce over-all amplification.

The next method is to employ straight R. F. transformer coupling as in Fig. 3. Even such a system has a tendency to regenerate and produce radio-frequency howling. But, even if it did not oscillate, it has one disadvantage. Radio-frequency coupling transformers will give amplification only over a very

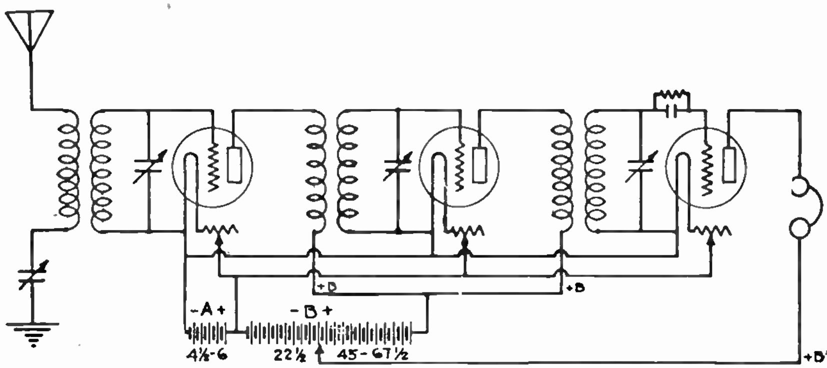

Fig. 2—A Two-Stage Tuned Radio-Frequency Amplifier and Detector With Grid Circuits Tuned.

narrow band of wave-lengths. Maximum amplification is secured at one wave-length, and then falls off as this wave-length is departed from. We, therefore, cannot avail ourselves of the full amplification of the tube at all wave-lengths with this system.

The third alternative method of radio-frequency amplification is straight resistance coupling as in Fig. 4. But at high frequencies corresponding to the broadcast wave-lengths, this has one very great disadvantage: it does not amplify very well. A resistance-coupled amplifier does not amplify well at these frequencies because the capacity of the tubes from plate to filament and from grid to filament partially short-circuits the amplified voltage. Thus, in Fig. 4, consider the coupling resistance R, which is of the order of 50,000 ohms. The amplified voltage is devoted across this resistance and applied to the grid of the succeeding tube, *provided* there is nothing to stop this voltage. But actually we have in parallel with this resistance R, two capacities: (1) The plate-filament

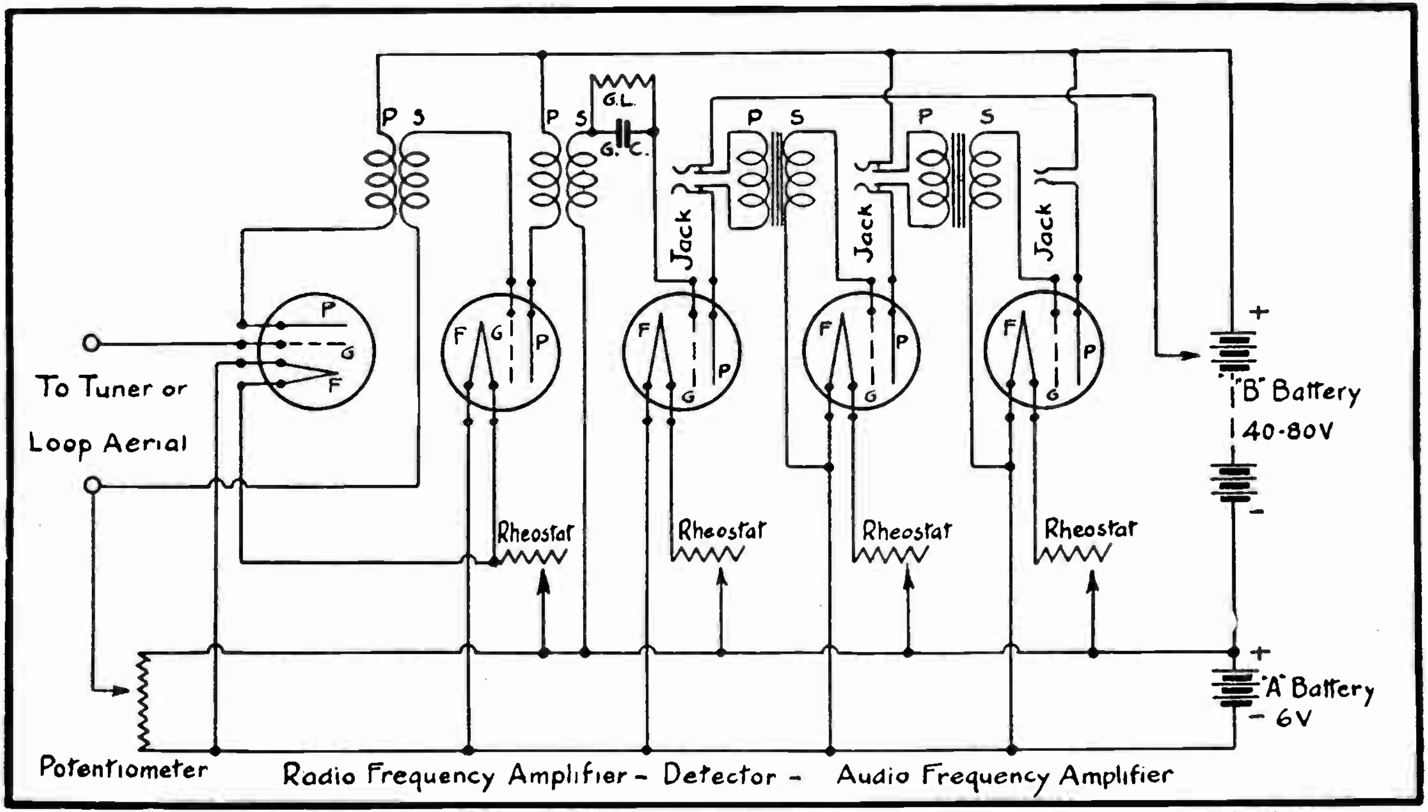

Fig. 3—Diagram of Two Stages of Untuned Radio-Frequency Amplification, Detector, Two Stages of Audio-Frequency.

capacity of tube A, and the grid-filament capacity of tube B. These capacities have no influence on the voltage across R at direct currents or audio-frequency currents because their reactance is so great. However, at radio frequencies, their reactances become so small that they practically short-circuit the resistance R and hence destroy amplification. Approximate values for plate-filament capacity and grid-filament capacity are 4 micro-microfarads and 6 micro-microfarads, respectively. Since they are in parallel, the total is 10 micro-microfarads. The reactance of this capacity at 200 meters is about 10,600 ohms. In other words, our coupling resistance R of 50,000 ohms or more is short-circuited by a reactance of 10,600 ohms which is less than the internal impedance of the tube. Hence, little amplification at these frequencies can be

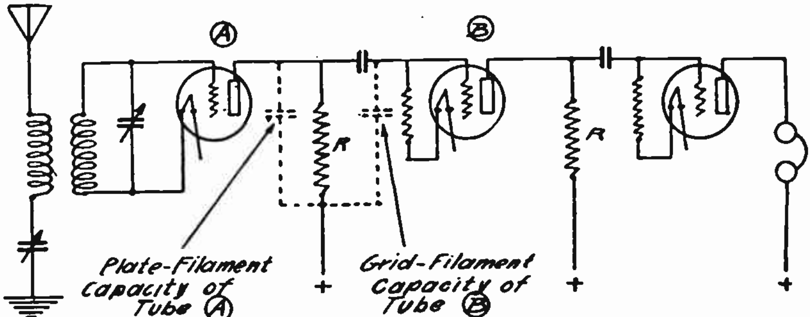

Fig. 4. Resistance Coupled R. F. Amplifier

secured. Students who have wondered why resistance-coupled R. F. amplification at low waves is not practical will now see the reason for it, and will also understand why it operates better at very long waves, for at very long waves the reactance of the tube capacity is high compared to the coupling resistance R, and hence does not short-circuit the voltage.

We now readily understand some of the obstacles which were in the way of developing radio-frequency amplification at broadcast wave-lengths. Numerous attempts at a solution have been made all over the world, and some of these are both of importance and interest. One of these solutions attempted to broaden the band of wave-lengths received and amplified by making a radio-frequency transformer wound with resistance wire. The effect of the resistance winding was to change the amplification curve from that of Fig. 5-(a) to that of 5-(b). The same effect was secured by using radio-frequency transformers with an iron core, the losses in the iron core being equivalent to resistance losses. This resistance effect also partially prevented regenerative action in the amplifiers.

Armstrong attacked the problem of radio-frequency amplification from an entirely different angle. Radio-frequency amplification at long waves had proved very successful. If some means are used for converting the incoming wave into a long wave-length then the problem of R. F. amplification would be solved. *This meant a conversion of the high-frequency into a low-frequency.*

Such conversion of frequency had been practiced for some time in C. W. heterodyne reception, in which the phenomenon of beats is used. For example: If a continuous wave oscillation of a frequency of 100,000 cycles per second is combined with another of 99,000 cycles per second, then the well-known phenomenon of beats is produced, and the result of these two oscillations is another oscillation whose amplitude varies at a frequency equal to the difference of the two component frequencies. In this case the difference between 100,000 and 99,000, is 1,000 cycles. Thus, a 1,000-cycle note will be heard.

The Super-Heterodyne receiver makes use of the beat principle. A local oscillator is used to generate radio-frequency oscillations differing slightly from the frequency of the incoming signal oscillations. The incoming signal oscillations are combined with those of the local oscillator and another frequency is set up which is the difference between the frequency of the incoming signal and that of the local oscillator. This beat frequency is then passed through several stages of radio-frequency amplification and is amplified at radio-frequency. It is then detected and amplified by one or more stages of audio-frequency amplification.

Suppose the incoming signal has a frequency of 700,000 cycles, and suppose also that we have an oscillating circuit capable of generating oscillations over a range of frequencies. If the oscillator is set for a frequency of 650,000 cycles and its output is coupled to the receiver carrying the 700,000-cycle signal, then according to the heterodyne principle explained above, the output will be an oscillation whose amplitude varies at a frequency equal to the difference of the component frequencies, namely, 700,000—650,000, or 50,000 cyles (50 Kcs.) The only change that occurs is that by means of an external oscillator a 700,000-cycle signal is converted into a 50,000-cycle signal of the same characteristics as the original 700,000-cycle signal. Thus, a high frequency signal is converted into a low frequency signal, and, since R. F. amplification is efficiently accomplished, this is a solution to our original problem. For, if we use a 50,000-cycle (50 Kcs.) R. F. amplifier, to amplify the 50,000-cycle beat oscillations, and then detect and rectify them, we will hear the original signal of the 700,000-cycle wave.

The above explanation will be readily understood in the case of the 700,000-cycle signal and the 650,000-cycle oscillator. Suppose one happens to be receiving, not a 700,000-cycle signal, but, say, at 640,000-cycle signal. What then? The external oscillator is adjusted so that it will oscillate at 690,000 cycles per second, in which case the difference between the

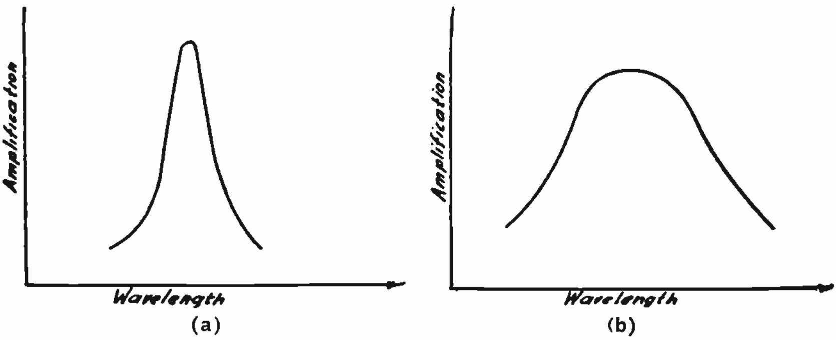

Fig. 5—Amplification Curves, (a) With Ordinary R. F. Transformers (b) With Transformers Wound With Resistance Wire or Having Iron Cores.

two, or the beat oscillations, will be 50,000 cycles as above, which frequency is capable of efficient amplification. Of course there is no necessity for this particular frequency of 50,000 cycles to be chosen. Any other frequency, such as between 30,000 and 100,000 cycles, could just as well be chosen. The important point is that the beat frequency, which is called the "intermediate frequency," should correspond to a low-frequency at which radio-frequency amplification may be accomplished more efficiently.

THE THREE DIVISIONS OF THE SUPER-HETERODYNE

The Super-Heterodyne as a whole, and as we are accustomed to use it at the present time, may be, for convenience sake, divided into three distinct parts. By taking these up separately and studying their individual functions, the student can more easily grasp the significance and importance of each.

I. In the first section, we may place the input tuning apparatus, the frequency changing and oscillating tubes, together with their auxiliary apparatus, such as oscillator, coupler, tuning condensers, etc. (See Fig. 1.) The first tube in the Super-Heterodyne is commonly called the first detector, although it is a somewhat confusing and misleading name. As it is difficult for the average person to understand why there should be two detectors in any set, it is much more reasonable to consider the first tube merely as a frequency changer or a mixer for the two wave-lengths with which we have to deal, namely, the incoming wave-length and the wave created by our local oscillator. The incoming wave, which is picked up by a loop or antenna, as the case may be, is fed into the frequency changing tube, and the local wave which is being produced by the oscillator tube is likewise fed into the frequency changing tube. These two wave-lengths are so combined here as to create a resultant higher wave which may be adjusted to any desired frequency by slightly changing the wave-length of the local oscillator, whose wave-length is increased as the capacity of the condenser across the oscillator coil or coupler is increased and vice versa. This predetermined intermediate wave may be almost any wave-length above that of the incoming signal. The wave-lengths which are in common usage today for this purpose usually lie between 1,500 and 10,000 meters.

Thus it is seen that the function of the first part of our Super-Heterodyne is to tune in and receive the desired signal with the tuning apparatus, which may consist of either a loop and tuning condenser, or antenna tuning coils, such as a vario-coupler with its tuning condenser. Then by means of the local wave, generated by the oscillator tube, to change the received signal to some predetermined higher wave-length at which we propose to amplify it.

II. The second division of the Super-Heterodyne is the intermediate wave amplifier (see Fig. 6) whose function is to amplify the longer wave-length signal which is passed on to it from the first section. In other words, after the signal has been received and changed to some predetermined longer wave-length, the first section has done its duty. It then passes this changed frequency signal on to the second section, the intermediate wave amplifier, where it is amplified as much as we desire. This amplifier is the engine of the Super-Heterodyne and it is here that the engery is amplified and the signal built up in amplitude preparatory to its rectification in the final detector tube. This amplifier is designed with two things in view—

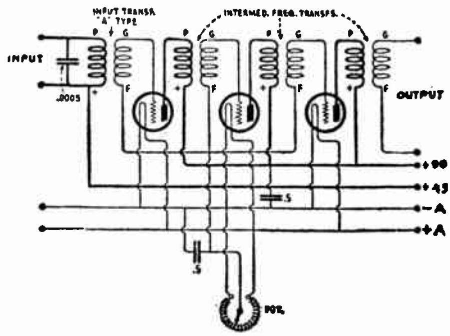

Fig. 6—Intermediate Wave Amplifier.

First: To give as great efficiency in amplification per stage as is possible.

Second: To do this without distorting the wave form, that is the signal must be built up, amplified and passed on from tube to tube throughout the amplifier without introducing any false harmonics or eliminating any of the desirable ones.

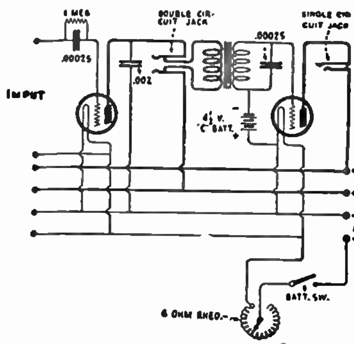

Fig. 7—Detector and a One-Stage Audio Amplifier.

III. The third division is composed of a detector tube and audio-frequency amplifier, if we desire power for the operation of a loud-speaker (see Fig. 7). The signal which is built up in the intermediate amplifier is fed into this third section and rectified here by the detector tube. That is, it is changed from an alternating high-frequency wave to an audible pulsating direct current, which should correspond exactly to the modulations of the high-frequency waves. This is done in order to change it into a form of current that will allow it to actuate the diaphragm of our receiver or loud-speaker, giving us a faithful reproduction of the voice or music, as the case may be, as it was originally produced at the transmitting studio. The function of this detector tube and its following audio-frequency amplifier is practically the same as in any radio receiving set and its action is quite familiar. The only point to be noted here is that there is no advantage gained by using a soft or gaseous detector tube at this point, as we no longer have weak impulses of small amplitude to deal with. The wave which reaches this final detector tube is always of great amplitude even at its minimum, due to the heterodyne action of the oscillator and the amplification which it has undergone.

THE OSCILLATOR

The function of the oscillator is to generate a frequency slightly different from the frequency of the incoming signal so that a beat frequency is produced. This oscillator is nothing more than the essential parts of a transmitting set, with a small coupling coil called the pick-up coil. Any reliable circuit may be used such as the Hartley or Meissner. It should oscillate freely over the entire scale of wave-length that it is intended to receive. It is tuned by a variable condenser. The pick-up coil is used to transfer the oscillator energy to the first detector where it is mixed with the incoming signal and the resultant frequency produced.

THE INTERMEDIATE AMPLIFIER OR THE HEART OF THE SUPER

Now the heart of the Super-Heterodyne is the middle unit, which as we have already stated above, is comparable to the engine which gives the car its power. It is the intermediate frequency amplifier which we depend upon to furnish the amplification which is characteristics of this receiver and it is this section which should be given the most attention and consideration.

MAINTAINING QUALITY IN THE AMPLIFIER

As has already been stated, there are two basic general requirements that should be met in any amplifier. As they are the fundamental requirements, it will be well to repeat them. They are roughly as follows:

1. In order to build up maximum voltage and maintain maximum selectivity, the interstage transformers should be designed to tune sharply.

2. The received signal must not be distorted as it passes through the amplifier. This means in the case of the intermediate frequency amplifier that the modulation frequency component of the received signal must not only be passed through the transformers, but must also receive an approximately uniform degree of amplification.

This latter consideration is of the utmost importance when considering an amplifier for use in the Super-Heterodyne, for here we must handle frequencies that are relatively low where it is comparatively easy to cause distortion of this nature and as we are considering the reception of radiophone signals, quality reproduction is one of the first considerations.

SHARP TUNING VERSUS DISTORTION

In order to maintain good quality reproduction, the intermediate frequency amplifier must not be tuned too sharply. Since the modulation frequencies extend on either side of the carrier wave frequency it is, therefore, necessary that the intermediate frequency transformers amplify equally well over a narrow band of frequencies to either side of the carrier frequency. As an example, suppose that the modulation frequencies extend from say something like 30 to 10,000 cycles. This means then that if the intermediate frequency is 50 kilocycles (50,000 cycles) that the intermediate frequency amplifier must pass without discrimination all frequencies between 40 and 60 kilocycles, since 50 kilocycles minus 10 kilocycles equal 40 kilocycles and 50 kilocycles plus 10 kilocycles equals 60 kilocycles. This is the ideal condition and the average intermediate frequency amplifying transformer will not pass these frequencies equally without giving preference to some frequencies over others.

If the amplifier does not pass these frequencies and amplify them equally then some of the upper voice frequencies are cut off and the high pitch notes are not reproduced.

WHY THE SUPER IS SELECTIVE

The underlying principle of the Super-Heterodyne is that the frequency of the signal wave is changed to a much lower frequency and then amplified before being detected and amplified at audio-frequency. The ordinary receiver amplifies the signal without changing its frequency. As previously explained, the intermediate frequency is obtained by mixing with the signal another frequency current which is different from the signal frequency by the amount of the intermediate frequency. As an example, suppose that the signal frequency is 1,000 kilocycles and the intermediate frequency transformers are designed to operate on 50 kilocycles. Therefore, if we tune the oscillator so that it generates a high frequency current which is different by 50 kilocycles from the signal frequency, we will have an intermediate frequency of 50 kilocycles. Thus the oscillator can be tuned either to 950 kilocycles or to 1,050 kilocycles.

In the mixing of the oscillator and signal frequency, in order to obtain the intermediate frequency, it can readily be understood that in changing the signal frequency to the intermediate frequency all outside currents having a different frequency will not be combined into the intermediate frequency. First, due to the fact that the oscillator frequency is very sharp and does not cover a wide band of frequencies and next due to the fact that the intermediate frequency amplifier is so constructed that the band of frequencies which it will amplify is limited. Thus, selectivity greater than that of the ordinary tuned radio-frequency receiver is gained.

TUBE NOISES AND STATIC INTERFERENCE

The limiting factor of distant reception with a Super-Heterodyne can be summed up in two words—the noise level. If the radio-frequency noises such as static and atmospheric disturbances impress a much stronger voltage on the antenna than the signal the reproduction will not be very pleasant. This applies to all types of receiving sets as well as the Super-Heterodyne. This relation between the static or atmospheric noises and the signal is often referred to as the "noise level," "signal-noise ratio" or "signal-static ratio." In other words, the greater the strength of the signal in comparison to the static, the better is the reception.

Now the higher the wave-length which is used, the lower the frequency becomes, gradually approaching an audible frequency. Accordingly the higher the wave-length to which the amplifier is tuned, the greater is its tendency to amplify audio-frequency noises. In fact many radio-frequency transformers which are designed for wave-lengths of 6,000 meters or greater are fair audio-frequency amplifying transformers and a three-stage audio-frequency amplifier even if its efficiency per stage is not great, can build up quite a volume of sound. This, of course, may be overcome to some extent by the use of an air core filter transformer in the amplifier output, but this does not correct it entirely. The real solution to this problem is to reduce the wave-length of the intermediate amplifier to such a point that comparatively low impedance air core transformers may be used which will not allow a large audio-frequency potential difference to build up across them and will accordingly result in a considerable increase in the signal-noise ratio. *This, as pointed out above, is the fundamental limit of the Super-Heterodyne's amplification powers and accordingly anything which increases the amplification of the receiver at a sacrifice of this ratio is hardly worth while.*

HAND CAPACITY EFFECT

There is another thing which we must take into consideration and that is the troublesome hand capacity effect on some sets.

This hand capacity or body capacity effect is very annoying in sets whose intermediate frequency amplifier works on 30 K. C. or 10,000 meters. Complete shielding of the oscillator and intermediate frequency amplifier is usually the only solution of this difficulty.

IMPORTANT TUNING CONSIDERATION

There is still another important point in favor of the low-wave amplifier. In heterodyning the incoming signal—changing its frequency suitable to use in the intermediate amplifier—we may use either the sum of the local oscillator frequency and the incoming wave frequency or their difference; that is, in actual practice there will be at least two places on the oscillator dial where any station may be received, providing the loop or antenna tuner, as the case may be, is not detuned from the station and also providing that the oscillator has sufficient range to cover both of these points. Now as the wave-length of the intermediate amplifier is increased, these two points at which the station will be reproduced come closer and closer together on the oscillator dial, until when we amplify at a wave-length of 10,000 meters, for instance, these two points are separated by only a very few degrees on the oscillator dial. In fact, they are so close together that when tuning the set, the antenna tuner is not sufficiently far out of resonance by the time the second one is reached and consequently the station is brought in at two points close together. This is not only confusing to the operator, but it often happens that the station will come in again on its upper point exactly on top of the lower point of some other station, thus causing needless interference. Now the cure for this situation is to reduce the wave-length of the intermediate wave amplifier to such a point that a low wave station will not be heard again until the high broadcasting wave-lengths have been passed or at least until the two resonance points are so far apart that by the time the upper one is reached, the antenna or loop tuner is far enough out of resonance to prevent it from coming through again. Thus the local oscillator or heterodyne may be so designed as to merely cover the sum or difference of the oscillator frequency and the incoming wave frequency, and the operator is not bothered by having the low wave stations repeating on him when he is attempting to receive those on high wave-lengths.

STABILITY AND EFFICIENCY

The Super-Heterodyne owes its existence to the well-known fact that high wave-lengths are easier to handle at radio-frequencies than the low ones. In other words, as we go up in wave-length it becomes easier to build the radio-frequency amplifier and obtain stability and efficiency. However, this problem is not a serious one at any wave-length over 1,000 meters. In fact at any wave-length greater than this, even a resistance-coupled amplifier shows good efficiency and while it becomes easier to obtain a greater efficiency per stage as the intermediate wave-length is increased, at the same time we do this at a sacrifice of other desirable features, as have been pointed out above.

On the other hand there are several advantages of using iron core transformers in preference to air core transformers. This is especially true when their operating frequency is about 50 K. C. or 6,000 meters. A properly designed air core transformer has a sharp peak at which it amplifies most efficiently. In an efficient amplifier using these transformers all of these peaks must coincide. If one of them is out of resonance with the rest, the amplification falls off greatly, hence, the necessity for having all the transformers matched. Although it is possible to have a set of perfectly matched transformers, they may not be in resonance when connected into the circuit. The reason for this is obvious. The capacity effect between the wiring of the set is sufficient to throw the amplifier out of resonance. Also the external field of an air core transformer may be cut by that of another transformer or by some metallic object which will shift the resonant point. The greatest difficulty is experienced from tubes that have different internal capacity. This capacity is shunted across the transformer, thus increasing its wave-length. If different values of capacity are shunted across the different transformers, their peaks would not be in resonance.

One way to largely overcome this difficulty is to match the tubes or to shift the tubes around in the set until best results are obtained. There is quite a noticeable decrease in the wave-length of the intermediate frequency amplifier when the 199 type tube is used in place of the 201-A type. This is on account of the lower internal capacity of the 199 type.

The above difficulty is eliminated by using iron core transformers because these transformers have a sufficiently flat top peak that such capacity variations do not affect the amplification or throw the different stages out of resonance.

The iron core transformers cause the amplifier to be more stable in operation thereby permitting the grids to carry more of a negative bias. This causes the set to consume less "B" battery current. The battery consumption of the air core amplifier is from 40 to 60 per cent higher than with the iron core amplifier due to the use of a positive grid bias obtained by a potentiometer across the "A" battery. The potentiometer may be used with iron core amplifiers also, but in case it is, it has to be turned practically all the way toward the negative side to cause the amplifier to become unstable.

WHICH SHALL WE CHOOSE—HIGH OR LOW?

It can easily be seen that in order to draw a conclusion from the above considerations and pick a best wave-length for our amplifier, it is going to be necessary to make compromises. There are one or two considerations which would seem to indicate the high wave-lengths as being best, while on the other hand there are sufficiently strong arguments to make it well worth while to sacrifice something in order to gain the beneficial results which the low waves will give us. If we use a good high wave intermediate amplifier, we will obtain good stability and large amplification per stage. On the other hand, to get this we have somewhat complicated the tuning and have *decreased our signal noise ratio, which after all seems to be the answer.* Amplification, sharpness of tuning and all other considerations are of little avail if our receiver brings in such a quantity of noise together with the signal that it is either unpleasant to listen to or even impossible to do extreme distance work when conditions are not perfect. *This one consideration alone is sufficient to indicate a comparatively low wave-length as the best.* However, if we carry this too far, we are going to sacrifice our sharp tuning, which is such a valuable characteristic of this type of receiver and on account of this latter consideration, a lower wave-length than 1,500 meters cannot be recommended. With the other points in view a higher wave-length than 8,000 meters also becomes undesirable.

The most satisfactory all around wave-length for an intermediate amplifier lies in a compromise between these two extremes of 1,500 and 8,000 meters. Such an amplifier will combine practically all of the desirable characteristics enumerated above.

TRANSFORMER CONSTRUCTION

For the benefit of any student who may contemplate building his own transformer, a few words about their actual construction and difficulties encountered will perhaps save time and trouble. In the first place if you are going to wind your own, choose a low wave-length, something in the neighborhood of 2,000 or 3,000 meters. This is not only on account of the points brought out above, but also because it is more practical and simpler to build a transformer for these wave-lengths with the limited facilities and equipment available to most people. This is mainly due to the fact that when the higher wave-lengths are used, it is almost imperative that an iron core in some form be used. This is done in order to flatten the curve sufficiently to prevent the transformers from distorting, which would be the case if they were tuned too sharply at the higher wave-lengths. While an iron core at radio-frequencies introduces a considerable loss, at the same time if the construction is carried out very carefully, thin laminations being used, each insulated from the other, this loss is well compensated for by the step-up ratio which may be used in the transformers themselves. However, the design of such transformers and the construction is rather difficult and the materials hard to obtain, therefore, if one wishes to experiment with transformers, by all means buy them instead of trying to build them.

On the other hand, it is possible for the average person to build a set of fairly efficient transformers having their resonance point in the neighborhood of two or three thousand meters. This task is by no means a simple one and cannot be recommended to anyone who has not had some experience with this type of work. At the same time it is a very fertile field for experimentation for the man who takes pleasure in this sort of work. There is one important consideration in this construction work which is well worth calling attention to, that is the fact that these transformers are comparatively sharply tuned and it is necessary that their natural wave-length should fall within approximately 100 meters of each other. It is a physical impossibility to wind two coils to exactly the same natural wave-length, due to slight variations in the wire insulation, etc. If the mechanical dimensions of the forms are all the same and exactly the same number of turns are wound on each, the error will not be serious and they will almost always come within 25 or 30 meters of each other. However, it sometimes happens that one coil is wound considerably tighter than the others, or that wire from another lot or possibly a different manufacturer is used, which results in throwing it considerably out of resonance. A simple test for the transformers after they are wound may be made as follows:

Place the transformer in an oscillating circuit by connecting its secondary to the grid and filament of a vacuum tube and its primary to the plate and "B" battery of the same tube, placing a pair of phones in series with the plate circuit. We now have the transformer hooked up as it is in an amplifying circuit, with the exception that both primary and secondary are being used on a single tube instead of between two tubes, and as the primary acts as a feed-back or tickler coil, the circuit will oscillate providing, of course, the primary polarity is correct. Now by using a wavemeter and placing the wavemeter coil over the transformer, that is, just above it, the natural resonant frequency of the transformer may be measured by moving the wavemeter condenser until a click is heard in the phones. When the wavemeter is tuned to resonance with the transformer, it absorbs the energy in the oscillating circuit and at one point stops the circuit from oscillating. This registers as a click in the phones. If there are two distinct clicks, the wavemeter is too close to the transformer and should be lifted until this narrows down to a single click, or two clicks which are very close together, in which case the proper wave-length is one-half way between the two clicks. When the wave-length is noted on the meter, the other transformers may be tested similarly in operation and if they should not fall together, the turns may be decreased on those of higher wave-lengths until they are all approximately matched.

It is not necessary to go through this procedure with the tuned transformer, as the condenser which is used to tune it, can be made to throw the wave-length of this transformer one way or the other to coincide with the rest. While it is not necessary to have the transformers closer than 100 meters, at the same time, due to the fact that when placed in the circuit, variations in tube capacities, sockets, wiring, etc., will make them vary, it is well to have them fairly accurately matched, then any slight variations will not be noticed.

FILTER TRANSFORMERS

A filter or tuned transformer is very necessary when the higher wave-lengths are used, and in this case it is best used in the output, that is immediately preceding the final detector tube. There are two reasons for this. First, as it is necessary to build the high wave inter-stage transformers so that they will cover a wide wave-length band, they give, of course, in themselves very broad tuning and it becomes necessary to have a sharply tuned air core transformer to determine the frequency at which the amplifier will function and to exclude other frequencies.

Second, due to the higher impedance of the longer wave transformers to audio-frequency impulses, such an amplifier will amplify static and other disturbances at an audio-frequency and this becomes very disagreeable when carried through three stages. This objection, however, can be somewhat overcome by using an air core filter transformer in the last stage, that is, coupled to the detector tube, which will have a tendency to suppress the audio frequencies.

The foregoing describes a standard Super-Hetereodyne circuit. There is one change that is commonly made now that makes the circuit more sensitive and selective. This is accom-

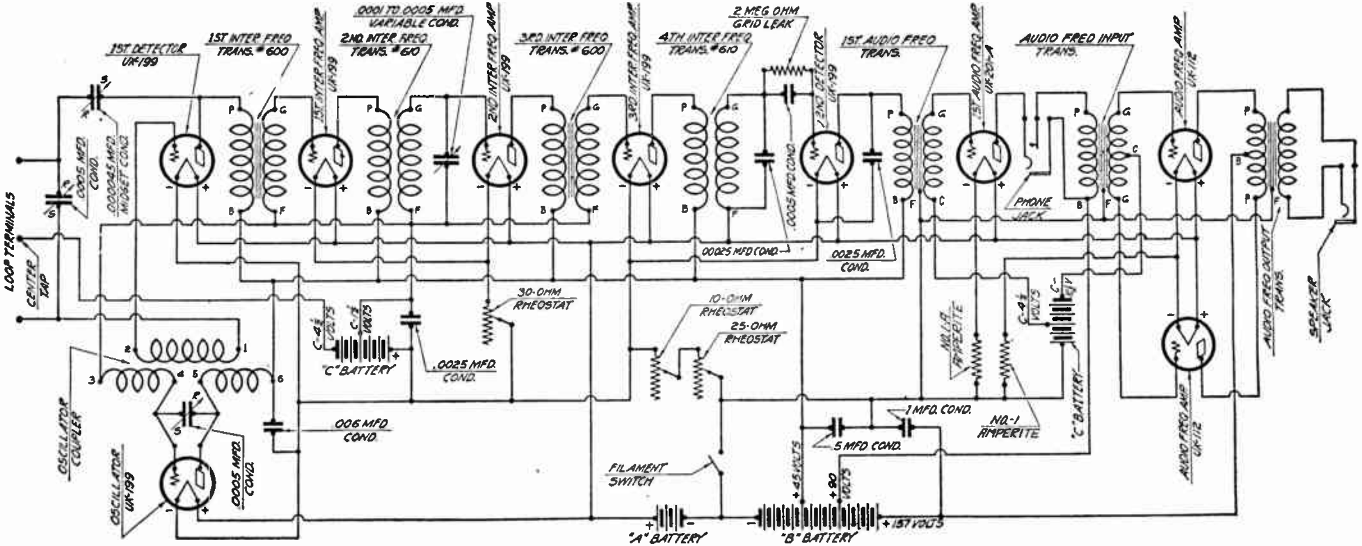

Fig. 7-(a)—Schematic Wiring Diagram of the Remler 45 K. C. Super-Heterodyne Receiver, Using the Rice Split-Loop to Obtain Regeneration.

plished by making the first detector circuit regenerative which increases the amplification considerably and sharpens up the loop tuning condenser. The Rice split-loop method is used or more commonly called the three tap loop method. Regeneration is introduced by a small capacity feed-back from the plate of the first detector through a midget variable condenser to one end of the loop.

If a circuit uses the filter transformer in the input, regeneration cannot take place if the filter transformer is tuned by a fixed condenser across the primary. If regeneration is desired in this circuit, the tuned stage must be placed at the output.

HELPFUL HINTS

While a good Super-Heterodyne is a very simple set to operate, once it has been properly built and adjusted, the layout of the apparatus and the mechanical difficulties encoun-

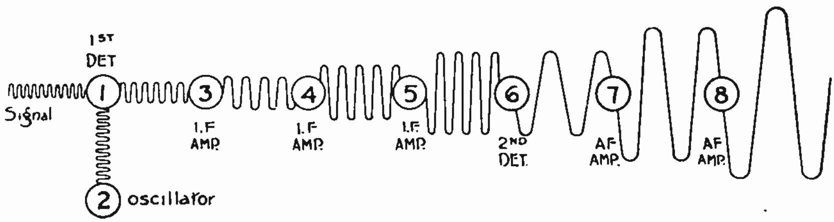

Fig. 8—How the Well-Known Phenomenon of Beats is Produced in a Super-Heterodyne Receiver.

tered in its construction—particularly when it is assembled as a single unit—make it a rather difficult receiver for the average experimenter to successfully construct at his first trial. Without aid he will invariably stumble over the innumerable small technical difficulties which he must necessarily encounter and overcome before his Super has attained that flexibility and ease of control for which it is noted.

VARIOUS TYPES OF THE SUPER-HETERODYNE

While all Super-Heterodynes are built on the same general principle, there are various modifications of them. The difference lies chiefly in the frequency changing section. We will consider a few of the most popular types.

The Ultradyne is a modification of the Super-Heterodyne. It is different in that the first detector does not receive its plate supply from the "B" battery but instead operates with an alternating current plate supply. This alternating current is of radio-frequency and is supplied by an oscillator of the usual type. The action, as explained by Mr. Lacault, the inventor of the circuit, is that the incoming signal through the first detector modulates the radio-frequency from the oscillator. The principal difference of this circuit lies mainly in the absence of a direct current in the detector plate circuit.

The Radiola Super-Heterodyne has some features different from the regular type. This receiver uses a method of reflexing and by using the same tube for both the oscillator

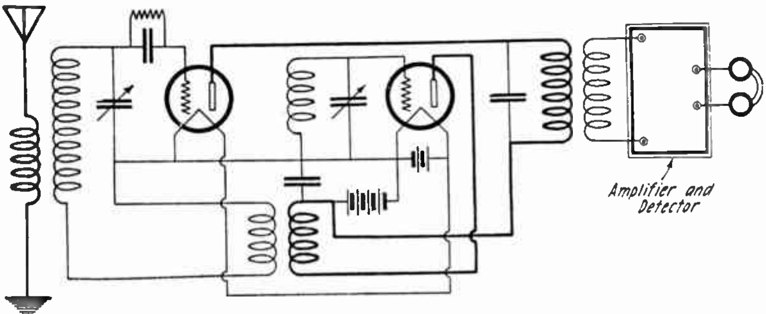

Fig. 8-(a)—Arrangement of the Oscillator and the First Detector in the Usual Super-Hetrodyne Receiver. Contrast This With the Ultradyne Arrangement, Shown in Fig. 8-(b).

and the first detector. This method is explained by Armstrong as follows:

"In view of our knowledge of the self-heterodyne, it appears quite obvious to perform the first rectification by means

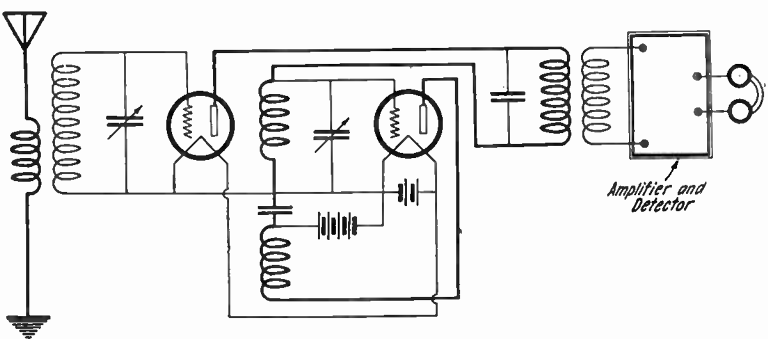

Fig. 8-(b)—Arrangement of the So-called Modulation System Used With the Ultradyne Receiver. No Pick-up Coil and Grid Condenser are Employed and no "B" Battery is Connected With the Modulator Tube, the Plate of Which is Supplied With High-Frequency Current From the Oscillator.

of a self-heterodyne oscillator and thereby save a tube. As a matter of fact, this was one of the very first things tried in France, but, except for very short wave-lengths, it was never very successful when a high intermediate freqeuncy was necessary. The reason was this: If a single tuned oscillating circuit was used, the detuning to produce the proper beat caused a loss of signal strength which offset the gain of a tube. If two tuned circuits were used on the oscillator, one tuned to the signaling frequency and the other arranged to oscillate at the heterodyning frequency, then on account of the relatively small percentage difference in frequency, a change in the tuning of one circuit changed the tuning of the other. The solution of this problem was made by Houck, who proposed an arrangement to connect two tuned circuits to the oscillator, a simple circuit tuned to the frequency of the incoming signal and a regenerative circuit adjusted to oscillate at such a frequency that the second harmonic of this frequency beating with the incoming frequency produced the desired intermediate frequency." The general arrangement is illustrated by Figure 9.

The circuit A is tuned to the incoming signal frequency. Circuit B is tuned to a frequency such that twice its frequency

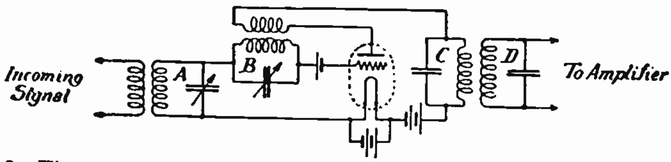

Fig. 9—The Fundamental Circuit of the Second Harmonic Method of Producing the Oscillator Frequency.

is different from the frequency of the signal by the amount of the intermediate amplifier. Thus, if the incoming signal frequency is 1,000 kilocycles and the intermediate frequency is 50 kilocycles, then 1,000 K. C. minus 50 K. C. equals 950 kilocycles. Since 950 is the second harmonic of the frequency to which the circuit B is tuned, then circuit B must be tuned to one-half this or 475 kilocycles. Also if circuit B is tuned to 525 kilocycles, the second harmonic of this is 1,050 kilocycles and when this is mixed with 1,000 kilocycles a beat note of 50 kilocycles is also produced.

By reason of the varied action of the tube, there are created in circuit B a variety of harmonics. The second harmonic combines to produce beats with the incoming signals of the desired intermediate frequency, the tube mixes them to produce the desired intermediate frequency and, through C and D, the new frequency is supplied to the amplifier. On account of the fact that circuits A and B are tuned to frequencies differing by approximately 100 per cent, a change in the tuning of one has no appreciable effect on the tuning of the other. It can be seen from the foregoing that the action of the second harmonic system is fundamentally the same as the ordinary heterodyne system, the only difference being that one tube is used as a detector and oscillator and the second harmonic of the oscillator is used instead of the fundamental frequency. This is accomplished by having a circuit which is tuned to respond to the second harmonic instead of the fundamental. This arrangement solved the oscillator problem and, in addition, practically eliminated radiation.

The next step in the reduction of the number of tubes was to make the radio-frequency amplifier (first tube) perform the function of amplifying at the signal frequency as well as at

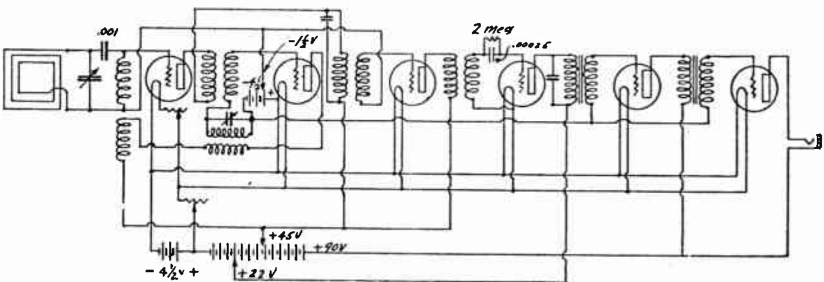

Fig. 10—The Schematic Circuit of the Radiola Super-Heterodyne. This is not a detailed wiring diagram of the set, but shows the general layout of a second harmonic type of Super-Heterodyne Receiver.

the intermediate frequency. This can be done with none of the difficulties inherent in audio amplification as the very small amplitude of voltage handled by the first tube precludes the possibility of the grid becoming positive with respect to the filament. The general arrangement of the circuits for carrying this out is illustrated by Fig. 10. In this arrangement, the signals received by the loop are amplified at radio-frequency by the first tube and applied to the grid of a second harmonic oscillator by means of an untuned radio-frequency transformer. The combined signaling and heterodyning currents are then mixed by the second tube producing a current of intermediate frequency which is applied to the grid of the first tube, amplified therein, and passed on to the second stage of the intermediate frequency amplifier. Thus, the first tube is reflexed and performs the action of double duty amplification. It amplifies the signal before it is heterodyned and by having the tube reflexed it also amplifies the signal at the intermediate frequency.

There are several other types of Super-Heterodynes that use the self-heterodyne principle. Some of them go by the name of Tropadyne, Pressley, Silver Super-Autodyne, etc.

TESTING THE SET

The Intermediate Frequency Amplifier

Let us start by testing the intermediate frequency amplifier. Snap on the filament switch and turn the filament rheostat on until the tubes assume approximately their normal brilliancy. In the case of 201-A tubes, when a 6 ohm rheostat is used, this will be practically all the way around on the rheostat; but if a low resistance power rheostat is used, it should be approximately half on. Next, note the polarity of the potentiometer connections, and move the arm on the po-

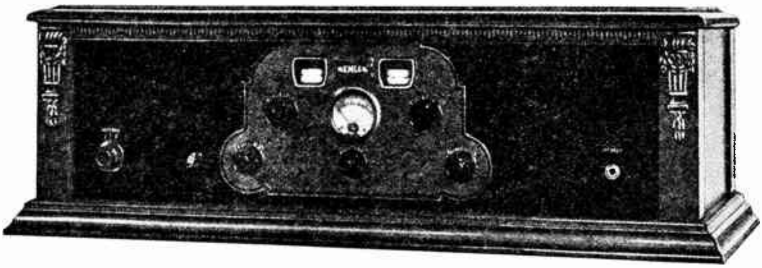

Fig. 11—Typical Super-Heterodyne Receiver.

tentiometer completely over to that side which is connected to the positive "A" battery line. Plug the receivers into the detector jack and proceed as follows:

Move the potentiometer arm gradually around toward the negative end. At approximately half way around, the amplifier should go into oscillation with a slight "hiss" or "click." If a grating sound is heard in the phones as the potentiometer is varied, the potentiometer winding should be cleared with a piece of find sandpaper. The normal operation point of the amplifier is at the position just before the amplifier goes into oscillation, which is found by having the potentiometer arm just on the positive side of the click. If no "click" is heard and the wiring checks out O. K., look for trouble first in the potentiometer itself, making sure that there is an electrical connection between all three posts of the poteniometer, regardless of where the arm is placed. This may be tested with a pair of phones and battery in series, after disconnecting the potentiometer. If the trouble does not lie here, test out the transformers by the same method. When phones and battery are connected across either the primary or secondary windings, a distinct sharp click should be heard—both when this connection is made and when broken.

Assuming that the amplifier is satisfactory, move the potentiometer arm just beyond the point of oscillation, toward the negative side. Now, the entire amplifier is oscillating, and, whenever the grid connection of any of the three radio-frequency transformers is touched, there should be a distinct thud as the finger touches and also as it leaves the post.

The Oscillator

Leaving the amplifier oscillating, test out the oscillator in the following manner: Place the rotor of the oscillation coupler almost all the way in; that is, so that the windings of the stator and rotor are nearly parallel. Now, vary the oscillator condenser slowly over the entire scale. If the oscillator is working properly—that is if it is oscillating—a succession of whistles or heterodyne notes should be heard in the phones as this condenser is varied. If this is not the case and the oscillator wiring checks out correctly, the trouble may be found in the coupler itself. On the stator of this coupler there are two windings—one in the plate and one in the grid circuit. This means that there are four leads that are brought from this stator. If one of these leads where it leaves the tube has rubbed against the preceding turn of wire so as to short circuit it, it will prevent the oscillator from functioning. If this is the case, it will be well to remove one turn of wire from this end of this particular coil, bringing it back through the coil form as previously. In fact, there is sufficient leeway left in the coupler to remove one turn from either end of each of the two coils, if necessary, without reducing the wave-length range to any great extent. If after convincing yourself that the coupler wiring is satisfactory, and it still does not oscillate, try varying the "B" battery potentials; also check up the "B" battery voltage and try turning the tube filaments a bit higher, to make sure that they are at the proper operating point. With so many tubes controlled from a single rheostat, there will be no danger in burning out the filaments or injuring the tubes—even if they are turned all the way on for a short time.

Now, suppose you have both the oscillator and intermediate wave amplifier operating properly, turn back the potentiometer arm toward the positive side until the amplifier stops oscillating, and the set should be ready to receive signals.

Other Sources of Trouble

There are several troubles that are sometimes encountered, even after the amplifier and oscillator are performing properly. The most common of these is defective tubes. A bad tube should be suspected above all else, as it is the easiest test to make and occurs quite often. The tube may not be worthless; but its characteristics may be so different from the other tubes used in the circuit that it will not operate satisfactorily with them. And again, a tube which might operate quite satisfactorily as an audio-frequency amplifier or detector might not work properly as an oscillator. Therefore, do not neglect to change tubes when hunting trouble in either the amplifier or oscillator; and also, after the set is operating, change the tubes around until the best possible combination is found. One or two spare tubes are very valuable assets for this purpose.

An infrequent source of trouble is found in the grid condensers and leaks, as either of these is liable to be defective or open-circuited, and occasionally in the case of condensers, short-circuited. Good fixed grid leaks should be used, and, as a general rule, it will be found that a value of about two megohms is satisfactory for the second detector tube and about five megohms for the first detector tube. Do not omit the by-pass condenser from the plate to the negative filament on the last detector tube—otherwise, the set will be unstable and hand capacity will be noticeable.

If the set does not tune sharply, or poor volume is obtained, it can usually be traced to the fixed condenser, across the tuned transformer. These small fixed condensers are bound to vary somewhat in capacity. A small variation in the capacity here will have no bad effect on the operation of the set; but occasionally a condenser is obtained which is so far off as to seriously affect the operation of the circuit.

This can be checked by temporarily placing a .001 variable condenser across the terminals of the intermediate frequency transformer which is tuned. The capacity of the variable condenser should be varied until maximum signal strength is obtained. If it is necessary to use the entire capacity of the variable condenser then a .001 fixed condenser should be placed in parallel with the condensers and the variable condenser varied again until maximum signal strength is obtained. Thus, it is possible to determine the exact capacity necessary to tune the tuned transformer to exact resonance.

Whenever a potentiometer is inserted in the "B" battery lead it should have connected across its terminal a large fixed condenser so as to by-pass the radio-frequency current. The capacity of this by-pass condenser should not be smaller than .005 mfd. and preferably should be .5 mfd. or larger.

In constructing a Super-Heterodyne, one should not attempt to make the transformers or oscillator, unless he has had considerable experience in radio construction and designing. It is best to buy a complete Super-Heterodyne kit. In addition to the instruction given in the kit, the following may be helpful:

It is best not to use too high plate voltage on the detector tubes and on the oscillator tube. Clearer and sometimes louder signals are obtained by using 45 volts or less. If the oscillator does not work, check over the wiring and be sure that the by-pass condenser from the "B" battery plus to the filament is used. The tubes should be switched around for best results. Oftentimes a tube will work good as an amplifier, but not so good as an oscillator, or detector, or vice versa.

The so-called first detector can be operated as a bias detector or as a detector using the grid leak and condenser method. Experience has proven that the set is slightly more sensitive when using the grid leak and condenser method of detection. However, the loop or antenna tuning sometimes is quite broad when using this method of detection. It has been proven that by using the bias method of detection and using a very large negative bias such as something between -6 and -10 on the grid of the first detector tube the loop or antenna tuning can thus be materially sharpened.

A five megohm grid leak should be used on the first detector and a two megohm on the second detector.

A potentiometer for controlling oscillation of the I. F. tubes should be used in nearly all cases as it is an efficient means of controlling volume and stability.

One rheostat is usually sufficient if the same types of tubes are used throughout. A two ohm rheostat is used for the 201-A tubes and a six ohm rheostat is used for the 199 type.

Low ratio transformers should be used in the audio amplifier. Any type that has a turn ratio of not more than four to one is satisfactory. If the amplifier howls or wheezes, it may be necessary to reverse the connections on the primaries of the audio transformers. A .0025 mfd. condenser across the primary of the second stage transformer often helps.

In many Super-Heterodynes using two stages of transformer-coupled audio-frequency amplification, the quality is none too good in the last stage. A simple and cheap way to improve this condition is to use impedance-coupled amplification in the last stage. The audio transformer is still used

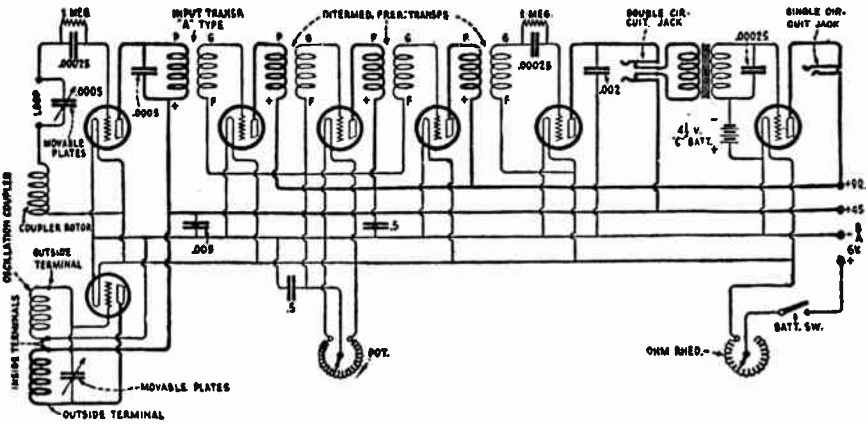

Fig. 12—Circuit Diagram of a Seven-Tube Super-Heterodyne Receiver.

as a choke coil for audio-frequencies. This will greatly improve the audio-frequency signals. Only the secondary of the transformer is used as this has sufficient impedance to prevent the passage of audible frequencies, thereby forcing them on to the grid of the next tube through the blocking condenser.

A grid leak of about one megohm is used on the last tube. The blocking condenser may be any value large enough to handle the current, about a .006 mfd. is satisfactory.

Short Wave Reception

There are several broadcasting stations experimenting with short wave-lengths in the neighborhood of 100 meters, and it is entirely possible to obtain good reception at these wave-lengths with this outfit, particularly when the above method is used to reduce the minimum capacity of the oscillator condenser. To do this, it is merely necessary to provide a tap on the loop, which will allow the two outside turns to be used, that is, only two turns of the loop are across the tuning condenser, the rest being left open. Now if the oscillator is tuned to what is normally the proper point for 200 meter reception, wave-lengths of 100 meters may be received. This is due to the fact that the double frequency harmonic of the oscillator will heterodyne these signals and bring them through the Super in exactly the same manner as when using the fundamental frequency.

TEST QUESTIONS

Number your answer sheet 21 and add your **Student Number.**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Why is an oscillator used in a Super-Heterodyne Receiver?
2. What is the function of the intermediate wave amplifier?
3. Draw a circuit diagram of an oscillator and frequency changer as used in the Super-Heterodyne.
4. Explain the principle of the Super-Heterodyne Receiver and its advantages.
5. Why are iron core transformers used for radio-frequency amplification in the Super-Heterodyne Set?
6. Draw a circuit diagram of a Super-Heterodyne Receiver using six tubes.
7. What is the principal difference and advantage of using a six tube receiver?
8. Explain what is meant by the second harmonic method of producing the oscillator frequency.
9. How can the quality of the audio-frequency signals be improved?
10. What changes would you make in this type of set for reception of short wave-lengths?

Change [illegible] to a value
suitable for desired wavelength

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ELEMENTARY RADIO MEASUREMENTS

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WRITE AND ANSWER QUESTIONS

A Personal Message from J. E. Smith

When one has finished studying a book, it is worthwhile to go over the list of chapters and write a series of questions dealing with each chapter, and then, of course, answer these questions. The ability to ask pertinent questions about a subject is often an indication of clearer understanding of it than the mere statement of facts and theories about it.

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ELEMENTARY RADIO MEASUREMENTS

You have progressed far enough in your course in practical radio and now are undoubtedly interested in measuring some of the things we have been talking about in the previous lessons. You might think that this would be very difficult and would require extremely elaborate apparatus. While it is true that complicated apparatus is necessary for certain types of radio measurements, there are many interesting and valuable experiments which can be performed by the aid of inexpensive measuring apparatus. We will now discuss the construction and calibration of some measuring sets which you will find very valuable in connection with your work.

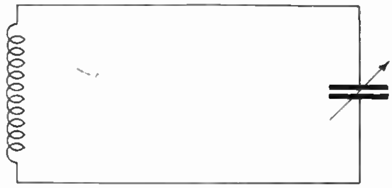


Fig. 1—Basic circuit for a frequency or wave meter.

THE MEASUREMENT OF FREQUENCY OR WAVE LENGTH

In the early days of radio communication, radio stations were designated by their wave lengths and the term frequency was but little used. Devices for measuring wave lengths were called **wave-meters.** The same devices when calibrated to measure in terms of frequency are now known as **frequency meters.** In general the apparatus involved in either case is the same. No matter what phase of radio communication you happen to be interested in, you will want to be able to measure the frequencies produced by radio stations or to calibrate receiving apparatus in terms of frequency or wave length. **In view of the recommended exclusive use of frequencies to designate stations, we suggest that you calibrate such circuits as you construct in terms of frequency and not in terms of wave length.**

You have already learned that if an inductance is connected to a condenser the resulting circuit is oscillatory if the resistance is low and the circuit responds best to a particular frequency. If the condenser is charged and allowed to discharge through the inductance the circuit will produce oscillations of this frequency. In Fig. 1 the inductance is shown as fixed in value while the condenser is shown as variable. This is the usual method of construction. The frequency to which such a circuit is resonant is as follows:

Frequency = 159,154 divided by a square root of the product obtained by multiplying the inductance of the coil in microhenries by the capacitance of the condenser in micro-microfarads.

If you like the algebraic method of presenting a formula of this type then the frequency in kilocycles is given by:

$$f = \frac{159{,}154}{\sqrt{LC}} \qquad (1)$$

in which

f is frequency in kilocycles.

L is inductance in microhenries.

C is capacitance in micro-microfarads.

If, however, we desire to compute the wave length to which the circuit is resonant we use the following formula:

Wave length in meters equals 1.885 times the square root of the product obtained by multiplying the inductance of the coil in microhenries by the capacitance of the variable condenser in micro-micrafarads.

The algebraic expression for the above statement is:

$$\text{Wave Length} = 1.885\sqrt{LC} \qquad (2)$$

Variable condensers of many types are on the market and can be purchased at very reasonable prices. The movable plates of some condensers are semi-circular while others are specially cut in different ways. Figure 2 shows the form of rotary condenser plates which are semi-circular. The capacitance of such a condenser will vary directly with the condenser reading. This will be explained shortly. Figure 3 shows the form of condenser rotary plates for which the capacitance varies as the square of the angular displacement, that is, as the square of the condenser dial reading.

For the purposes of our experiment let us select a variable condenser in which the rotary plates are semi-circular. Figure 4 shows a calibration curve for such a condenser having a maximum capacitance slightly less than 500 micro-microfarads. Note that over a large portion of the graph we have a straight line. Where one variable varies directly as another then the resulting graph is always a straight line. In this case the capacitance varies directly as the angular displacement, that is, as the dial

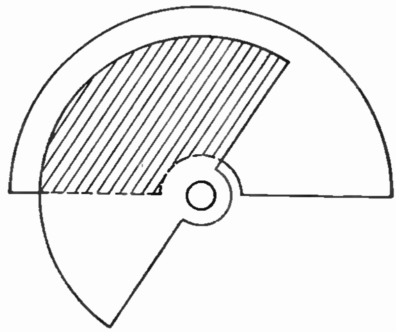


Fig. 2—Form for rotary condenser plates for which capacitance varies directly as the angular displacement.

reading. The curve slopes toward the horizontal at the top and bottom due to what is known as the "end effect" of the plates. This is a term used to account for the departure from the "straight" line characteristic due to the effect of the ends of the

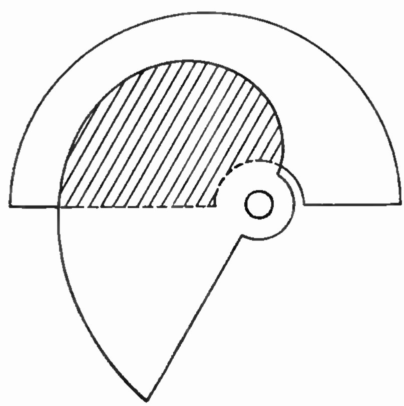


Fig. 3—Form of rotary condenser plates for which capacitance varies as the square of the angular displacement.

plates when the dial is set at 0 or at the maximum reading. Figure 4 is not meant to represent any particular condenser. As a matter of fact, the calibration curve has been so drawn as to permit the easy determination of the values of capacitance for particular dial settings.

DESIGN OF A COIL FOR USE WITH A FREQUENCY METER

Having selected a variable condenser for our frequency meter and having obtained the calibration curve given in Fig. 4, from the manufacturer or from some laboratory, our next problem is to choose a suitable inductance for use with this condenser. The value which this inductance must have will depend upon the frequency range we desire to cover with our frequency meter. If we are interested in a wave-meter, it will depend upon the wave length wave range we desire to cover. Let us assume that we are interested in obtaining a frequency meter which will cover as much of the broadcast band (that is the band lying between 550 kc. and 1,500 kc.) as it is possible to cover with a single coil and let us further assume that we are more interested in covering the frequencies nearer the lower end of the band than those toward the upper end. Our first step then is to calculate the value of inductance which with some capacitance near the maximum capacitance of the condenser will tune the circuit for a frequency of 550 kc. This is calculated as follows:

Inductance equals 25,330,000,000 divided by the product obtained by multpilying the capacitance in micro-microfarads by the square of the frequency in kc. or

$$L = \frac{25,330,000,000}{C \times f^2} \qquad (3)$$

The same notations apply to the algebraic letters as in Formula 1.

We desire that our frequency meter shall easily extend down to 550 kc. Referring to Fig. 4 we note that our condenser has a maximum capacitance slightly less than 500 micro-microfarads. Let us therefore design our inductance so that the frequency meter will tune down to 550 kc. with a capacitance of 460 micro-microfarads. Using Formula 3, we find that this requires a fixed inductance of 182.0 microhenries.

The proper value for inductance can also be obtained without the aid of formula 3, from Table 2 given in text-book No. 16 entitled "Inductance and Condenser Design" which you have already received. In Table 2 of Text No. 16 the L C product is shown for each frequency in the kc. column. You will note that opposite the frequency 550 kc. the figure .083734 is given as the L C product. In that table however capacitance is given in microfarads instead of in micro-microfarads. 460 micro-microfarads equal .00046 microfarads. Dividing .083734 by .00046 gives 182.0 microhenries, the same value we obtained from Formula 3.

Our next problem is to design a coil which will have an inductance of approximately 182.0 microhenries. This can be done by the aid of the graphs given on Pages 25, 26, 27 and 28 of the text-book entitled "Inductance and Condenser Design" already referred to. Let us assume that we have available a cylindrical form which has an outside diameter of two inches. Figure 15 on Page 26 of the text we have just mentioned gives the design data for coils two inches in diameter. Referring to the

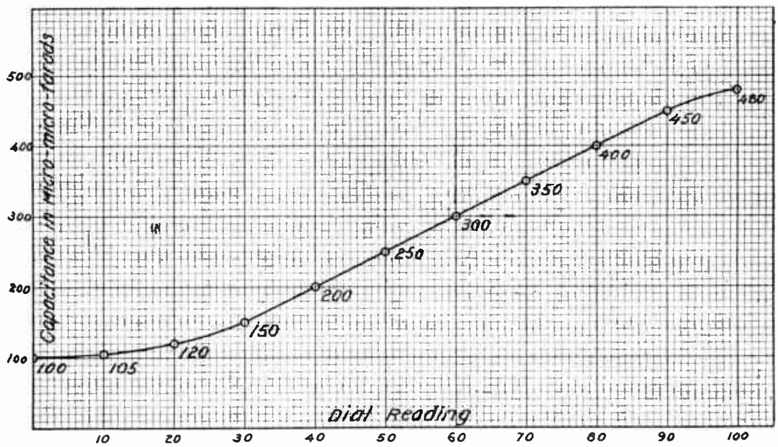


Fig. 4—Possible calibration curve for a variable condenser having a maximum capacitance slightly less than 500 micromicrofarads.

ordinates giving inductance in microhenries note the value corresponding to 180 microhenries. A line extended from this point to the right will intercept the curve for a coil 3 inches long where the abscissa is 27.5 turns per inch. The same line intercepts the curve for a coil two and one-half inches long where the abscissa is 31 per inch, and the curve for coils 2 inches long where the abscissa is 36 turns per inch. This means that (a) a three-inch coil on a 2-inch diameter forming 27.5 turns per inch will have an inductance of 182 microhenries (b) a 2½-inch long coil of wire wound on a 2-inch coil having 31 turns per inch will also have 182 microhenries and (c) a 2-inch long coil wound on a 2-inch diameter form having 36 turns per inch will also have an inductance of 182 microhenries.

Referring now to Table 3 given on Page 28 of Lesson

Text 16, you will note that 27 turns per inch can be obtained by using No. 20 B and S single cotton covered wire, that No. 22 B and S double cotton covered wire will give 30 turns per inch and No. 24 B and S double cotton covered wire will give 35.6 turns per inch. On the basis of the wire you have available you can therefore easily wind a coil having an inductance of approximately 182 microhenries. If you have available forms of 3 inches diameter or some other value you can easily determine the size of wire and the number of turns that will be necessary using the graphs given on pages 25, 26 and 27, Text-book No. 16.

We now have available a variable condenser having a maximum capacitance slightly less than 500 micro-microfarads, the calibration curve for which, is given in Fig. 4 and in addition a fixed inductance of 182 microhenries which can be used with this condenser. Inasmuch as we may desire to use other coils with the same condenser it may be found desirable to mount the condenser rigidly on a form and to provide single contact plugs and jacks so that the coils may be readily interchanged. If plugs and jacks are not available then binding posts may be connected in such a way as to permit rapid changing of coils.

CALCULATION OF FREQUENCY AND WAVE LENGTH CURVES

You will become most thoroughly acquainted with the action and calibration of frequency meters if we now calculate calibration curves for the condenser and coil combination we have been discussing. For practice we will not only calculate and plot a frequency curve but also a wave length curve, although it is recommended that only frequency curves be used in actual practice. Let us continue to assume that the curve given in Fig. 4 is the calibration curve for the variable condenser we are using and that upon measurement we find that the coil we have designed has an inductance of 180 microhenries, instead of 182 microhenries which we calculated would be the correct value. An inductance of 180 microhenries is entirely suitable for our purposes.

The information contained in Table No. 1 has been calculated from data obtained from the calibration curve for our condenser (Fig. 4) and the known inductance of our coil. From the condenser curve we determine the capacitance for readings ten degrees apart on the dial. Thus the figures appearing in Column 1 are 100, 90, 80, etc. Column II shows the capacitance of the condenser for each of these dial settings. Column III shows the

L C product obtained by multiplying each of the capacitances by the inductance we are to use which is 180 microhenries. Column IV is obtained by taking the square root of the figures shown in Column III. Column V shows the frequency for which the circuit will resonate for each dial setting as calculated by means of Formula 1. Column VI shows the wave length for each of the dial settings as calculated by the use of Formula 2.

TABLE NO. 1

Calculations for Data for Drawing Calibration Curves for Frequency and Wave-meters.

Using 180 Microhenry Coil, with Condenser Having Calibration Curves Shown in Fig. 4.

I Condenser Dial Reading	II Capacitance in Micro-microfarads	III L X C	IV $\sqrt{LC}$	V Frequency in KC=$\frac{159,154}{\sqrt{LC}}$	VI Wave Length in Meters= 1,885 $\sqrt{LC}$
100	480	86,400	293.94	541.45	554.07
90	450	81,000	284.60	560	535.47
80	400	72,000	268.32	593.15	505.78
70	350	63,000	250.99	634.10	473.11
60	300	54,000	232.37	684.92	438.02
50	250	45,000	212.32	749.59	400.22
40	200	36,000	189.73	838.84	357.64
30	150	27,000	164.31	968.62	309.72
20	120	21,600	146.99	1082.75	277.08
10	105	18,900	137.47	1157.73	259.13
0	100	18,000	134.16	1186.30	252.89

Let us now plot a curve which will give us frequencies for all possible dial settings of the condenser. We consider a dial setting as the independent variable and the corresponding frequency of our combination the dependent variable. Dial settings will therefore be plotted along the X axis while frequencies will be plotted along the Y axis. Referring to Columns I and V (Table No. 1) you will note that the frequency corresponding to a dial setting of 100 is 541.45 kc. We cannot, of course, plot this figure more accurately than if it were 541 kc. unless we used a very large sheet of paper. We first read out the X axis to the point marked 100 and then read vertically 541 division and there make a circle as is shown in Fig. 5. The circle corresponding to the setting we have just described is at the extreme right end of the curve. Referring again to Columns I and V we note that a dial setting of 90 corresponds to a frequency of 560 kc. We then read out the X axis to 90 and then up 560 division and make another circle. This is the circle to the left of the one just mentioned. In a similar manner the other figures shown in Column V are plotted as functions of the figures shown in Column I, Table No. 1. A curve is then drawn joining all of the circles and the result is Fig. 5. Should we desire to use our condenser coil combination as a wave-meter we obtain a curve as is shown in Fig. 6 by plotting the data shown in Column VI of Table 1 as a function of the corresponding dial settings shown in Column 1. We can then use either Figs. 5 or 6 depending upon whether we are interested in frequencies or wave lengths.

Assume now that we desire to set our frequency meter so that it will resonate to a frequency of 900 kc. We first read vertically up the Y axis until we reach the 900 kc. line. We extend this line to the right until it strikes the curve as is shown in Fig. 5. We then turn our line at right angles and extend it down parallel to the Y axis until it strikes the X axis where we note the reading. In this case the reading on the X axis is 35. If we now set the dial on the condenser incorporated in our frequency meter at 35 degrees the circuit will be resonant to 900 kc.

Suppose, however, that we have adjusted our frequency meter to some source, the frequency of which is unknown to us and find that resonance occurs when the condenser dial is set at 66.5 degrees. To find the frequency corresponding to this we project a line up from the 66.5 mark on the X axis until it strikes the curve and then to the left until it strikes the Y axis where we read the correct frequency. In this case we find that our unknown source possesses a frequency of 650 kc. The wave length curve shown in Fig. 6 can, of course, be used in the same way if we are interested in wave lengths rather than frequency. Bear in mind that we have as yet not discussed any method of detecting resonance in our frequency meter. This will be discussed shortly.

You will note that the frequency meter we have made, using a 180 microhenry coil with the condenser having a calibration curve such as shown in Fig. 4, will not cover the entire broadcast band lying between 550 and 1,500 kc. It will not tune to frequencies above 1,186 kc. We can, however, easily extend the range of our frequency meter by designing and building a coil of somewhat lower inductance than our 180 microhenry coil.

The maximum capacitance we can obtain from our condenser is obtained by setting the condenser dial at 100, when the capacitance will be 480 micro-microfarads. Since it is desirable to have a certain amount of overlapping of the ranges covered by a frequency meter using more than one coil, let us determine the inductance of a coil which, when connected across a condenser having a capacitance of 480 micro-microfarads, will give a circuit resonant to 1,100 kc. The frequency range between 1,100 and 1,185 kc. can then be covered either with our 180 microhenry

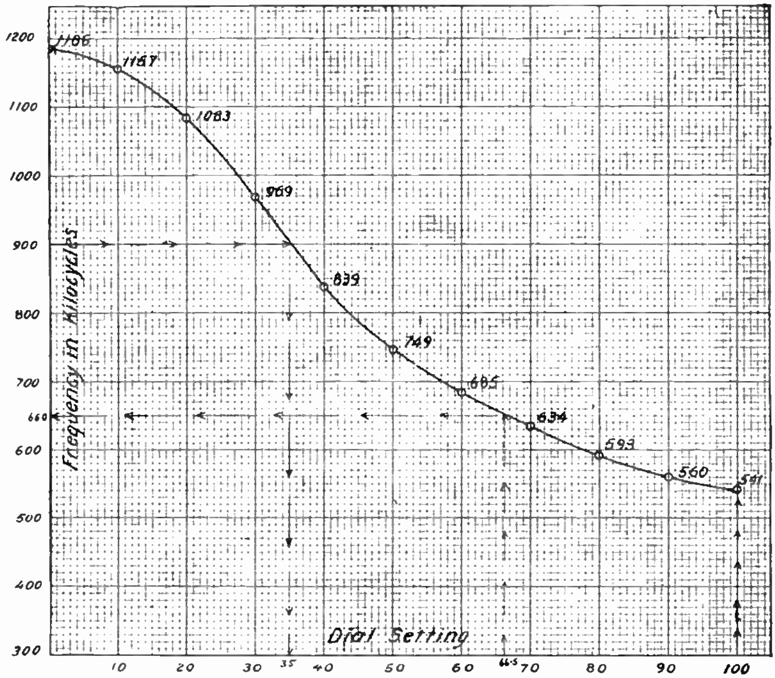


Fig. 5—Calibration curve for frequency meter using a coil of 180 microhenries with condenser having calibration curve shown in Fig. 4.

coil or with the new coil, the inductance of which we will now calculate.

Using Formula 3 we have:

Inductance equals 25,330,000,000 divided by the capacitance (480) multiplied by the square of the frequency (1,100 x 1,100), or:

$$L = \frac{25{,}330{,}000{,}000}{480 \times 1{,}100 \times 1{,}100} = 43.61 \text{ microhenries} \qquad (4)$$

Our new coil should therefore have an inductance of 43.61 microhenries. With this information, the size of wire, number of turns and diameter of coil can be determined using the data given in the text, "Inductance and Condenser Designs."

If we desire to find the **highest** frequency in kilocycles to which our frequency meter will resonate with this new coil, we refer again to Formula 1 and use in this formula the new value for inductance 43.61 microhenries and the **minimum** capacitance we can obtain from our condenser. This minimum capacitance will be obtained when the condenser dial is set at 0, which, as can be seen from Fig. 4, will be 100 micro-microfarads. Formula 1 states:

Frequency equals 159,154 divided by the square root of the quantity (LC) obtained by multiplying 43.61 microhenries by 100 micro-microfarads or $43.61 \times 100 = 4361.00$ $\sqrt{4361.00} = 66.0378$.

$$F = \frac{159{,}154}{\sqrt{43.61 \times 100}} = \frac{159{,}154}{66.0378} = 2{,}410 \text{ kilocycles.} \qquad (5)$$

Our new coil when used with our condenser will, therefore, cover the range extending from 1,100 kc. up to 2,410 kc. In a similar manner, coils can be designed which will cover the frequencies below 550 kc.

If you have received the radio apparatus which we send to our students, you can easily construct a frequency meter using one of the variable condensers and one of the coils you have wound. The condenser ordinarily supplied has a capacitance of approximately 350 micro-microfarads. The coil which you have built probably has about 71 turns of No. 24 double cotton covered wire wound on a form 2½ inches in diameter. The coil will be approximately 2 inches long.

By the aid of the design data already referred to, you can determine that the inductance of the coil will be approximately 245 microhenries. A coil of 245 microhenries used with a condenser having a capacitance of 350 micro-microfarads will, according to Formula 1, resonate at a frequency of 543.4 kc. when the condenser is set to give the maximum capacitance.

The condenser and coil you have may possess characteristics slightly different than those given in the above paragraphs but you will find that the coil has an inductance such that the circuit will cover at least most of the broadcast band with the condensers supplied to you. The condenser very probably has its plates cut quite differently from those illustrated by Fig. 2. They may be so cut as to result in a calibration curve showing frequency as a function of the condenser dial setting which is nearly straight. Such a condenser is often referred to as a "straight line frequency" condenser. See if you cannot think of the advantages possessed by such a condenser when used in a broadcast receiving set.

Very probably you do not have a capacitance calibration curve for the condenser you have nor will you know the exact inductance of the coil used with this condenser. You may then

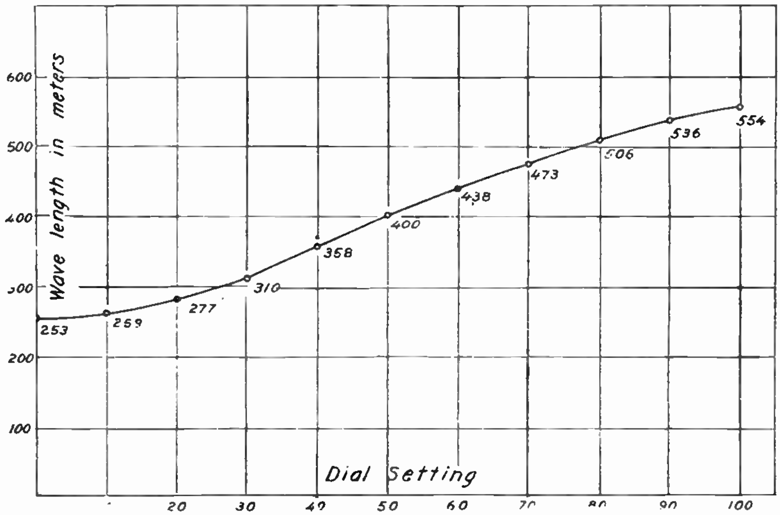


Fig. 6—Calibration curve for wavemeter using coil of 180 microhenries with condenser having calibration curve shown in Fig. 4.

very properly ask how a calibration curve covering the use of this coil and condenser as a frequency meter or as a wave-meter can be obtained. A little later in this lesson we will consider in detail a method by which you can easily calibrate a frequency meter for broadcast frequencies without knowing the inductance of the coil or possessing a capacitance calibration curve for the condenser. Before discussing this, however, let us consider some of the auxiliary apparatus that may be associated with our very simple condenser coil circuit.

The circuit we have been discussing is the basic circuit incorporated in practically all frequency and wave-meters. Ordinarily certain auxiliary apparatus is associated with an oscillatory circuit, the type of apparatus depending upon the particular use to which the meter is to be put. However, as we shall see later, the condenser-coil circuit in its simplest form as shown in Fig. 1 is often used; the auxiliary apparatus for detecting resonance being incorporated in other circuits.

USE OF A FREQUENCY METER WITH A THERMAL GALVANOMETER

A very common use for a frequency meter is for the measurement of the frequency transmitted by a radio transmitting station. Frequency meters intended for this purpose usually have a thermal galvanometer or a hot wire meter connected in series with the circuit as is shown in Fig. 7. **The meter is placed near the transmitter and the dial of the condenser varied until the maximum reading of the thermal galvanometer is obtained.** The dial reading at which this occurs is then noted and the frequency corresponding to this dial reading is obtained from the calibration curve according to the method already described. If it is desired to adjust the transmitter to a particular frequency then the dial reading for this frequency is obtained by noting the desired frequency on the Y axis, extending a line to the right to the curve and then down vertically parallel to the Y axis until it strikes the X axis where the corresponding dial setting is observed. The dial on the meter is then set for this value and the frequency control of the transmitter varied until the maximum reading on the galvanometer is obtained. The frequency radiated by the transmitter will then correspond to the frequency for which the frequency meter is adjusted.

There are one or two important facts to be noted in connection with the use of frequency or wave-meters of the type we have been discussing. In the first place it is essential that the frequency meter be not placed too close to the transmitter. Otherwise the current in the galvanometer may be so high as to cause damage to the galvanometer when the circuit is tuned to resonance.

Due to resistance in the circuit it is often difficult to determine the exact point of resonance. Because of this fact frequency meters of this kind are not ordinarily accurate enough for adjusting radio broadcasting stations. Too great an error in setting is likely to result. Consequently frequency meters of this type are not recommended for use under modern broadcasting conditions although they have very wide uses for other purposes. Meters which will meet modern conditions in the broadcast field will be described in later text-books.

USE OF A BUZZER AND BATTERY WITH A FREQUENCY METER

A very common use of a frequency or wave-meter is for the production of radio frequency energy of known frequency. One of the simplest ways of doing this is to incorporate with a circuit such as is shown in Fig. 1 a small buzzer and a dry cell or two as is shown in Fig. 8. The method by which a circuit of this type produces radio frequency energy has been described in a previous text-book. During the period when the buzzer contacts are closed a current from the dry battery flows through the coil. This current also flows through the winding of the buzzer causing the buzzer contact to open. Due to the inductive effect of the coil the current tends to flow even after the contact has opened and since it cannot flow through the buzzer circuit it flows into the condenser. Since the resistance of the circuit is

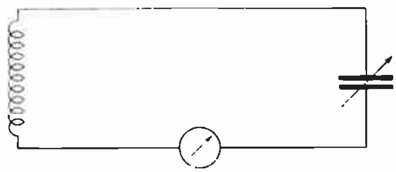


Fig. 7—Frequency meter circuit with thermal galvanometer for the measurement of frequency at a radio transmitting station.

very low the condenser will first charge up on one side then discharge through the coil and charge on the other side. We will therefore have an oscillatory discharge of the condenser through the coil and the frequency produced by the oscillation will be approximately as computed by Formula 1.

As has already been mentioned in previous texts the frequency produced by such a device is referred to as "damped." In addition to the one frequency for which the circuit is tuned there will be produced others of approximately the same value. As a result a device of this kind is said to tune rather broadly. For this reason its use is somewhat limited to measurements where a high degree of accuracy is not required. However, frequency meters of this type require so little apparatus and can so conveniently be used for a number of simple measurements that you will probably find it of interest to construct one.

You will note that we have used the term "frequency meter" almost to the exclusion of the term of "wave-meter" and that all of our instructions have applied to the construction and use of "frequency meters" rather than "wave-meters." This is in accord with the universal policy of recommending the use of frequencies in designating radio stations rather than the use of wave lengths. Unless you have already done so, you will find it to your advantage to adapt yourself as rapidly as possible to thinking in terms of "frequencies" rather than "wave lengths." Were it not for the fact that there are still in use many meters calibrated in terms of wave lengths we would use the term still less frequently in our lessons than we do.

A SIMPLE VACUUM TUBE RADIO FREQUENCY GENERATOR

We have shown by connecting a buzzer and a battery to our basic frequency meter circuit how we can produce damped waves of known frequency. However, the use of damped waves for radio measurements is open to the objections we have already pointed out. A much more suitable source of radio frequency energy can be obtained by incorporating our basic frequency meter circuit with a vacuum tube in such a way that the tube produces undamped radio frequency energy. Energy of this type will be free from the objections we have pointed out above and therefore far more suited to radio frequency measurements. Vacuum tube circuits which can be used to produce energy such as has been described are known as **vacuum tube radio frequency generators or vacuum tube oscillators.**

Figure 9 shows the circuit for a radio frequency generator which will be found very useful. The way in which a vacuum tube produces high frequency continuous waves has been thoroughly discussed in previous lessons. We will therefore concern ourselves now only with the details of operation of the circuit and not with the fundamental theory involved. For our purposes we may assume that we have substituted a vacuum tube and a couple of batteries in place of the buzzer and batteries in Fig. 8. The result as we have seen is that we now generate continuous waves instead of damped waves.

We have learned that if we used buzzer excitation the frequency produced would be approximately that determined by the value of inductance and capacitance used. However, since the buzzer circuit has some capacitance, the calibration curve for a circuit consisting of a condenser and coil alone will be somewhat different from the curve for a circuit using the same condenser and coil with a buzzer and a battery. It is also true that the incorporation of a vacuum tube with the associated batteries will result in a calibration curve somewhat different from that obtained when using the coil and condenser alone. In fact, the addition of the vacuum tube and batteries will have a greater effect upon frequency than will the buzzer and battery. If it is necessary that the frequency produced by a vacuum tube generator be known fairly accurately then the same vacuum tube should be used at all times and the filament and plate voltages should be kept at the same value. If very accurate results are desired, voltmeters should be connected across the filament terminals and across the plate battery as is shown in Fig. 9 by the

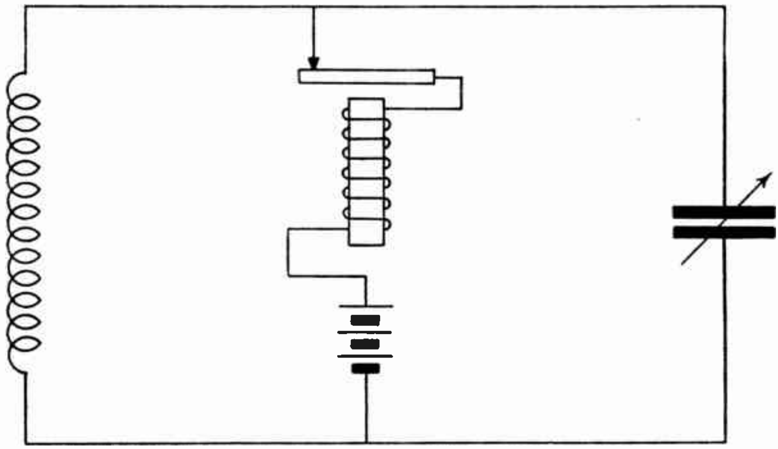


Fig. 8—Buzzer excited frequency meter circuit.

dotted lines. The voltmeter shown across the plate battery is, however, not so necessary as the one across the filament.

The above precautions are necessary if accurate measurements are desired. However, they are not necessary for the experiments we are going to discuss. It is possible to design vacuum tube oscillator circuits so that the frequency produced will not vary to any appreciable extent with the filament or plate voltage or even if different tubes are used in the circuit. Such circuits, however, require more apparatus than the one shown in Fig. 9, and, inasmuch as we are now primarily concerned with the simplest of radio measurements, we will reserve the more complicated circuits for later study. The vacuum tube circuit we have given is entirely practical and will permit you to make a number of very interesting experiments and to secure much valuable information.

The parts necessary for the vacuum tube generator shown in Fig. 9 are as follows:

T—One vacuum tube 199 type.

—One vacuum tube socket.

C—One variable condenser maximum capacitance 350 micro-microfarads.

L—One coil of approximately 245 microhenries (72 turns of No. 24 wire on a cylindrical form 2½ inch in diameter) tapped near the center of the coil. Note: If tap is not at center connect the smallest section of the coil between the grid and filament.

R—One filament control rheostat approximately 30 ohms.

A—Three dry cells for lighting filament of tube.

B—Two 22½ volt "B" batteries for plate voltage.

One baseboard of wood about 10 inches square.

One panel large enough to mount condenser.

If desirable the following may also be used:

VM_1—Filament voltmeter 0-5 volts.

VM_2—Plate voltmeter with switch 0.50 volts.

Figure 10 shows a very simple radio frequency generator such as we have just described. This was constructed at the National Radio Institute using parts such as are sent to National Radio Institute students. In order that there might be plenty of space available upon which to mount both "A" and "B" batteries, the standard 18-inch panel with the wooden baseboard 10 inches wide was used. Except where a high degree of portability is desired, much trouble is avoided by allowing plenty of space for apparatus.

There are many ways in which we might modify the simple circuit shown in Fig. 9 and greatly increase its usefulness. Since continuous waves will not ordinarily produce any sound in the head-set or loud speaker of a radio receiving set unless some special form of reception such as heterodyne reception is used, it is very convenient to be able to modulate the output of an oscillator as shown in Fig. 9, so that signals from it can be readily detected in an ordinary broadcast receiving set. A very convenient method of doing this is to connect a buzzer as is shown by the dotted lines in Fig. 9. The buzzer is so connected that it is energized by one of the "A" batteries. The making and breaking of the buzzer contacts periodically shorts the plate circuit coil. The interruptions can, of course, be clearly heard in any receiving set. If you have available a key and buzzer set such as used by students studying the continental code, you can readily modulate the output of the oscillator shown in Fig. 9 by connecting the extreme left-hand binding post of your buzzer and key set to the + terminal post of the "A" battery which has

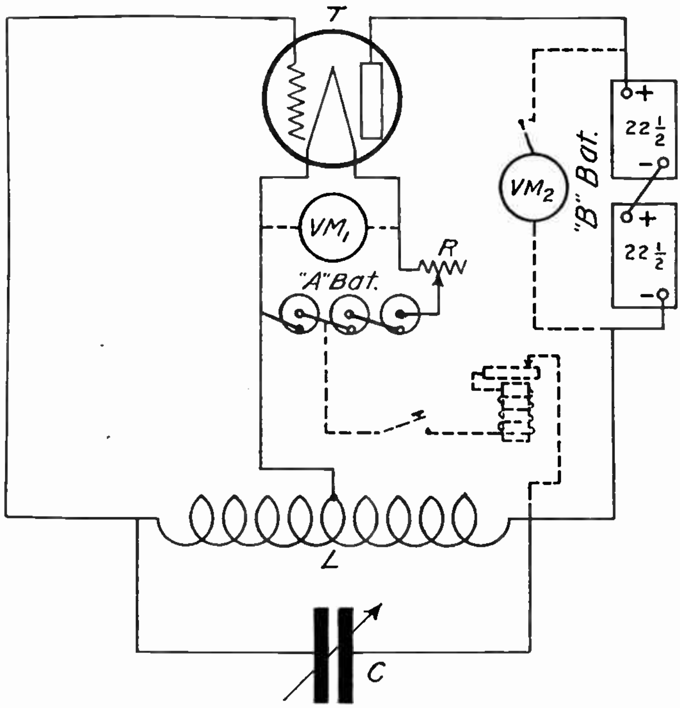


Fig. 9—A very simple vacuum tube continuous wave generator using buzzer shown in dotted lines for modulation.

its — post connected to the — filament and the right-hand binding post of the buzzer set to the — B. Upon pressing the key, the filament battery will actuate the buzzer and the interruptions will occur as described. A buzzer set connected as described here can be seen in Fig. 10.

Another very convenient method of modulating a high frequency generator, such as is shown in Fig. 9, is to insert in the grid lead a condenser of about 250 micro-microfarads with a grid leak of approximately 5 megohms connected across it. The periodic charging and discharging of the condenser through the leak will modulate the output of the generator at an audio frequency, the exact value of which will depend upon the capacitance of the condenser and the resistance of the leak.

It is important to note that the **interrupted continuous waves** furnished by a circuit such as is shown in Fig. 9 are far superior for measuring purposes to those which can be produced by the buzzer excited frequency meters shown in Fig. 8. In Fig. 8, oscillations are produced by charging a condenser and allowing the condenser to discharge through an inductance. In Fig. 9, a generating device is incorporated in the circuit which,

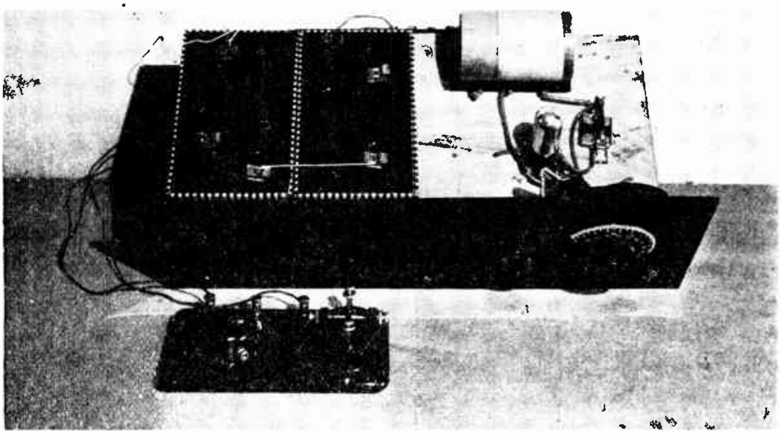
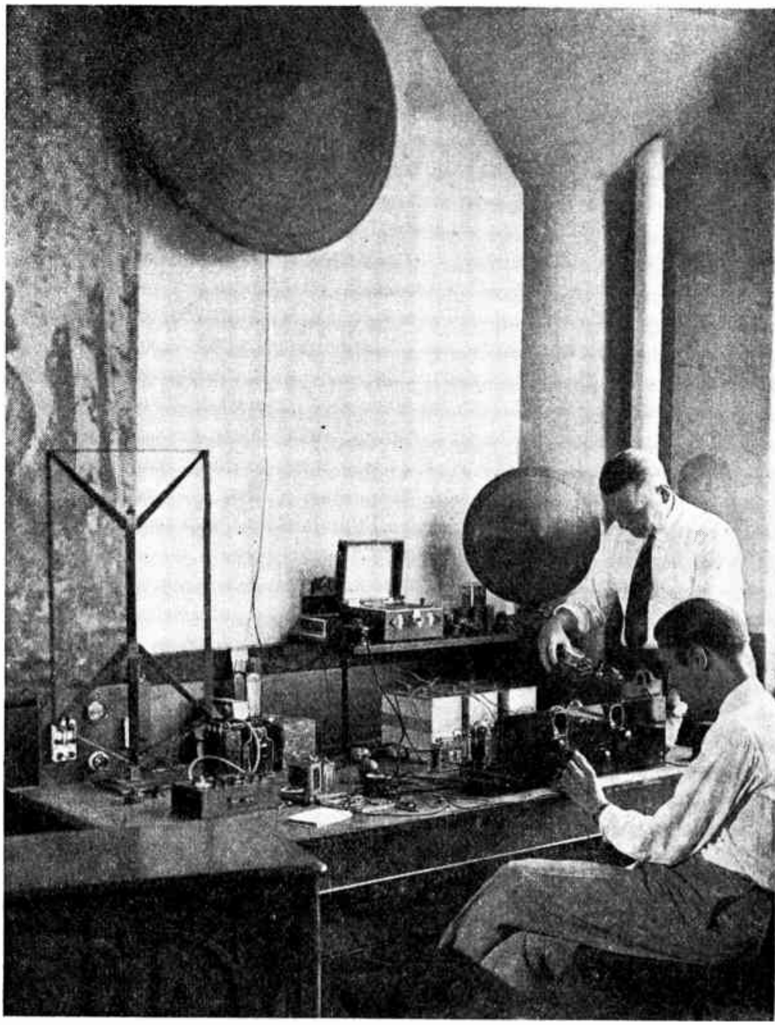


Fig. 10—Simple continuous wave generator built at the National Radio Institute, Washington, D. C.

except for the action of the buzzer, would produce continuous waves. The waves produced by the circuit shown in Fig. 9 are much sharper and the results that can be obtained by using a generator of this type are much more satisfactory.

If you remove the tube from the circuit shown in Fig. 9 and then close the buzzer key, the inductance—capacitance circuit will be excited in a way identical with that shown in Fig. 8. You can readily notice the difference in the sharpness of the energy produced in the two cases by listening with a receiving set to the note produced by the generator with the tube out and then with it in the circuit.



A corner of an experimental radio laboratory showing engineers at work in calibrating receiving apparatus.

If your home is wired for electric lights and is supplied by 60-cycle alternating current, then you can readily construct an oscillator for use in radio frequency measurements which will derive all of its power from the lighting circuit. The same circuit can also be used if direct current is used to light your home with the exception that the waves produced by the circuit will be practically continuous except for such disturbances as occur on the line. With the alternating current supply, however, the alternations of the electric voltage will serve to modulate the output of the oscillator. The oscillator can, therefore, be used with any receiving set.

Figure 11 shows the circuit for an oscillator such as we have been discussing. If the oscillator is intended for use with a 110-volt source and a 201-A or a 301-A type tube is used, then the electric light bulb connected in series with the filament circuit should be a 25 or 30-watt light.

The current through the filament of the vacuum tube will then be approximately .25 amperes which is the correct value for the 201-A or 301-A tube. These types are recommended as the plate voltage will be 110 volts. This total line voltage is applied directly to the plate of the tube as can be seen from Fig. 11.

A coil of the same design as we have described can be used with a condenser having the appropriate capacitance but it will be necessary to cut the wire in the middle of the coil thereby completely isolating the plate and grid sections, as is shown in Fig. 12. The condenser shown as connected across the 110-volt source is ordinarily not necessary. The condenser must be capable of standing 110 volts and should not have a capacity greater than .01 microfarads otherwise a considerable alternating current will flow through it. The stopping condenser should have a capacitance of .00025 microfarads or greater and the grid leak should be of the order of 1 megohms.

CALIBRATION OF FREQUENCY AND WAVE-METERS DESIGNED TO COVER THE BROADCAST BAND

The entire frequency spectrum lying between 550 and 1,500 kc. is occupied by radio broadcasting stations, all of which are operating upon specific frequency assignments. These assignments have been made by the Federal Radio Commission and Call Books showing what stations are operating on specific frequencies are readily obtainable. It is possible therefore to obtain a fairly satisfactory calibration curve for a vacuum tube oscillator or a frequency meter using buzzer excitation by the use of an ordinary radio-receiving set and a Call Book, showing the frequency assignments upon which broadcasting stations are operated. The accuracy of calibration, which can be obtained by this method, will depend primarily upon the accuracy with which the broadcasting stations, whose signals are to be used, can be relied upon to maintain their carrier frequencies at the assigned values. Some broadcasting stations can be depended upon to keep their

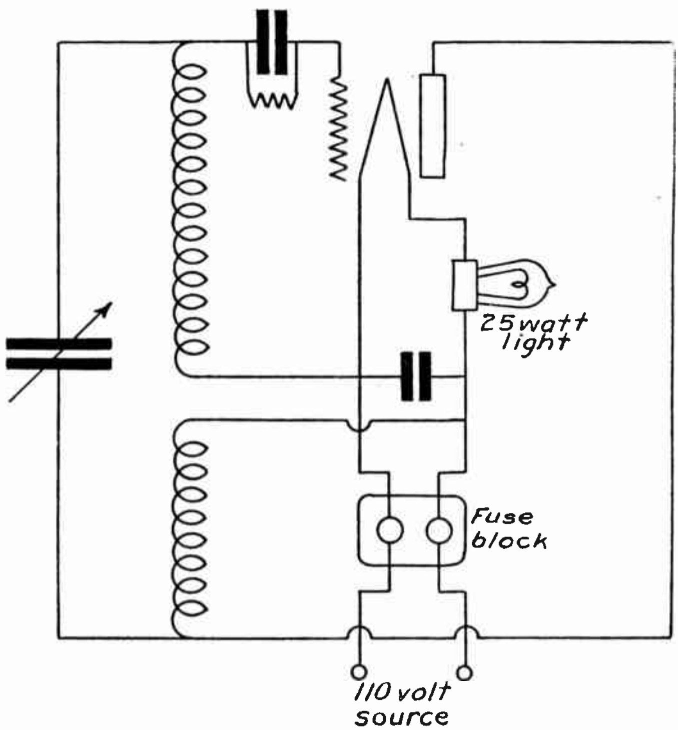


Fig. 11—Circuit for a vacuum tube high frequency generator for operation from a 110-volt source.

transmitters operating on the correct frequency with a high degree of accuracy while others cannot. If an accurate calibration is desired it is essential that as many reliable stations as possible be utilized.

Any type of radio receiving set designed for operation throughout the broadcast band can be utilized for the experiment we are about to describe. In the experimental work conducted at the National Radio Institute prior to the preparation of this text-book, a very simple regenerative receiver wired according to the circuit shown in Fig. 13 was used and a calibration curve obtained for the vacuum tube continuous wave generator shown in Fig. 10 was obtained. This vacuum tube generator was equipped with a buzzer and was wired in accordance with the circuit shown in Fig. 9. In addition to obtaining a calibration curve for the vacuum tube generator data a similar calibration curve for the receiving set was obtained. However, since the set was of the regenerative type this data would be of value only in case the same antenna and the same degree of coupling between the antenna and the receiving set were maintained. It should be

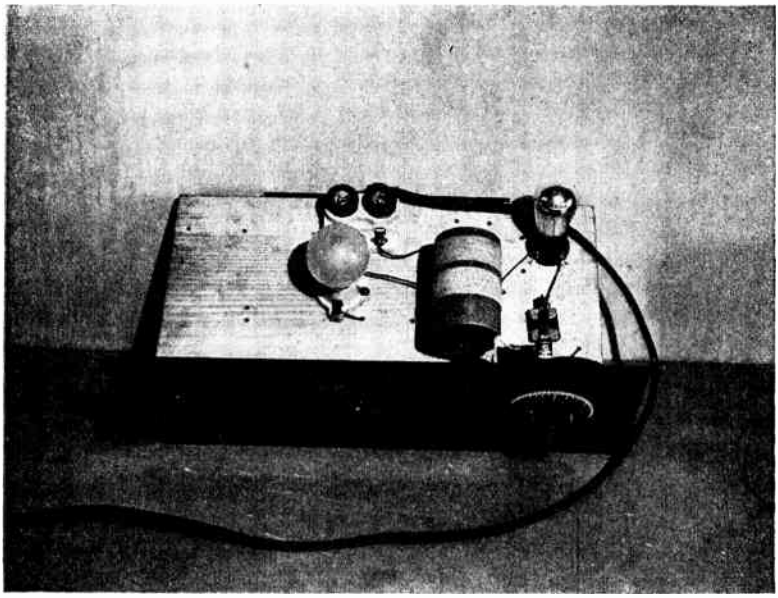


Fig. 12—High frequency generator for operation from 110-volt source built at the National Radio Institute.

borne in mind that the tuning of a regenerative receiving set will to some extent depend upon the setting of the dial controlling regeneration, the dimensions of the antenna in use and the degree of coupling between the antenna circuit and the receiving set itself, etc. If, however, you happen to use a receiving set of the tuned radio frequency type, as is probably the case, these factors will not be involved and the calibration curve which you can obtain by the methods to be described will be of great value to you.

The receiving set was connected to a small antenna from the roof of tne National Radio Institute's building. The vacuum tube generator was placed upon the same table as the receiving set and about three feet from it. The receiving set was placed in operation and tuned for Station WRC, which at the time of the experiment was operating upon a frequency of 640 kc. The tuning dial and the regeneration dial were adjusted until the signal reached its maximum intensity in the head-set. The dial readings were then recorded in Columns III and IV of Table II.

The filament of the tube in the vacuum tube generator circuit was then lighted and the rheostat adjusted until the voltage across the filament terminals was 3 volts. The condenser

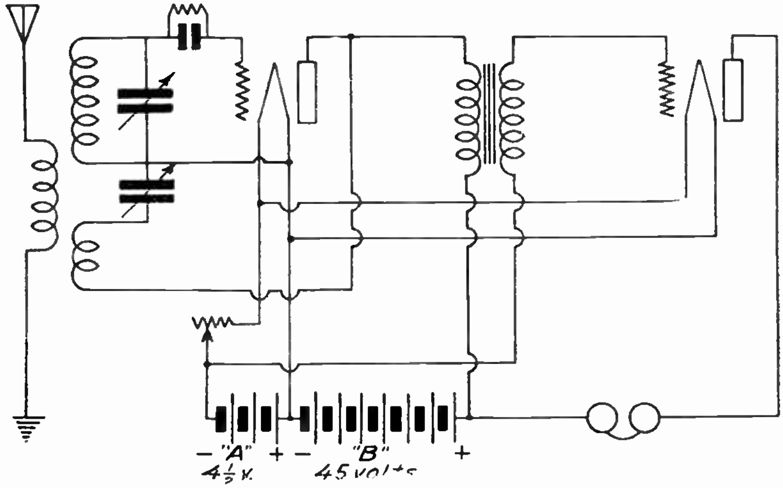


Fig. 13—Schematic circuit diagram for radio receiving set used to obtain data for calibration curve for high frequency generators shown in Figs. 10 and 12.

dial of the generator circuit was then adjusted until the frequency produced by the generator was so close to that produced by station WRC that a heterodyne beat note could be heard in the head-set connected into the circuit of the receiving set. The vacuum tube generator was then moved back and forth across the table until a suitable intensity of this heterodyne note was obtained. The dial on the generator circuit was then very carefully adjusted until the beat note became so low as to be almost inaudible. When this is the case, you can readily see that the frequency produced by the generator must be almost the same as that produced by Radio Station WRC. The reading on the generator circuit condenser dial was then recorded in Column V of Table II. This reading was 82. Thereafter to produce a frequency of 640 kc. it was only necessary to turn on the vacuum tube generator and to set the condenser dial at 82.

The radio receiving set was then tuned for another station which happened to be station WRHF also located in Washington, D. C., and at the time of the experiment transmitting upon a frequency of 930 kc. With the tuning and regeneration dial set

TABLE NO. II.

Calibration Data for Vacuum Tube Continuous Wave Generator Shown in Fig. 10.

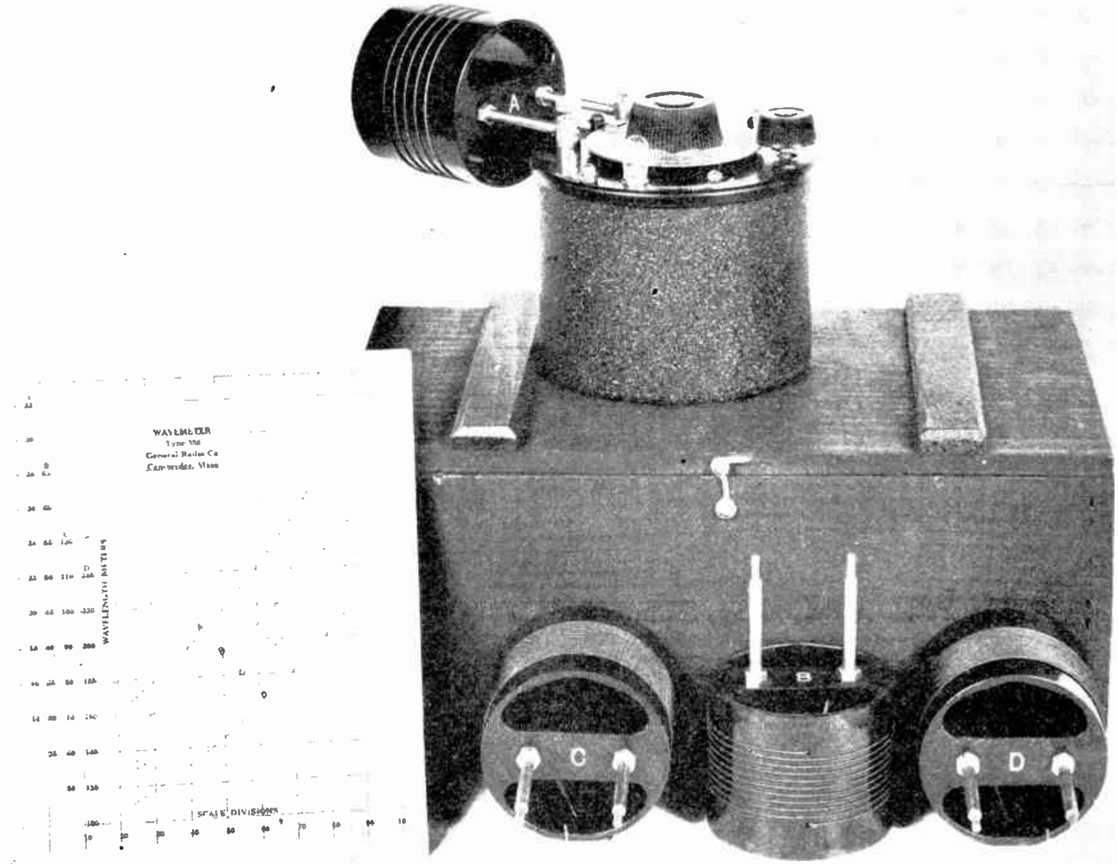
I Station	II Assigned Frequency	III Receiving Set Tuning Dial Setting	IV Receiving Set Regeneration Control dial Setting	V Vacuum Tube Generator Dial Setting
WRC.........	640	84	90.5	82
WKBW.......	1380	15	91	77.5(690kc)*
WGY.........	790	61	60	68
KDKA.......	950	51	85	54
WBAL.......	1050	48	84	44.5
WPG.........	1100	29	86	39
WMAL.......	1240	0	100	25
WRC.........	640	22	77	18 (1280)†

*Note: Generator tuned to frequency one-half that of transmitting station.

†Note: Receiving set and oscillator both wired to second harmonic from WRC.

for maximum volume from this station, the oscillator was then adjusted as before until the beat note between the oscillator and station WRHF was as low as possible. The reading of the generator circuit condenser dial was then noted and found to be 57. In a similar manner additional data were obtained as shown by the additional figures in Table II. The data given in Table II were then plotted so as to give a calibration curve for the radio frequency generator. Figure 15 shows the curve obtained. Dial settings are plotted as abscissa and frequencies as ordinates.

Harmonics from broadcasting stations, if they are of sufficient intensity, and harmonics from the continuous wave generator may also be used to obtain points on the calibration curve. Two sets of data shown in Table II illustrate how this is done. At the time the calibration curve was obtained the receiving set was only a very few blocks from station WRC. This station in addition to radiating energy at the fundamental frequency 640



General Radio type 358 wave-meter, showing various size coils used to check wave lengths between 14 and 224 meters.

kc. also radiates a small amount of energy at the second harmonic, 1,280 kc. By very careful tuning of the receiving set it was possible to hear the program from station WRC when the set was adjusted for 1,280 kc. The continuous wave generator was then adjusted so as to produce this frequency using the heterodyne beat note between the double frequency energy from WRC and the fundamental produced by the oscillator to deter-

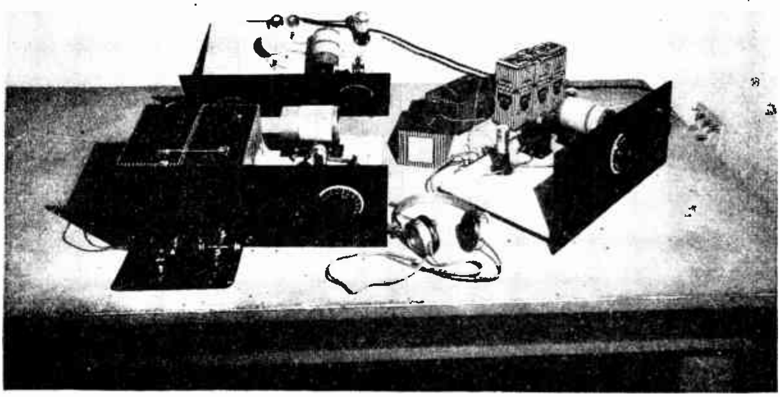


Fig. 14—Radio receiving set and continuous wave generator on table preparatory to calibration.

mine when the oscillator was set at 1,280 kc. The data obtained are plotted on Fig. 15.

In a somewhat similar way the harmonic produced by the continuous wave generator can also be used. The receiving set was adjusted to receive signals from station WKBW assigned a frequency of 1,380 kc. The continuous wave generator was not capable of producing a frequency as high as this with the coil in use. However, when the generator was adjusted for 690 kc. the 1,380 kc. harmonic (second harmonic) produced was of sufficient intensity to beat with the incoming signals from station WKBW. The generator dial was then adjusted until the beat frequency was reduced to zero and the data obtained used to plot the point shown in Fig. 15.

The student will find in this text-book much valuable and understandable data concerning the calculation of inductance, wave length, frequency, capacity, etc., also a description of the simple devices with which these measurements may be made.

Perhaps there is no more important instrument used for radio measurements than the frequency or wave-meter. It may be employed in many calculations and, contrary to what might be expected, it may be constructed and operated by students of the science with little or no trouble.

A frequency meter is really a combination transmitter and receiver of the calibrated type. That is, it may be adjusted to admit a wave of a definite length or frequency and it may be set to receive a wave or frequency of a definite length. In this way, it is possible to calibrate transmitters and receivers by its use.

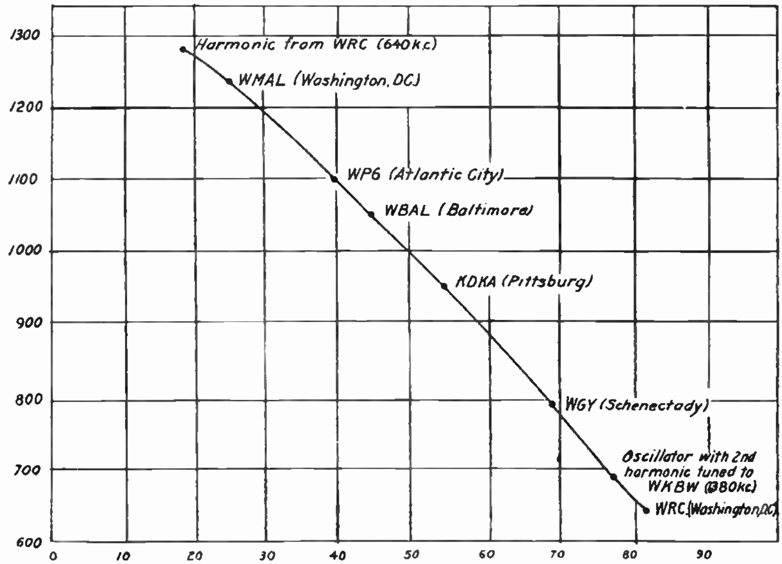


Fig. 15—Calibration curve obtained with a radio receiving set of continuous wave generator shown in Fig. 10.

UNITS OF THE METRIC SYSTEM

Electrical units are based upon the units of the metric system which is the name given to the system of units used throughout the world of science.

In connection with the units of the metric system, the prefixes given in Table III are used to indicate the smaller or larger units.

The **units of capacity** actually used in radio work are the **farad, microfarad** and the **micro-microfarad.**

1,000,000 **microfarads** equals one **farad.**

1,000,000 **micro-microfarads** equals one **microfarad.**

1,000,000,000,000 **micro-microfarads** equals one **farad.**

TABLE III

Prefix	Abbreviation	Meaning
micro	μ	One-millionth
milli	m	One-thousandth
centi	c	One-hundredth
deci	d	One-tenth
deka	dk	Ten
hekto	h	One hundred
kilo	k	One thousand
mega	M	One million

The **units of inductance** commonly used in radio work are **henry, millihenry** and the **microhenry.**

Another unit sometimes used is the centimeter of inductance.

1,000 **millihenries** equals one **henry.**

1,000 **microhenries** equals one **millihenry.**

1,000,000 **microhenries** equals one **henry.**

1,000 **centimeters** equals one **microhenry.**

1,000,000 **centimeters** equals one **millihenry.**

1,000,000,000 **centimeters** equals one **henry.**

TEST QUESTIONS

Number your Answers 22—3 and add your **Student Number.**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Why is it advisable to calibrate receiving apparatus in terms of frequency?
2. At what frequency will a circuit resonate using a 180-microhenry coil, the capacitance of the condenser being 300 micro-microfarads? (See Table No. I.)
3. Draw a circuit diagram of a frequency meter using a thermal galvanometer or a hot wire ammeter.
4. Explain how the apparatus used in Fig. 7 is used for measuring the frequency of a radio transmitter.
5. Draw a circuit diagram of a buzzer excited frequency meter.
6. What kind of waves will the buzzer excited frequency meter produce?
7. Draw a circuit diagram of a vacuum tube continuous or modulated continuous wave generator.
8. State what device is used in Fig. 9 to modulate the output of the oscillator.
9. What other methods can be used for modulating a high frequency generator such as shown in Fig. 9 ?
10. Draw a circuit diagram of a vacuum tube high frequency generator which can be operated from a 110-volt line.

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STANDARD RADIO RECEIVING CIRCUITS

Originators of Radio Home Study Courses
...Established 1914...
Washington, D. C.

FRANKLIN said—

"An investment in knowledge pays the best interest."

WHAT NOTES TO TAKE

A Personal Message from J. E. Smith

What notes should be taken in reading is a matter largely of individual needs. Most students, in reading a book or listening to a lecture, take too many notes.

They then depend on their notes rather than their memory, which is always unwise. If one wants to look up data, he had better refer to the book rather than his own notes on the subject, unless, of course, it is a rare book which he may never have the opportunity to consult again. To the average student seeking simple knowledge of the subject, the taking of notes is principally to fix the points in mind. Some critical notes, too, are useful. Points which seem to be rather doubtful are worth noting, so that he may think them over later with more care.

BF5M—63030 Printed in U.S.A.

STANDARD RADIO RECEIVING CIRCUITS

There are hundreds of Radio receiving circuits used by the various manufacturers of both complete receivers and kits, which may all be classified under one of the following headings:

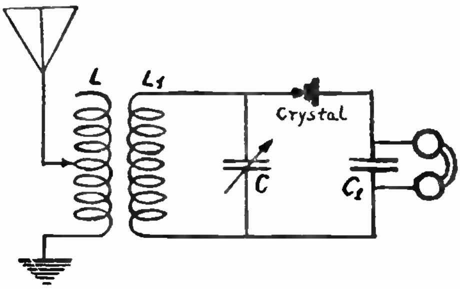

Fig. 1—Crystal receiving circuit

Non-regenerative.
Regenerative.
Reflex, which also includes the Inverse Duplex.
Tuned Radio-frequency.
Super-Heterodyne.

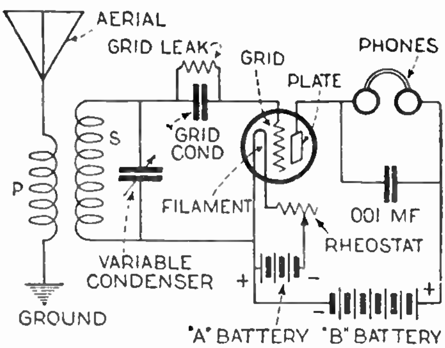

Fig. 2—Non-regenerative vacuum tube receiving circuit

Most of the above circuits have been carefully taken up in the earlier text-books, and in case any of the circuits presented in this book are not clearly understood from the brief description, the student is advised to refer back to the text-book dealing with this particular class of receiving circuit.

One of the simplest forms and least expensive type of receiving circuit of the non-regenerative type is the crystal receiver as shown in Figure 1. This outfit includes a variocoupler or radio-frequency transformer, a variable condenser, crystal detector or rectifier as it is sometimes called, and a pair of head-phones.

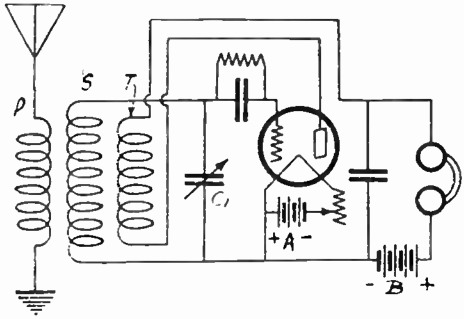

Fig. 3—Regenerative circuit using the tickler coil method

Under normal conditions, this type of receiver should give good head-phone reception from stations as far away as 25 miles. While this receiver is useful in cities where Broadcasting Stations are close by, it is of little use in the suburbs and country.

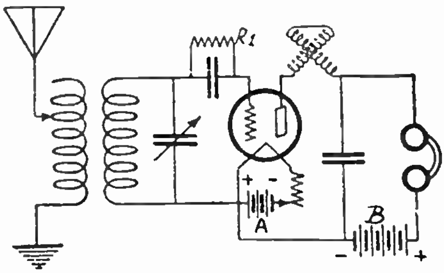

Fig. 4—Regenerative circuit using the tuned plate method

From the fundamental circuit of the simplest form, we have the circuit of a vacuum tube receiver as shown in Figure 2. Although the first one uses a crystal detector and the second one a 3-element vacuum tube, both are in the same category and are classified as belonging to the non-regenerative variety. The U. S. Bureau of Standards' measurements show that the vacuum tube is 25% more sensitive than the crystal although the latter gives 50% more clarity.

With the discovery of the 3-element vacuum tube came the regenerative circuit. Regeneration increases the volume and sensitivity of a receiving set to a very large degree. There is one draw-back, however, that of radiation. When the set starts to oscillate, it is due to over-regeneration.

A regenerative receiving circuit is shown in Figure 3, using the tickler feed-back method of regeneration. Regeneration can also be obtained through the use of a tuned plate circuit system, in which case the internal capacity of the vacuum tube plays an important role. Figure 4 shows the circuit diagram of a regenerative receiver using the tuned plate circuit method.

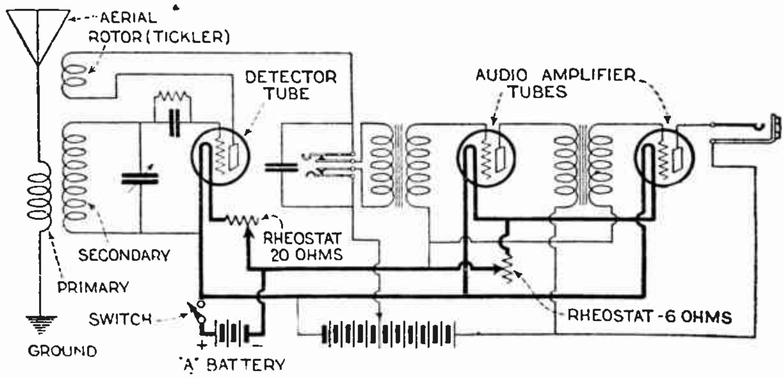

Fig. 5—Regenerative receiver in conjunction with two stages of audio-frequency amplification.

Figure 5 shows the circuit diagram of a standard 3-tube regenerative receiver using two stages of audio-frequency amplification after the detector tube.

REFLEX CIRCUITS

A Reflex receiver is sensitive, selective, and gives signals of excellent volume and clarity. The quality of reproduction depends greatly upon the inductive relations of the various coils. The circuit shown in Figure 6 is known as the Harkness single tube Reflex, and uses a special tuner and radio-frequency transformer with a crystal detector.

Figure 7 shows a 2-tube Reflex circuit using a stage of radio and audio-frequency amplification with a vacuum tube detector.

In ordinary single-tube non-regenerative receiving circuits, the received signals are rectified and partly amplified by the vacuum tube. To increase the volume of the incoming signals in these circuits, the usual procedure is to incorporate one or two stages of audio-frequency amplification. If the range of the receiver is to be increased, it is customary to incorporate one or more stages of radio-frequency amplification. For every such stage added, another tube is necessary. Not so, however, in a Reflex circuit, where one tube is made to perform the duties of two or possibly three. The manner in which this is accomplished is quite simple.

For example, the incoming radio-frequency current is amplified at radio-frequency by the vacuum tube, passed through a detector (which may be a crystal or vacuum tube), where they are rectified, and the resultant audio-frequency currents are passed through an audio-frequency transformer and then amplified at audio-frequency, using the same vacuum tube. The audio-frequency currents then flow in the circuit containing the head-phones or loud-speaker.

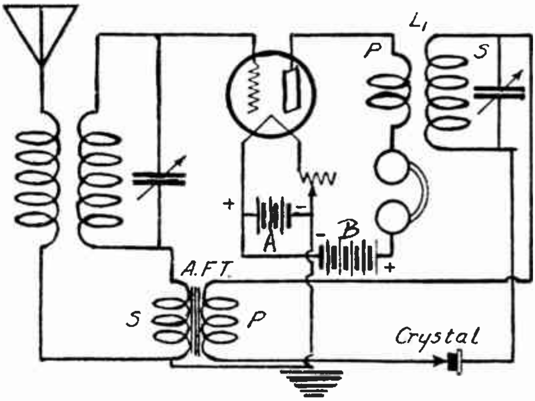

Fig. 6—Harkness single tube reflex circuit using a crystal detector

The chief trouble with reflex amplification circuits is that they tend to oscillate at audio-frequency. That is, a continual squealing or howling noise is often obtained when the circuit is connected, and no matter what adjustments are made, it is usually difficult to eliminate. This trouble is due chiefly to the individual characteristics of the component parts and the design of the circuit.

With a circuit of this type, employing one tube and a crystal detector, it is possible to operate a loud-speaker and to receive over a great distance when employing the head-phones. With two tubes, of course, much better results can be obtained.

The only object in employing the reflex principle is to reduce the number of tubes employed for accomplishing a given result. It is now generally conceded that while the over-all amplification of a reflex set is greater than would be obtained with the same number of tubes without reflexing, one tube when used both as a radio and audio-frequency amplifier, will not serve either function as efficiently as when used for only one of these purposes. It is also natural that the audio e. m. f.'s impressed on the input of the radio-frequency amplifier tube has a slight modulating effect on the high-frequency current and thereby produces a small amount of distortion. At all events, the lowering of the price of good vacuum tubes and the more general use of "A" and "B" Eliminators and AC tubes seem to have gone hand-in-hand with the swing of the public favor from reflex to

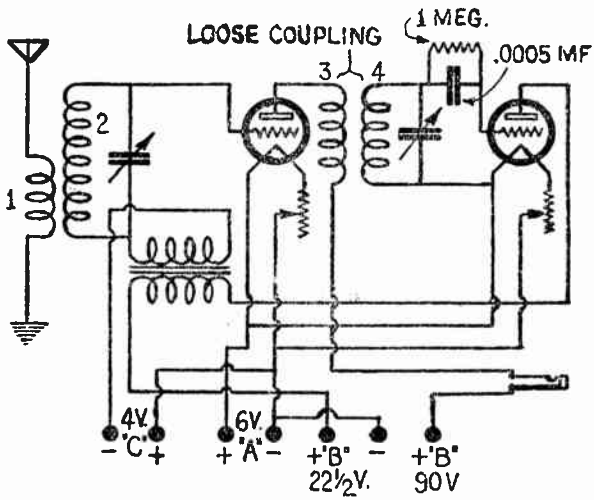

Fig. 7—Two-tube Harkness reflex circuit

straight model receivers, such as tuned radio-frequency and the Super-Heterodyne.

INVERSE DUPLEX CIRCUIT

Reflexing, which is the foundation of the inverse duplex system, permits one tube to function as both a radio and audio-frequency amplifier. Where it is employed in a circuit, special attention must be paid to the function of the various parts under different conditions. For instance, small condensers offer very little impedance to high-frequency currents, but their impedance to current flow at the relatively low voice, or audio, frequencies is extremely high. The circuits can, therefore, be so arranged that they discriminate against low frequencies in favor of radio frequencies and vice versa. These principles are used in reflexing.

The inverse duplex system is superior to the straight reflex system in several ways. It is more stable because any radio-frequency energy which passes the detector and first audio transformer through capacity coupling will only be impressed on the input of the stage ahead of the detector instead of two or

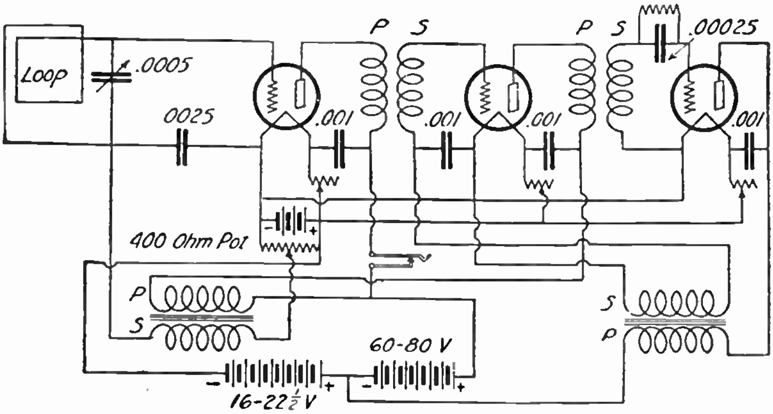

Fig. 8—Three-tube inverse duplex circuit

more stages ahead of it, as in the case of straight reflex. In the latter case, oscillation, due to feed-back, would be almost beyond

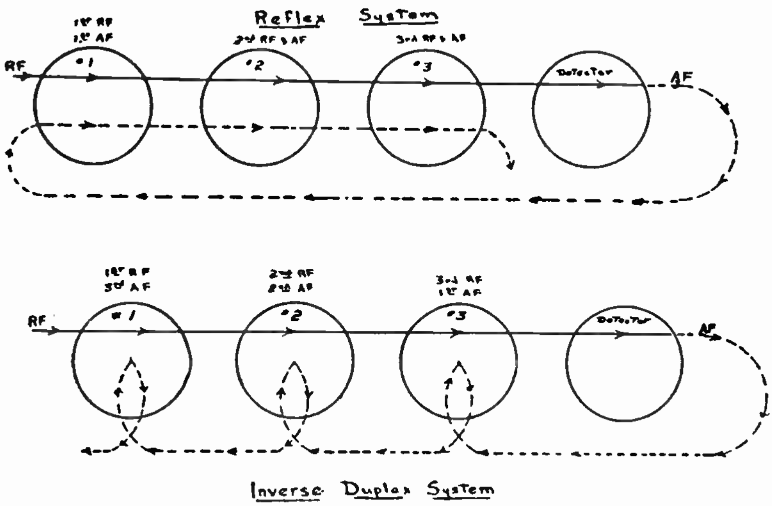

Fig. 9—Comparison of straight reflex with inverse duplex system

control. In a straight reflex receiver, the first radio tube is usually the first audio amplifier also. Therefore, if any audio-frequency noises, such as a hum from power lines, are induced into the antenna and passed on to the first tube, they may be amplified by the succeeding audio stages to loud-speaker volume. In the case of the inverse duplex system, the first radio tube is the last or next to the last audio amplifier. Hence, such noises seldom ever retain noticeable volume. Inverse duplexing also tends to equalize the load which the various tubes carry. This enables one to obtain a slightly greater output volume level before overloading begins. Figure 8 shows a simple three-tube Inverse Duplex circuit, and Figure 9 the comparison of Straight-Reflex with the Inverse Duplex system.

Figure 10 shows the wiring diagram of the Grimes Inverse Duplex receiver. One of the greatest advantages of the inverse

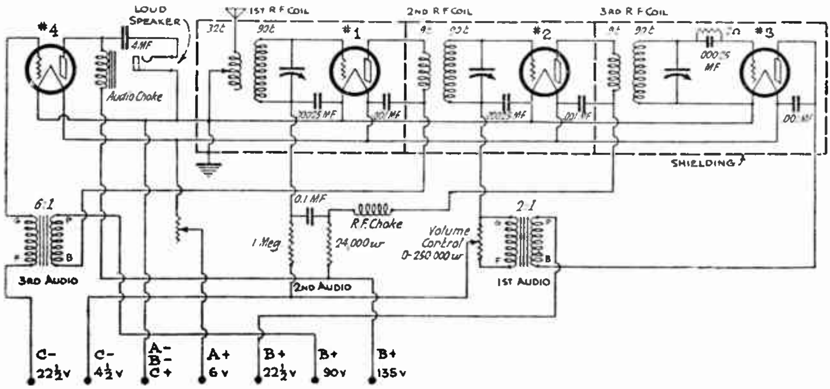

Fig. 10—Circuit diagram of Grimes inverse duplex receiver

duplex system is its economy of tubes and battery power. This is especially apparent if the receiver is to be operated by means of dry batteries either in part or entirely. The principle of reflexing has been applied to nearly all types of receiving circuits.

TUNED RADIO-FREQUENCY CIRCUITS

The popularity of 5-tube tuned radio-frequency receivers was caused by a very peculiar patent situation. While this type of circuit employs 5 tubes and is no more sensitive than a 3-tube regenerative circuit such as shown in Figure 5, it has many advantages that make it ideal for broadcast reception. The main advantages are non-radiation and simplified tuning. Thus, we see that due to the monopoly caused by the patent situation, the Radio public has benefited considerably.

A typical 5-tube tuned radio-frequency circuit is shown in Figure 11. The main trouble in all receivers of this class is due to coupling between the circuits causing oscillation, and in order to obtain amplification, it is necessary to prevent the circuits from oscillating. Several methods have been used for doing this, but only a few are satisfactory. In order to prevent feed-back coupling between the circuits, we must first understand where the feed-back occurs. Feed-back between the electrodes of the vacuum tube causes the most trouble. The grid and plate electrodes form a small condenser which couples the plate circuit to the grid circuit and causes oscillation. By means of a bridge connection, it has been possible to neutralize this tube capacity and the circuit is successfully used in Neutrodyne receivers. Feed-back also occurs between the coils themselves. The magnetic and electrostatic fields of the coils extend far out into the surrounding space and energy is fed from the plate circuit to the grid circuit and oscillations are produced.

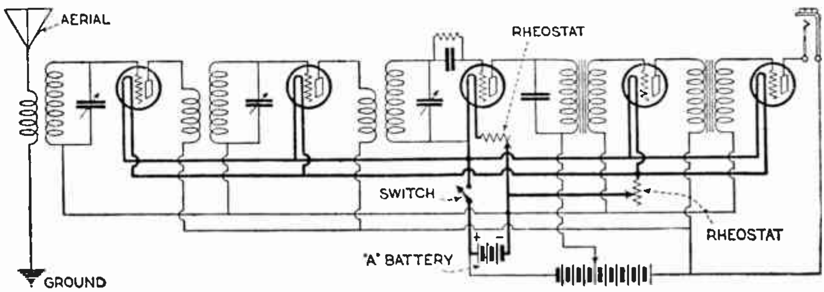

Fig. 11—A typical five-tube tuned radio-frequency hook-up with filament circuit emphasized by heavy lines.

In the Neutrodyne type of receiver, feed-back between the coils has been reduced by mounting the coils at such an angle that their fields have no effect on adjacent coils. There are many ways of preventing self-oscillation in receivers of this type.

The first preventative was the potentiometer. This permitted biasing the grids of the radio-frequency tubes with various values of either a positive or negative voltage. The manner in which the device was connected in a simple radio-frequency circuit is shown in Figure 12. If the vacuum tube or tubes had a tendency to oscillate, all one had to do was to move the arm of the potentiometer towards the positive side until everything was cleared up. This was good, except that in doing so, one introduced heavy losses in the circuit.

A fixed or variable resistance somewhere in the order of 200 to 1,000 ohms inserted in each grid circuit as shown in Figure 13 is another method that is very effective for stabilizing a set. However, this arrangement also is a "losser" and decreases both the sensitivity and selectivity of the set.

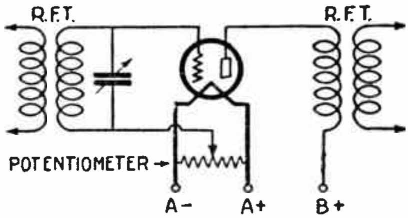

Fig. 12—The potentiometer method of oscillation control

The first real advancement came with the introduction of the first original neutralization system exploited under the name of Neutrodyne. This method, worked out by Professor Hazeltine, supplied a means for neutralizing the effect of the internal grid to plate capacity of the vacuum tube. This was accomplished by the use of a small adjustable condenser (C), with a very low capacity value connected in the circuit as shown in Figure 14.

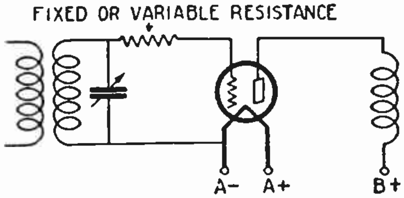

Fig. 13—Stabilizing a radio-frequency circuit by use of a series grid resistance

There is a very long explanation of the functioning of this arrangement in one of our previous lessons on the Neutrodyne receiver.

Referring to Figure 14, let us assume that the circuit is operating without the neutralizing condenser C and that the grid or secondary circuits A and B are not tuned to any particular station and are out of resonance with each other. In this case, there is very little regeneration taking place. However, as soon as we tune the circuits A and B to the wave-length of some Broadcasting Station, the point of resonance is reached and there is sufficient feed-back of radio-frequency current through the internal capacity C1 of tube V, to cause oscillation in the manner heretofore explained. Though there is no variable condenser connected across the primary coil of R. F. T. to the plate circuit of tube V, the coil nevertheless takes on a resonance effect, due to the tuning of the associated secondary coil in circuit B. Now if we connect condenser C in the circuit, something else happens. This condenser introduces in the grid circuit A of tube V, a radio-frequency current equal, but opposite in phase, to the current fed back through the internal capacity C1. In other words, there are two feed-backs—the natural feed-back through the capacity of the tube, and an auxiliary feed-back through the condenser C. Since these two distinct reactive currents are opposite in phase, they neutralize each other, and consequently, oscillation cannot take place.

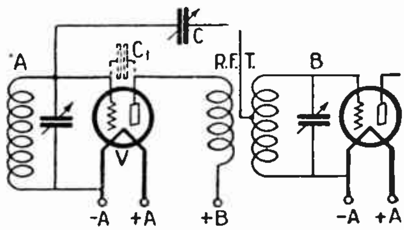

Fig. 14—Illustrating the Neutrodyne principle of oscillation control

The Rice system of neutralizing shown in Figure 15 is very similar to the Neutrodyne arrangement, but in this case, the condenser C is connected between the plate of the tube and the filament end of the grid coil. The action and effect is the same. That is, a current equal to the natural feed-back current, but opposite to it in phase, is fed back into the grid circuit.

There have been a number of other systems devised similar to the two just mentioned. They are all about equal in effectiveness. But they have one common fault, and that is that they do not act the same on all wave-lengths. Adjust a set using one of these forms of neutralization for stability on short waves, and there is a noticeable lack of sensitivity on the longer wave-lengths. If the set is adjusted for maximum sensitivity on long waves, it most certainly will oscillate on the short waves. Naturally, the best that can be done is to adjust the neutralizing system so that the set is perfectly stable in operation on short waves, and then to be satisfied with the results obtained on the longer wave-lengths.

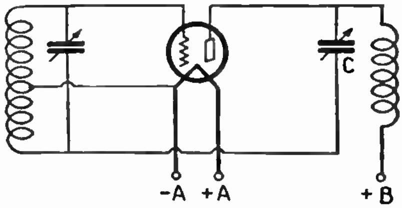

Fig. 15—The Rice method of neutralization

RESISTANCE STABILIZATION

Radio engineers soon learned that there was still much to be done in the way of developing, stabilizing or neutralizing systems. The main problem on hand was to devise a means to compensate for the change in electrical coupling between primary and secondary circuits at different wave-lengths. The problem was not an easy one as both capacities (condensers) and inductances (coils) change their reactance or impedance values with

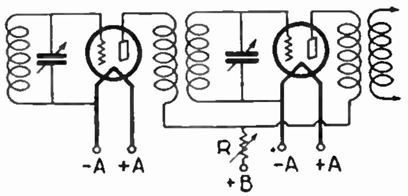

Fig. 16—A plate-resistance stabilized circuit

a change in wave-length or frequency. The only factor that does not change is a resistance unit, and this provided the first form of stabilizer following the bridge circuit. This arrangement is shown in Figure 16. Although it is fairly effective in some respects, it has a number of disadvantages. At any rate, it cannot be truthfully called a damping device in the same sense that former arrangements were called.

It will be noticed on the diagram that a variable resistance (R) is connected in series with the common "B" supply leads to the plates of the radio-frequency tubes. The fact that the resistance is there means that there will be a certain amount of damping, but this is offset by the functioning of the resistance. In the first place, it is associated with the primary circuit only and does not act as a damping factor in the grid circuit, where it certainly would decrease both the selectivity and sensitivity of the set as a whole. What it does do is slightly damp the action of the primary circuit, alter or adjust the plate-filament impedance of the radio-frequency tubes, and at the same move, you might say, adjust the "B" supply voltage.

CONSTANT COUPLING SYSTEM

The Loftin-White Constant Coupling System of radio-frequency amplification is a stabilized circuit with no theoretical losses to speak of, which is based on the fact that the reactance of a condenser increases as the frequency decreases, (or wave-length increases) and vice versa, and that the impedance of an

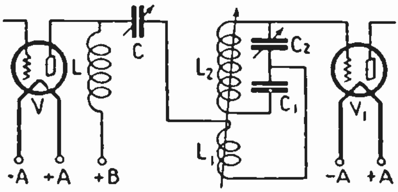

Fig. 17—The basic Loftin-White constant coupling system

inductance varies in exactly the opposite ratio. In other words, regardless of whether the wave-length is being increased or decreased, the reactance of either the inductance or the capacity is increasing while the other is decreasing, as the case may be. The circuit of this system is shown in Figure 17. It has its inductance and capacity so connected that there is both inductive and capacitive coupling. It is a well-known fact that when two circuits are coupled together inductively, transfer of energy will be greatest at the lowest wave-length and least at the highest wave-length. When a capacitively coupled system is used, the effects obtained are just the opposite to those obtained with the inductively coupled system.

In the case of the capacitively coupled system, the energy transfer is lowest at the low wave and increases to the high point at the high wave-lengths.

It is logical to assume that by combining the good qualities of the two coupling systems a method can be evolved which will add the two effects, thus obtaining equal energy transfer or amplification over the whole wave-length range. In the diagram of Figure 17, it can be seen that the inductive coupling is gained through the coils L1 and L2, while capacitive coupling is furnished by the condensers C1 and C2, and the connection to the primary L1. Coil L is a radio-frequency choke coil which prevents the leakage of any of the radio-frequency current into the "B" battery circuit, while "C" is the phase shifting condenser which is employed primarily for the purpose of neutralization.

The following diagrams show a number of popular manufactured tuned radio-frequency receivers and the methods they employ for stabilization.

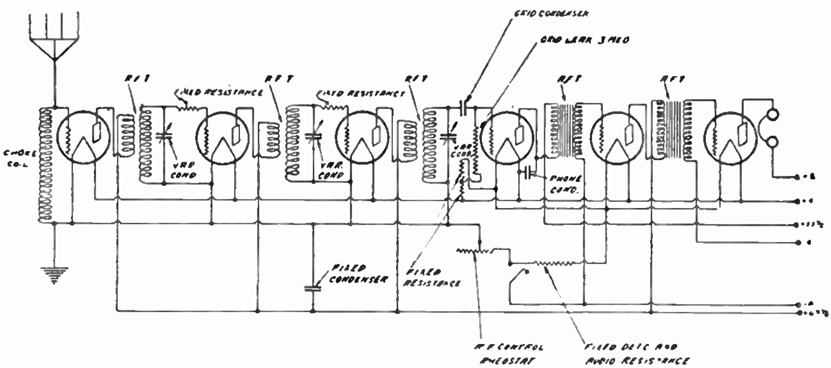

Fig. 18—Model 35 Atwater Kent receiving circuit using series grid resistance

Figure 18 illustrates the circuit diagram of a six-tube Atwater Kent receiver using series grid resistances for stabilizing the radio-frequency circuits. Figure 19 is the complete schematic diagram of a 5-tube Neutrodyne circuit employing small neutralizing condensers between the grid circuits of the radio-frequency tubes. Figure 20 is a circuit diagram of the Karas Equamatic receiver using a movable primary, which varies the coupling as the tuning condenser capacity is varied. Figure 21 shows the circuit used in the Universal Plio-Six receiver. This employs a variable resistance (R) connected in the plate circuit of the first two tubes. Figure 22 shows the circuit diagram of a Freshman Masterpiece receiver. The primary of the radio-frequency coils are reversed to prevent oscillation. Figure 24A illustrates the circuit diagram of the Majestic AC Receiver, Model 90. This receiver has four stages of tuned radio-frequency, detector and push-pull audio-frequency amplification.

The circuit diagram of the Loftin-White receiver is shown in Figure 23. A glance at this schematic wiring diagram will show the difference between this type of circuit and the ordinary type of tuned radio-frequency receiver.

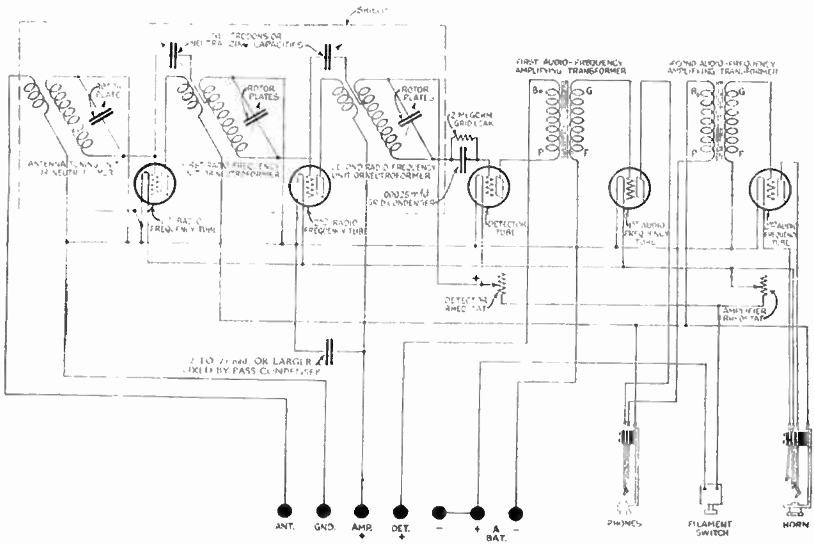

Fig. 19—Fada five-tube neutrodyne circuit

The B. T. Power Six receiving circuit is shown in Figure 24. Fundamentally, the circuit consists of three stages of balanced

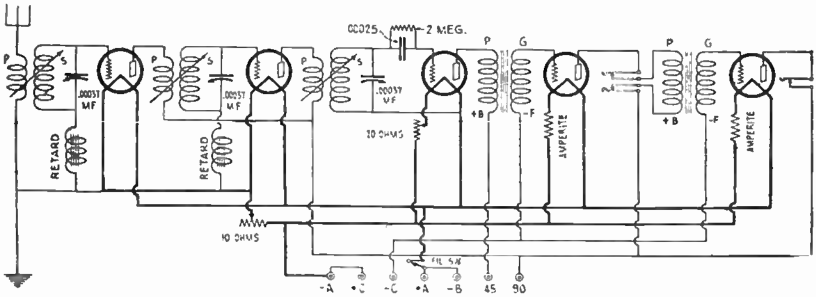

Fig. 20—Karas five-tube Equamatic circuit. The coils subject to automatic coupling variation are indicated by the three arrows.

tuned radio-frequency amplification, a detector and two stages of transformer coupled audio-frequency amplification. A tapped antenna coil is provided by means of which best coupling may be

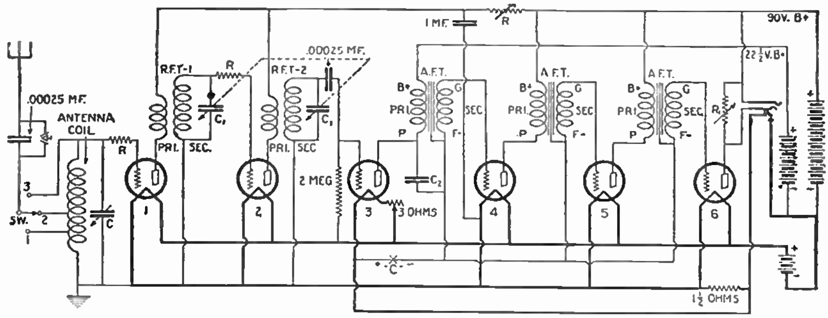

Fig. 21—The Universal Plio-6 receiving circuit

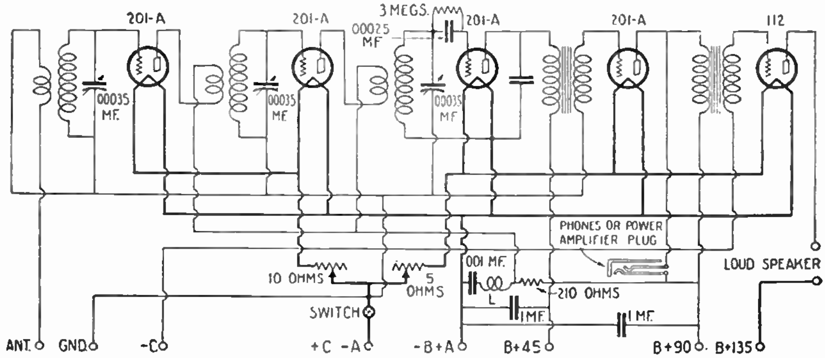

Fig. 22—Freshman Masterpiece circuit

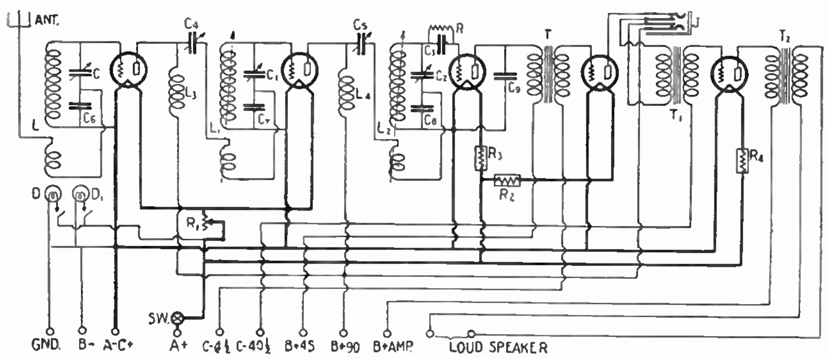

Fig. 23—Loftin-White receiving circuit

obtained by panel control for either long or short wave-lengths. The control of oscillation is accomplished by the use of an external circuit designed to feed back energy of the opposite potential, in such manner and amount to overcome or neutralize the regenerative action of the tube.

A peculiar and very fortunate result of this arrangement is that an increase in energy transfer per stage with greater amplification is realized.

The Counterphase circuit, as it is called, includes a bridge between output and input circuits. Counter potential is derived from a coil coupled inductively to the plate circuit and fed through an adjustable capacity (neutralizing condenser) to a coil inductively coupled to the grid circuit. Any connection be-

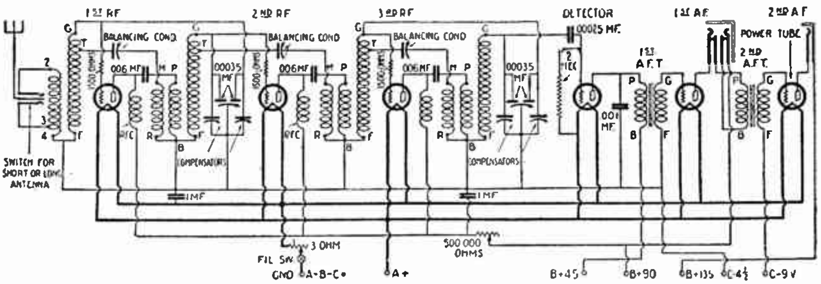

Fig. 24—The B. T. Counterphase circuit using six tubes; three stages of R. F. amplification, detector and two stages of A. F. amplification.

tween plate and grid circuits must to some extent increase grid to plate capacity, which in turn, tends to increase the tendency to oscillate. This tendency can be overcome with careful design so as to allow proper neutralization in any circuit at both the upper and lower ends of the broadcast wave-length band.

The method of balancing used in this circuit allows sufficient coupling at all frequencies without the mechanical and electrical weaknesses that prevail where attempts are made to vary the coupling between coils and other expediencies of that nature. Radio-frequency chokes are provided in the plate circuit of each radio-frequency tube, thereby effectually choking out any stray radio-frequency currents, preventing them from feeding back through the "B" supply, and coupling the radio-frequency stages or feeding frequency amplifying circuits with attendant distortion in reproduction.

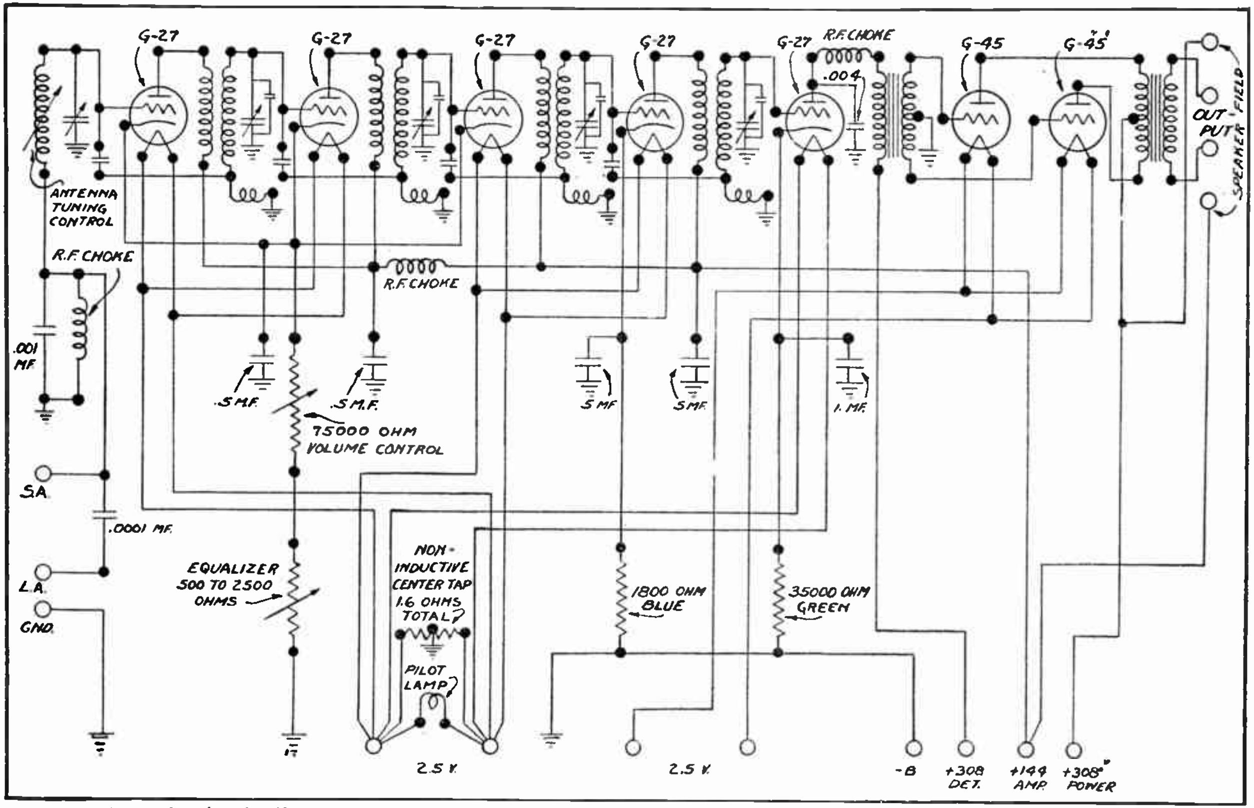

Fig. 24-A—Schematic circuit diagram of Majestic Receiver, Model 90. This receiver consists of four stages of R.F. amplification. The detector output is fed directly to the push-pull audio stage.

A resistance is inserted in the grid circuit of each of the radio-frequency tubes. The function of this resistance is one of stabilization and secures a smoother and more positive control over the entire wave-length range of the receiver.

The Hammarlund-Roberts Hi-Q receiving circuit is shown in Figure 25. This 5-tube set employs two stages of tuned radio-frequency amplification, a non-regenerative detector and two stages of transformer coupled radio-frequency amplification. Tuning has been held down to two major controls.

Shielding of the radio-frequency units produces a receiver of unusual selectivity and sensitivity, quality and volume. In theory, the Hammarlund-Roberts Hi-Q receiver is comparatively simple.

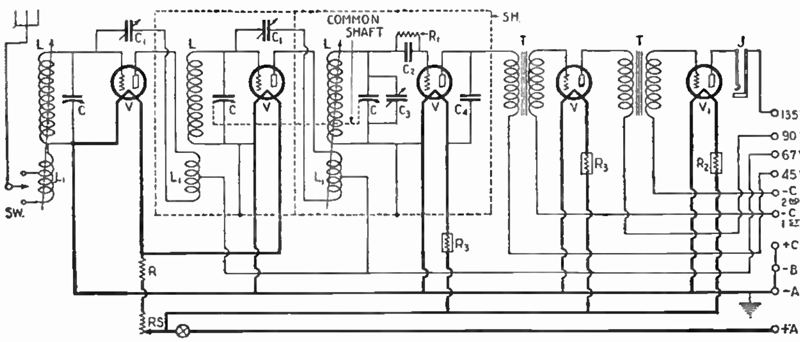

Fig. 25—The Hammarlund-Roberts Hi-Q receiving circuit

It combines the sensitivity and selectivity of two stages of radio-frequency amplification with the inherent stability and distortionless characteristics of a non-regenerative detector. While it is admitted that a regenerative detector provides a considerable degree of radio-frequency amplification, it is well known that amplification secured in this manner has many draw-backs. Chief among these is the tendency to cut side-bands, a type of tone distortion which has a very disagreeable effect when passed on to the loud-speaker.

The Leutz "Seven Seas" receiving circuit is shown in Fig. 26. The receiver employs three stages of tuned R. F., using screen grid tubes, screen grid detector, —227 first audio and push-pull power audio using two —250 tubes. The final output is fed into a dynamic speaker.

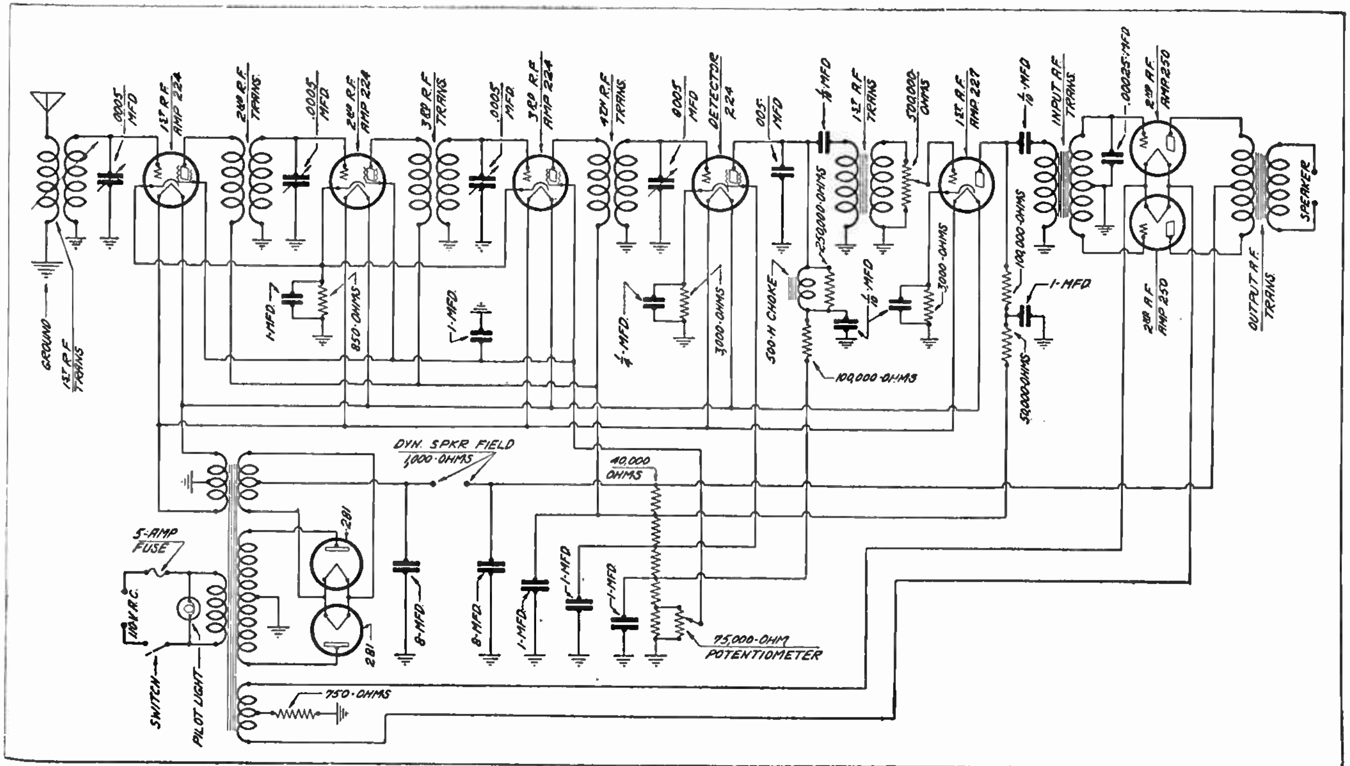

Fig. 26—The schematic circuit of the Leutz "Seven Seas" T. R. F. Receiver, using screen grid tubes.

The circuit diagram of the Browning-Drake receiver is shown in Figure 27. This consists of one stage of tuned radio-

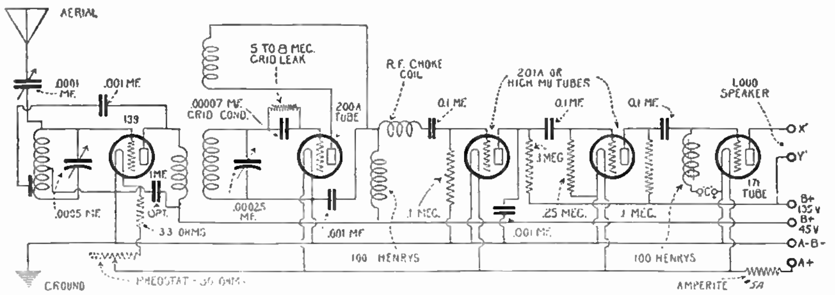

Fig. 27—Circuit diagram of the official Browning-Drake. A combination of resistance and impedance A. F. amplification is used in this receiver.

The symbol along side first R. F. coil represents a small circular plate which is adjustable at various distances from coil for neutralization.

frequency amplification neutralized, regenerative detector and a combination of resistance and impedance audio amplification.

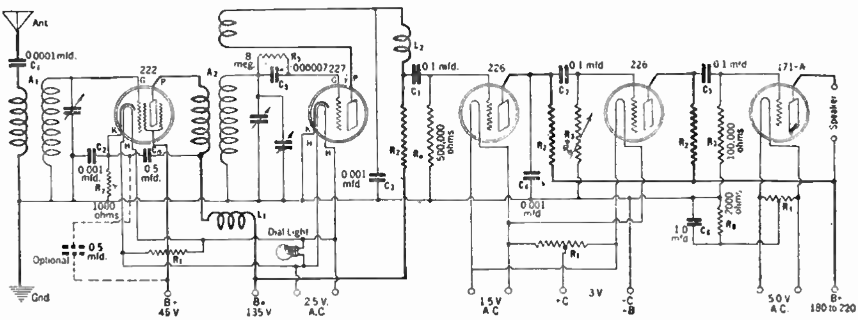

Fig. 27A—The schematic diagram of the A.C. Screen-Grid Browning-Drake Receiver.

SUPER-HETERODYNE CIRCUITS

One of the most satisfactory receiving circuits from the point of view of sensitivity, selectivity and simplicity of operation is the Super-Heterodyne. The quality of the signals is excellent because amplification is mainly done at radio frequency.

ACTION AND PRINCIPLE

The problems of radio-frequency amplification have led to the development of the famous Super-Heterodyne receiver. In

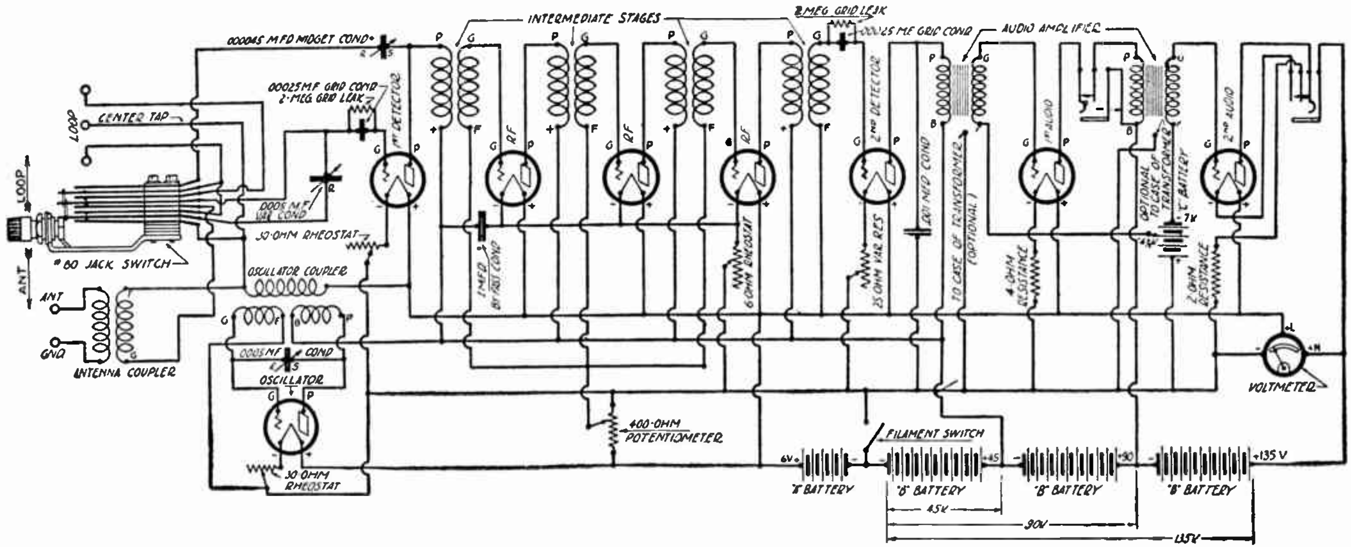

Fig. 28—Victoreen Super-Heterodyne circuit. The double scale voltmeter shown in the diagram is used to ascertain the "A" and "B" voltages at all times.

fact, the Super-Heterodyne is usually looked upon as a receiving set, whereas it is really an amplifier pure and simple introduced in a receiving set. The basic idea underlying the Super-Heterodyne is to convert the incoming signal from the broadcast frequency to the so-called intermediate frequency, which is higher than audio frequency but lower than radio frequency, and at which the signal can be amplified by means of fixed winding transformers with efficiency to almost any extent.

The intermediate frequency is generally around 30 kilocycles or 10,000 meters wave-length.

The signal is intercepted by a loop or a very small antenna for the reason that the receiver is super-sensitive and requires very little intercepted energy. The signal is converted from the broadcast frequency by the unit of the circuit known as the frequency changer. The usual method is to detect the signal by means of the first detector and then bring this signal in interference with a locally produced frequency so as to produce a beat note of the desired intermediate frequency. A beat note, as already explained in previous text-books, has a frequency equal to the difference between the two frequencies which produce it. For example, if a signal of 1,000 kilocycles is received and an alternating current of 999 kilocycles or 1,001 kilocycles is made to interfere with that signal, a beat note of 1 kilocycle (1,000 cycles) will be produced.

In the Super-Heterodyne receiver, an oscillating circuit controlled by means of a variable condenser so as to obtain any desired frequency is brought into interference with the first detector and produces a beat note for the intermediate frequency which has all the characteristics of the original signal. Thus no matter what may be the frequency or wave-length of the intercepted signal, the intermediate frequency amplification is always carried on at a fixed wave-length making for utmost efficiency. The intermediate frequency amplifier serves to amplify the signal until it is intercepted by a second detector which converts the intermediate frequency into audible frequency, the latter being passed through an audio-frequency amplifier and then to the loud-speaker.

The circuit diagrams given in this text-book show a number of popular Super-Heterodyne circuits which give excellent results if built properly. Figure 28 shows the Victoreen Super-Heterodyne receiving circuit. This is a well established hook-up con-

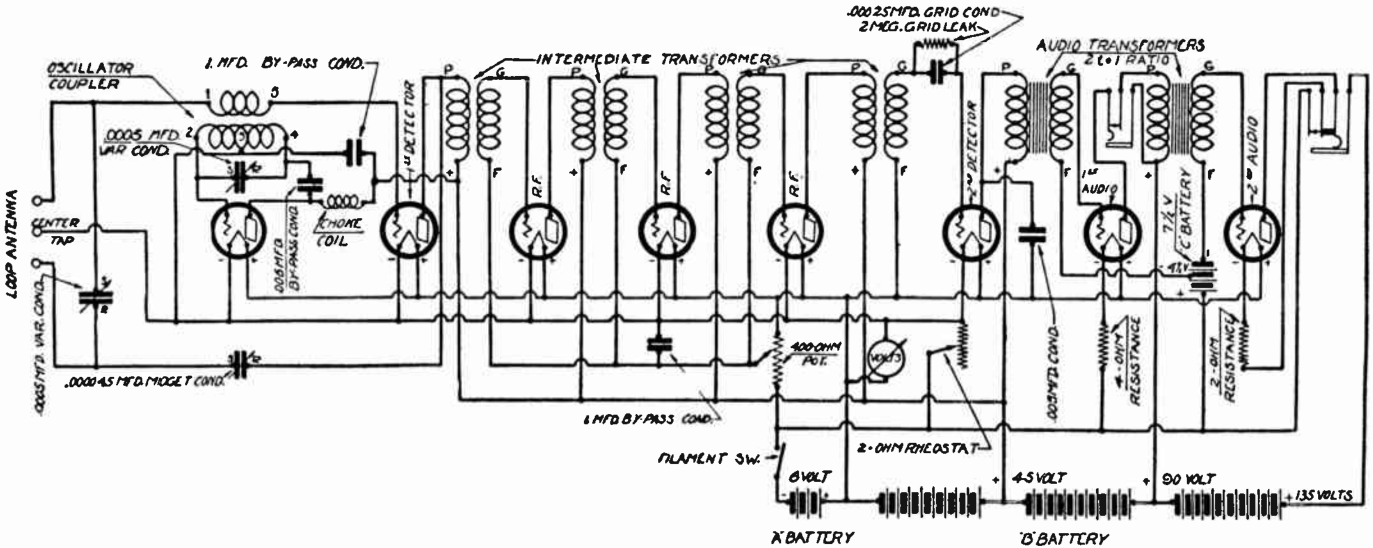

Fig. 29—St. James Super-Heterodyne circuit. A filament control jack is used in the last stage of audio. The filament circuit of the last tube is completed only when a loud-speaker is plugged in.

sisting of an oscillator, first and second detectors, intermediate frequency amplifiers, and two stages of audio-frequency amplification arranged for the use of a power tube in the last stage.

As may be observed from the illustration, a switch is provided by which either a tapped loop or antenna and ground may be used. When the switch is thrown one way, it operates the receiver on the loop, the wave-length condenser is automatically connected to the outside terminal of the loop and the tap to one end of the primary of the oscillator, which places a positive bias on the first detector tube. At the same time, the .000045 mfd. midget condenser is inserted in the plate circuit of the first detector tube to allow regeneration to be used when operating the receiver with a loop. The midget condenser is a very precise control over regeneration and serves as an excellent regulation for both sensitivity and selectivity. However, when the switch is thrown the other way, it operates the receiver with antenna and ground, the wave-length condenser is connected to the secondary of the antenna coupler which is tuned, and the outside terminals of the loop are automatically disconnected from the wave-length condenser. The midget condenser is also removed from the circuit since regeneration is not used while the set is operating from an antenna and ground system.

The Victoreen Super-Heterodyne receiver employs special air core intermediate frequency transformers which eliminate the tedious matching process and the oscillation suppressing method due to the design of these transformers. Any good vacuum tubes available may, therefore, be used without bothering to match them with the transformers.

The circuit diagram of the St. James Super-Heterodyne shown in Figure 29, employs a St. James oscillator, first detector, three stages of intermediate radio-frequency amplification, second detector and two stages of transformer coupled audio amplification.

The St. James intermediate frequency transformers are very unique in design and are the only ones of this kind now manufactured. Two air core coils, wound in a special manner to reduce inter-turn capacity to a minimum, are mounted on bakelite tubing. The coil terminals are soldered to terminal wires running to the transformer terminals. The bakelite tubing carrying the coils is mounted in a high lead content glass

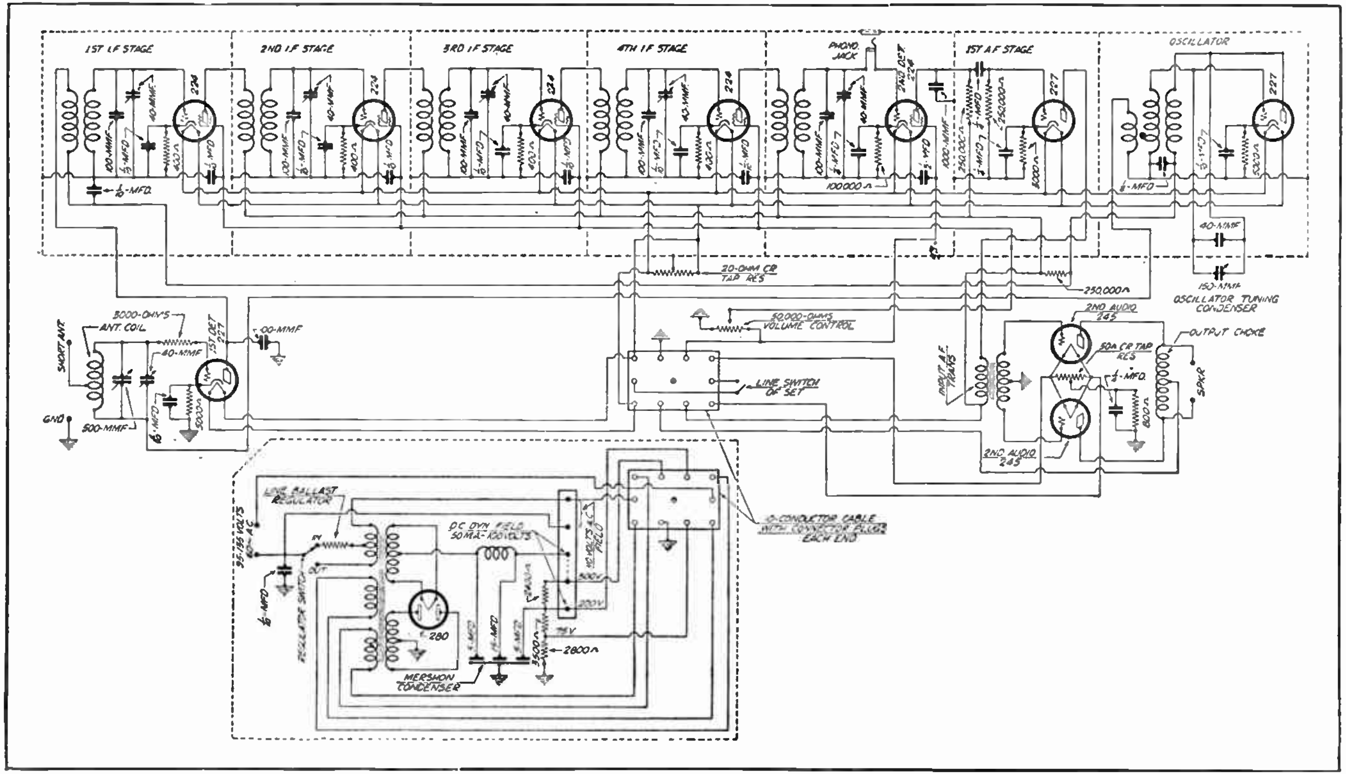

Fig. 30—Schematic circuit diagram of H F L "Mastertone" AC Super-Heterodyne Receiver using four —24 AC screen grid tubes as R. F. amplifiers and detector, —27 tubes for first detector, first audio and oscillator, —45 tubes in push-pull stage.

casing, the coils are then completely dehydrated by the repeated addition and subtraction of the dehydrated air. When delicate electrical tests prove that the last possible vestige of moisture is removed, the transformers are then sealed.

Figure 30 shows the circuit diagram of the H F L "Mastertone" Super-Heterodyne. This receiver was designed by the High Frequency Laboratories to take advantage of the amplifying ability of the —24 screen grid tube.

The Nine-in-Line Super-Heterodyne is shown in Figure 31. The oscillator and two detector tubes are operated with a common rheostat. This arrangement creates an additional helpful tuning control for lower wave signals when the oscillator dial might tune too sharply. The arrangement of the tubes from left to right is as follows: Oscillator 201-A, first detector 201-A, four intermediate frequency WX-12, second detector 201-A, first audio 201-A, and second audio UX-112.

From an inspection of the schematic diagram, it will be seen that there has been incorporated in this receiver two air core intermediate frequency transformers (filters) instead of the usual one. It is found that the passage of highly amplified signals through a second air core transformer improves selectivity to a marked degree.

However, more than three stages of air core intermediate frequency amplification tend to oscillate and cause distortion on the higher wave-lengths. Now this oscillating condition can be remedied by proper shielding or by placing the transformers at a sufficient distance apart. The air core transformers of this receiver are placed at an angle of 90 degrees to the iron core transformers so that their fields will not interfere with those of the latter. There are thus a total of four stages of intermediate frequency amplification in the combination.

The circuit diagram of the new World's Record Super-Heterodyne 10 is shown in Figure 32. This receiver is designed for operation with a short indoor or outdoor antenna of about 20 or 30 feet over-all length, a feature which contributes materially to the selectivity of the receiver.

Considering the circuit in its respective divisions, we find first, two tubes devoted to radio-frequency amplification, a first detector and oscillator, three stages of intermediate frequency amplification, a second detector and two stages of audio-frequency amplification. The output of the set is fed to the loud-

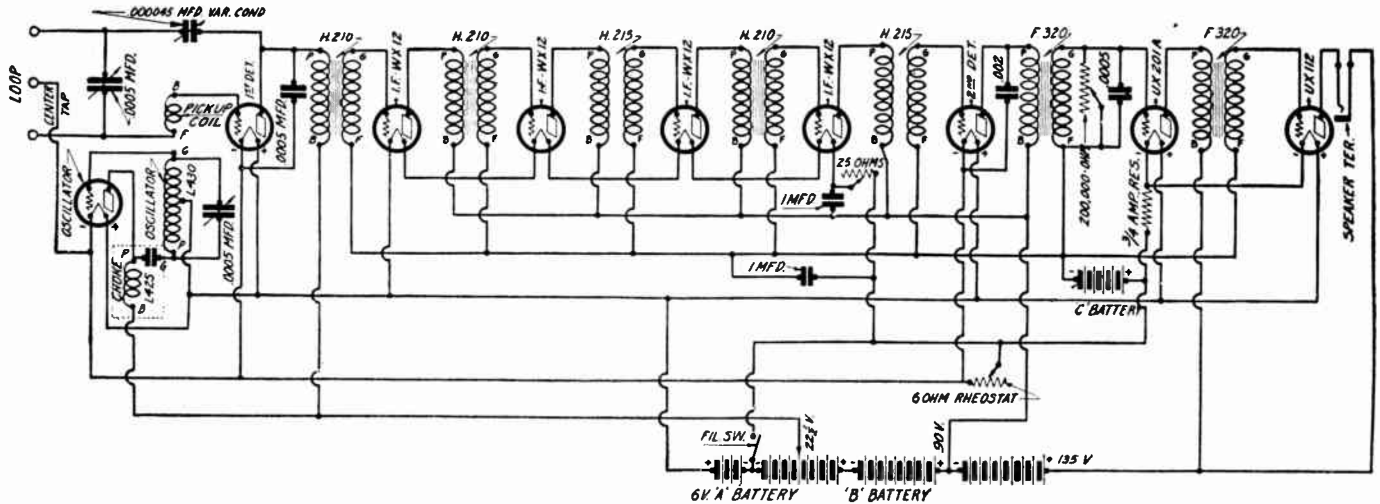

Fig. 31—Nine-in-Line Super-Heterodyne circuit. A common "C" battery of 4.5 to 6 volts is used for all grid-returns. It will be noted that this "C" battery will provide the necessary bias also for the second detector tube, so that rectification will be accomplished on the negative side of the static characteristic curve of this tube.

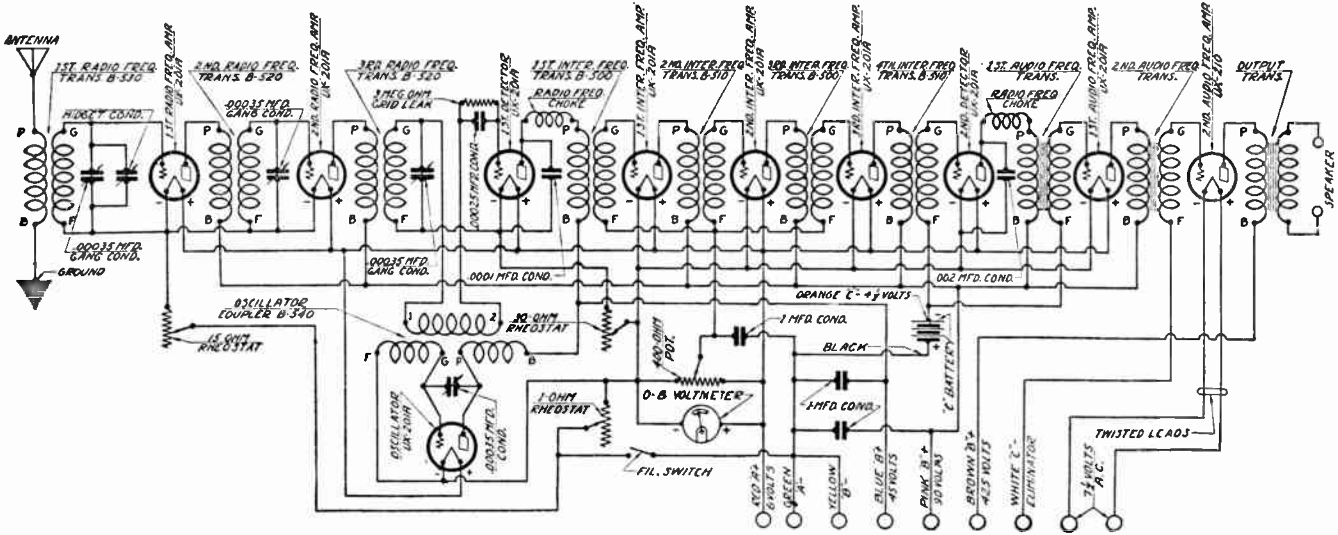

Fig. 32—Circuit diagram of the World's Record Battery Operated Super-Heterodyne receiver. The two stages of tuned radio-frequency preceding the first detector gives greater sensitivity and also extends the range of the receiver.

speaker through an output transformer used in the plate circuit of the last tube to isolate the direct potential from the loud-speaker winding.

The success you have with this type of receiver lies principally in the efficiency and perfect matching of the intermediate frequency transformers.

It is impossible to say what a receiving set will do in a given location, especially in cities, there being too many factors involved to permit any broad and sweeping claims to be made. However, if any of these receiving circuits are properly assembled and adjusted and the receiver built with the best parts obtainable it will give very good results.

TEST QUESTIONS

Number your Answer Sheet 23-2 and add your Student Number.

No. 1. Name the five classifications of receiving circuits.

No. 2. What is the chief trouble with reflex amplification circuits?

No. 3. What is the disadvantage of stabilizing a set by placing a resistance in the grid circuits?

No. 4. Draw a diagram illustrating a circuit in which the set is stabilized by the plate-resistance method.

No. 5. What is the purpose of condensers C1 and C2 in the Loftin-White circuit, part of which is illustrated in Figure 17?

No. 6. What is the chief disadvantage in using regeneration to secure radio-frequency amplification?

No. 7. Draw the circuit diagram of the Browning-Drake receiver.

No. 8. How many stages of intermediate radio-frequency amplification are in the St. James Super-Heterodyne?

No. 9. Which tube in Figure 31 acts as the second detector?

No. 10. What is the advantage of putting two stages of tuned radio frequency in front of the first detector?

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Lesson Text No. 24
(3rd Edition)

ALTERNATING CURRENT OPERATED RADIO RECEIVERS

Originators of Radio Home Study Courses
··· Established 1914 ···
Washington, D. C.

THE SECOND READING

A Personal Message from J. E. Smith

One reading is insufficient, if one is going to make a real study of a work. The second reading should be slower, but not too slow. The actual speed will depend, as in the first reading, upon the character of the book, the difficulty of the subject matter, the difficulty of the style, the reader's familiarity or unfamiliarity with the material. If in doing your first reading, you are jotting down words whose meaning you do not know, these should be looked up before the second reading. If you have not followed this practice, you should have a dictionary beside you for the second reading.

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ALTERNATING CURRENT OPERATED RADIO RECEIVERS

All radio receivers may be divided into two groups. There are the various types of radio receivers you have studied in previous lessons and which are in whole or in part operated by the current from batteries. They form one group. The other is made up of receivers that do not use batteries in any form. In this lesson, we shall study the operation of the most important type of batteryless receiver, the so-called "electric" set.

The term "electric" is confusing and really means nothing because, as your studies already have shown you, all radio receivers are operated by electricity. However, the average man has been educated to accept "electric" as meaning operated directly from the current flowing from the light wires without any intermediate apparatus such as a storage battery. Strictly speaking, a battery type receiver operated by "A" and "B" eliminators is an electric receiver, but while a "B" eliminator in some form is a vital part of all electric receivers, the use of special tubes makes it possible to do away with the "A" eliminator.

And so the radio receiver we are studying is one adapted for the A. C. tubes and fitted with a "B" eliminator. The "B" eliminator is, of course, merely an extra circuit in the receiver that takes the raw alternating current from the electric light wires and converts it into smooth direct current for use in the "B" and "C" circuits of the receiver. No way has been found to operate a radio receiving circuit on raw alternating current applied to the "B" and "C" circuits, and so the "B" eliminator which actually is a rectifier and filter circuit, is an absolutely indispensable part of every electric set. Get that firmly fixed in your mind. There is no such thing as a radio receiver that uses electric light current (alternating current) as it comes from the wires in the "B" and "C" circuits.

Before we take up the detailed study of the electric receiver, it may be well to see what possible advantages there are in this type of set as compared with the battery operated receivers studied in previous lessons.

Just as single dial tuning was developed to simplify the operation of a radio receiver, so A. C. operation literally has been forced on the manufacturers of radio receivers by the insistent demand of the average radio fan for simpler, more care-free operation.

A single dial tuned receiver will not bring in any more stations or give more selectivity than a radio receiver fitted with a separate dial on every tuning condenser. Similarly, the electric set considered from the point of view of radio reception results is no better than a battery operated receiver. From a radio standpoint, battery current is ideal. All that an electric set can do is to approach as closely as possible to the practically perfect operation of an equivalent battery operated set. The modern electric set has, however, reached that ideal so far as the ear can detect.

So much for the theoretical side of the matter. In actual operation, the electric receiver has many obvious advantages. When you want to listen, you snap the switch. When you are through, snap it again. Go away for six months and when you come back there is the set all ready to give you perfect results at the snap of the switch. No batteries to run down. Nothing to require any attention whatever unless a tube goes dead or something goes out of order inside the cabinet and such possible troubles are not peculiar to electric sets. Battery type tubes go dead and battery type sets are subject to breakdowns also.

To sum up, the electric set has no advantages over a battery operated set as far as receiving is concerned, but the electric set has manifest advantages from the standpoint of simple, care-free use.

THE A. C. TUBES

At first glance, the student who has mastered the operation of the battery type receiver is likely to think that the electric receiver using the alternating current tubes is a mysterious and complicated piece of apparatus. But the mystery, like all other mysteries, fades out of the picture when you begin to understand just how the A. C. tube differs from the battery operated tube with which you are familiar. (See Fig. 1.)

As far as the essential parts of the radio-frequency, detector and audio-frequency amplifying circuits are concerned, A. C. tubes are used just like battery tubes such as the 201A. There are the same tuning inductances, variable condensers and audio transformers used in ordinary battery circuits. And these parts differ in no particular way from the similar parts used in battery operated receivers. The wiring, too, is the same except for the filament circuits, the volume control and the method of obtaining the "C" bias.

Each of these peculiarities of alternating current operation will be treated at length, but first we must find out wherein the A. C. tube differs from the ordinary battery tube, the use of which you have mastered.

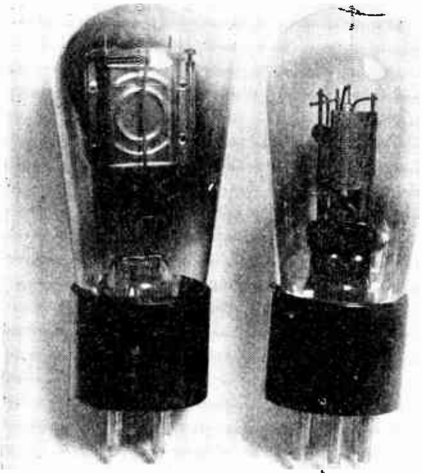

Fig. 1.—At the left is the type 226 A. C. tube which is operated by a 1½-volt A. C. current applied directly to the filament. It looks just like the 201-A battery-operated tube. At the right is the type 227 A. C. heater tube which is operated by a 2½-volt A. C. current applied to the heating filament which is inside of and insulated from the cathode from which the electron flow is obtained.

The ordinary battery operated vacuum tube has three electrodes, the plate, the grid and the filament. Just what these electrodes are for and how they work was the subject of previous Lesson Texts. In those lessons we found that the operation of the vacuum tube depends on the flow of electrons from the filament to the plate and that the function of the grid is to act as control gate to regulate the flow of these electrons. We found, also, that the "A" current which flows through the filament and heats it, performs no electrical function. If the filament could, in some way, be heated by a gas flame the tube would function.

In other words, we found that it was the heat which produced the electron flow and not the current that was passing through the filament.

Now, alternating current will heat a wire just as well as direct current. An electric soldering iron, for instance, works as well on alternating current as it does on direct current.

At this point you will quite naturally ask: If it is only the heating effect of the current that counts, why not apply alternating current to the ordinary battery tube?

As a matter of fact, you can do just that. The tube will function. The electron flow will be produced and the grid will regulate its flow to the plate. However, the experiment will not be successful because there will be a terrific humming noise from the loud-speaker.

So the problem before the scientists who developed the alternating current tube was first to find out what conditions caused the hum and then to find a way to eliminate the hum.

You can try a very simple experiment that will demonstrate quite clearly why the ordinary battery type tube will not work on alternating current. Screw a ten or fifteen watt electric light bulb in a socket supplied with alternating current. Now take some bright object such as a metal pencil or a piece of shiny wire and, while holding it so that the light glints on it, wiggle it back and forth a distance of a couple of inches, as shown in Fig. 2. You will notice that the wire seems to move in a series of tiny jumps. Try it again by candle light and the motion of the wire will seem uniform.

The flickering or jumping motion is due to the flickering of the electric light bulb. While you are moving the wire from one position to the other, the flow of the current through the filament of the lamp shifts from one direction to the other a number of times and, of course, no current flows while the voltage changes. During these extremely brief intervals when no current is flowing, the filament in the light bulb cools a trifle and the light drops off in consequence.

This is exactly what happens when you apply alternating current to the filament of a 201A tube. The temperature of the filament and consequently the flow of electrons from it increases and decreases in time with the alternations of the current.

Overcoming this flickering or pulsating effect was the chief problem in the development of the A. C. tube. It has been solved in two different ways.

One way, exemplified by the UX-226 and the CX-326 A. C.

vacuum tubes, has been to make the filament relatively very thick and heavy so that it will hold the heat and not flicker in time with the alternations of the current. (See Fig. 3.) Making the filament thicker, of course, cuts down its resistance and also makes it necessary to pass more current through it to heat it to the proper temperature. And so the 226 type tube operates on a filament voltage of 1½ and draws 1.05 amperes or slightly more than four times the current used by a 201A tube.

Other constructional details of the 226 type tube are practically the same as the 201A. The filament itself is of the same shape, an inverted V, and so are the connections to the base prongs. The 226 tube does excellent work as a radio-frequency amplifier and in the first audio stage, but it cannot be used as a detector. It could also be used in the last audio stage but as it

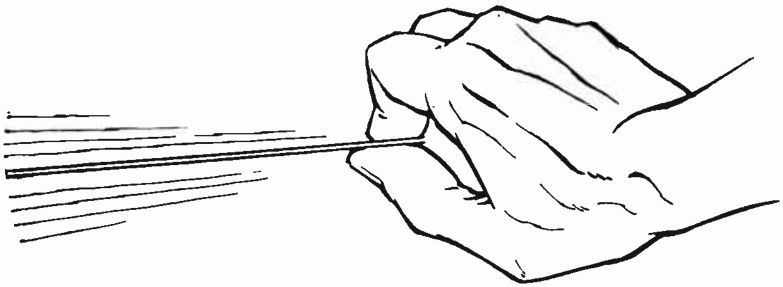

Fig. 2—Illustration showing a hand holding a thin flexible strip vibrating back and forth in front of a lamp bulb in which the filament is heated by alternating current.

would not give any better results in this stage for volume and tone quality than a 201A, it is not used in the last stage in any commercially built receiver.

THE A. C. HEATER TUBE

The detector stage of any radio receiver is, by far, the most sensitive stage in a radio receiver. Any A. C. hum introduced into the circuit at this point results in a terrific hum in the output to the loud-speaker. The type 226 tube is unsatisfactory as a detector because the residual ripple voltage that cannot quite be balanced out would cause trouble.

So the engineers have developed a still more perfect type of alternating current operated tube. The type 227 and 327 are outstanding examples. The construction of these tubes is radically different from that of the 201A. (See Fig. 4.) The plate is cylindrical and is made of fine meshed screening instead of sheet metal. The grid is a spiral of wire placed just inside the plate. Inside that is a tiny cylinder of sheet metal that is coated with oxides. This cylinder is called the cathode and emits a copious flow of electrons when heated to redness. No alternating current flows through it, however. In fact, there is no metallic connection between the cathode and the actual filament. The latter is a plain tungsten wire threaded through two extremely small holes in a tube of porcelain-like insulating material. This insulating tube is fitted inside the cylindrical cathode so that when alternating current is sent through the filament, the porcelain-like tube is heated and, in turn, communicates heat to the cathode.

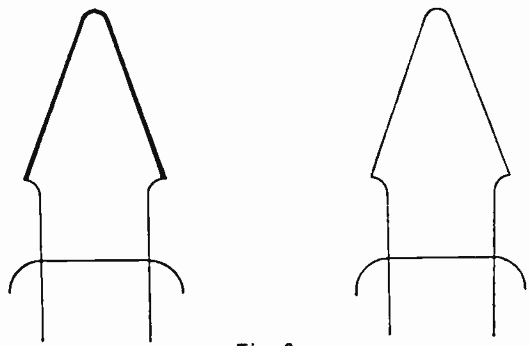

Fig. 3.

Filament 226 Tube. Filament 201-A Tube.

You can see that the possibility of an A. C. hum getting into a tube constructed in this way is very small. The plain tungsten heating filament, at the temperatures at which it is operated, radiates but few electrons and by establishing a positive potential on the heating filament, there can be practically no flow of electrons direct from the heating filament to the plate of the tube. All of the electron flow is produced by the cathode and this is not connected to the alternating current. This positive biasing of the heating filament will be discussed in detail later on in this lesson.

The type 227 tube operates on a filament voltage of 2.5 and draws 1.75 amperes. This low voltage and heavy current means that the heating filament is exceptionally heavy and the actual mass, consisting of the heating filament, the insulating tube and the metal cathode, causes the tube to get into action very slowly. From 15 to 45 seconds elapse from the time the current is turned on until the cathode becomes hot enough to throw off the maximum flow of electrons. Obviously, the rapid fluctuations of the alternating current cannot be reflected in corresponding changes in the heat of the cathode. In fact, so sluggish are the heat changes that you can break the 2½-volt circuit of any set using this type of tube for an appreciable length of time without causing any drop in the flow of sound from the loud-speaker.

By far the largest number of radio receivers sold today that are operated on alternating current use the type 227 tube in the detector stage. The 227 is, however, more expensive than the 226. Therefore in low priced receivers only one of them ordinarily is used.

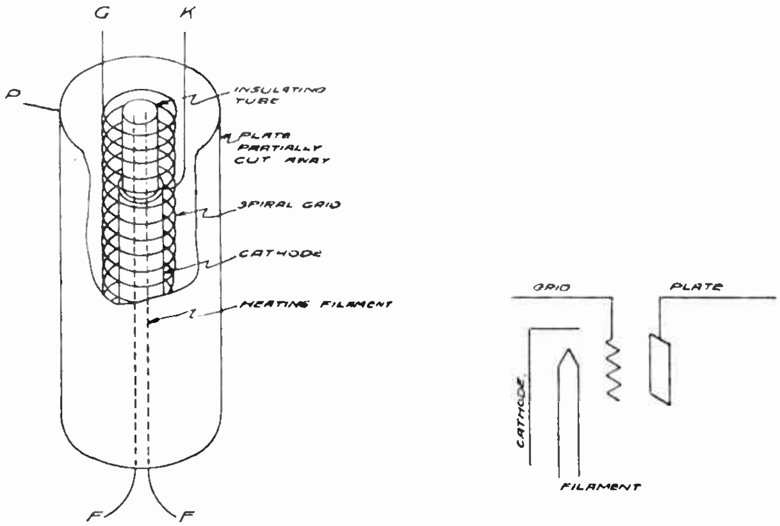

Fig. 4—Sketch showing details and symbols of AC Heater Tube (227 Type).

The 227 tube, otherwise known as the A. C. heater type, could be used in every stage of a radio receiver except, of course, the last as it is an excellent amplifier at radio and audio frequencies. Its hum-free characteristics make it even better than the 226 A. C. type as a first stage audio amplifier, and as its internal capacity is less than that of the 226 tube, it is somewhat better in the radio-frequency stages because of the lessened tendency toward oscillation.

The 226 A. C. tubes and the 227 heater type tubes are made by a number of different manufacturers and the different makes vary slightly in characteristics but these variations usually are not sufficiently great to prevent using the tubes in standard circuits. It is, however, a mighty good plan to have all the tubes of the same make as far as the radio-frequency stages are concerned as any variations in internal capacity would tend to throw the tuning out of synchronism.

Besides these two widely used tubes, there are types such as the Kellogg which is somewhat like the 227 except that instead of using a five-prong base and a socket with five holes, the Kellogg uses the standard X-type base and the heater filament terminals are brought out at the top of the tube to binding posts mounted in a cap of insulating material.

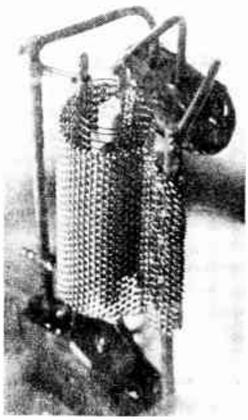

Fig. 5.—A photomicrograph of the electrodes of the type 227 A. C. heater tube (three times full size) taken through the glass of the tube. Note the wire screen plate, the spiral grid wire, the white, porcelain-like cathode insulator, at the top of which you can see the heater filament where it passes from one hole in the insulating tube to the other one.

Then there is another heater type tube known as the Arcturus.

This tube fits the standard X-type socket. This result is accomplished by connecting the cathode to one end of the heating filament.

Doubtless other types of alternating current tubes will appear on the market from time to time but it seems safe to predict that they will, in principle, be like the ones described.

POWER AND RECTIFIER TUBES

All alternating current operated receivers make use of power tubes and rectifier tubes as well as one or both of the strictly alternating current tubes described, which we have discussed under the type numbers 226 and 227.

We need not spend much time on the power tubes because you are already familiar with them in battery circuits. No special tubes have been found necessary in the last audio stage. The regular battery type power tubes will do very nicely when their filaments are supplied with alternating current at the same voltages required when direct current from batteries is used.

The type 171A tube is most widely used. It is always to be found in the last audio stage of the lower priced receivers. Two 171A tubes in a push-pull circuit are used in some receivers and more expensive sets use the 210 or even the 250.

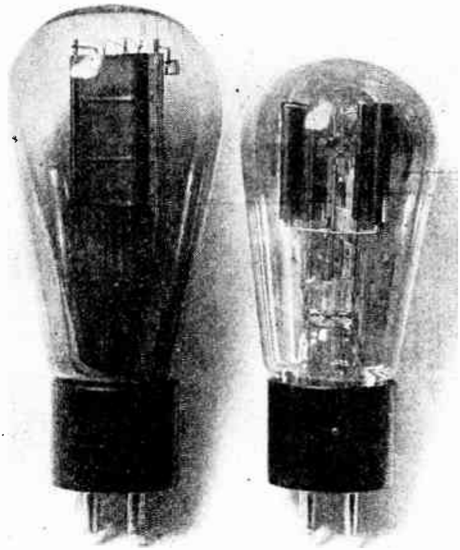

Fig. 6.—At the left is the type 281 heavy-duty, half-wave rectifier. It contains but two electrodes, the conventionally shaped plate and a heavy filament that is looped back and forth in the shape of an inverted W. At the right is the type 280 full-wave rectifier which is fitted with two plates and two filaments. The latter are connected in series.

The rectifier tubes are, of course, used in the "B" voltage supply circuits of the alternating current receivers. Three types are in common use.

THE GAS RECTIFIER TUBE

When the air in a closed vessel is partly pumped out with only a relatively few air molecules remaining, these molecules will become ionized if a high voltage is applied across two electrodes inside the vessel or glass container.

While air in its ordinary state is an almost perfect insulator, when it is ionized, it becomes a fair conductor owing to the countless number of electrons on which the current can, so to speak, ride from one electrode to the other. Now, if you make one electrode quite large and the other one very small, the current will flow much more easily in one direction than the other because many more of the flying electrons will hit the larger plate than will hit the smaller one. By a proper choice of the gas, this effect can be greatly magnified so that current in usable quantities can be passed from one electrode to the other.

This, briefly, is the principle on which the Raytheon and other similar rectifier tubes operate. (See Fig. 7.) The glass bulb is fitted with a large electrode that fits like a soldier's "tin hat" over two small electrodes that are merely wire ends. When the small electrodes are connected to the terminals of a high voltage winding on a transformer, a direct current will flow through a wire connecting the large electrode or plate and the center terminal of the winding. This direct current will, of course, be a pulsating one not suitable for "B" supply until it is smoothed out by means of a filter circuit.

The Raytheon Type BH rectifier tube and other similar tubes are operated for maximum output from a transformer winding that develops 350 volts on each side of the center tap, and the maximum current that can be drawn is 125 milliamperes. This output is more than sufficient to run any radio receiver using up to ten tubes with a 171A push-pull stage.

THE FILAMENT TYPE RECTIFIER TUBES

As you learned in a previous Lesson, a current will flow in only one direction in a vacuum tube. If an alternating current is applied across the plate and filament terminals while the filament itself is heated from an independent source of current, no flow of current will take place when the voltage is in one direction during one-half of the cycle. During the other half of the cycle, current will flow and the tube will, therefore, convert alternating current into pulsating direct current.

This is exactly the action that takes place in the type 281 half-wave rectifier tube which is used in the A. C. receivers that employ either a 210 or 250 tube in the last audio stage.

The type 281 half-wave rectifier tube has a filament that operates on 7.5 volts A. C. and draws 1.25 amperes. The maximum voltage which can safely be applied to the plate is 750 volts A. C., but in practice, usually not over 600 volts are applied. The maximum direct current output is 110 milliamperes.

We mention the type 281 half-wave rectifier tube first because it is the simplest possible type of rectifier tube. It has only two electrodes, the filament and the plate.

A far more widely used tube is the type 280 filament type full-wave rectifier tube. (See Fig. 8.) In construction it is much like the type 281. It has, however, two plates and two separate filaments. The two plates, each with an inverted V filament strung up inside, are mounted side by side and the two filaments are connected in series. In operation the current flows between one plate and the filament inside it during one-half of the cycle and between the other plate and filament during the other half of the cycle. The filament operates on 5 volts A. C.

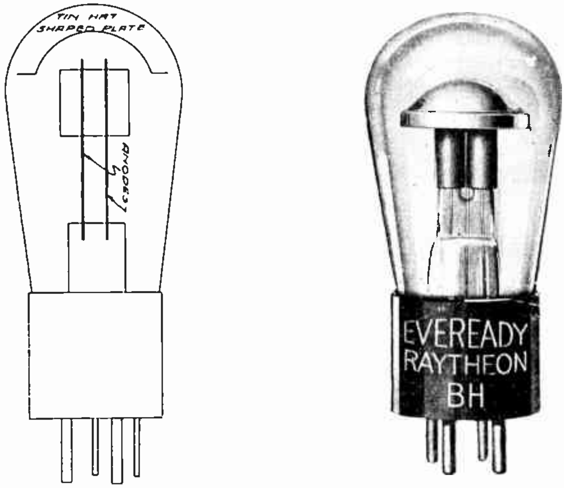

Fig. 7—Drawing and photo showing details of Raytheon Type BH Rectifier Tube.

and draws 2 amperes. The maximum safe voltage per plate is 350 and the combined output of the pair of plates and filaments is 125 milliamperes of pulsating direct current. From the output rating, you can see that the type 280 filament rectifier tube and the type BH gaseous rectifier tube have the same current output and for that reason any receiver that can be operated with one could be designed to operate the other.

When the "B" current and voltage requirements are greater than the capacity of either the type 280 full-wave rectifier or the type 281 half-wave rectifier, it is customary to connect two type 281 half-wave tubes with the filaments in parallel and apply up to 600 volts to each plate from a center tapped 1200-volt winding and in this way secure full-wave rectification. Such a circuit will supply up to 220 milliamperes at an actual working voltage of

500. This amount of current will take care of two type 250 power tubes in the push-pull circuit, supply all "B" and "C" current for any receiver, and in addition, supply 40 or 50 milliamperes to energize the field winding of a dynamic loud-speaker.

A CURRENT FOR A. C. TUBES

Perhaps the most valuable characteristic of alternating current is that you can take it at any voltage and by a simple piece of apparatus containing no moving parts, step it up to any desired higher voltage, or down to any wanted lower voltage. This you cannot do with direct current unless you employ an expensive motor-generator or rotary converter. That is why the use of alternating current is steadily increasing, while the use of direct current is largely confined to small, isolated power plants and to a few large cities where direct current was in use before alternating current became a practical possibility.

Stepping the voltage of alternating current either up or down is accomplished by means of a piece of apparatus known as a transformer. You already are familiar with it as the audio transformer used in each stage of a transformer coupled audio amplifier. It consists of a laminated iron core with two or more coils of wire wound around one leg of the core. One coil is connected to the source of current. This is called the primary. The other coil is called the secondary, and from its terminals, a current may be drawn, the voltage and amperage of which will depend on the size of the core, the number of turns in the primary and the number in the secondary. If the core is of adequate size, the voltage induced in the secondary winding will be in proportion to the number of turns in the primary as compared with the number of turns in the secondary. If, for example, the secondary has twice as many turns as the primary, the voltage developed will be twice the voltage applied to the primary. If half the number of turns, the voltage will be one-half and so on.

You must get clearly fixed in your mind that an alternating current transformer does not increase the total power. That would be impossible. When the voltage is stepped up, the output current is cut down. When the voltage is lowered, the output current is increased. The voltage applied to the primary, multiplied by the amperes flowing in the primary winding, always is a trifle greater than the voltage developed in the secondary multiplied by the current in amperes that can be drawn from the secondary winding. Remember this simple relation because it will enable you to figure out the current drawn from the light line for any electric receiver if you know how much "A" and "B" current is used in the set and the voltages.

From this discussion of alternating current transformers, you can see how the necessary low voltage alternating current required by the tubes we have discussed can be obtained.

Transformers with a winding suitable for connection to 110-volt alternating current are constructed with a secondary winding that will deliver the required low voltages.

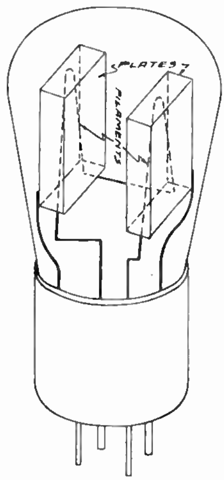

Fig. 8—An exposed view of the filaments and plates of a 280 filament type full-wave Rectifier Tube.

As a large number of electric receivers use types 226, 227, 171A and 280 tubes, four different low voltages are needed, and several secondary windings are placed on the same core. Each of these windings must be separate and distinct from all of the other windings and most carefully insulated from them. Each of these windings, except the 1½-volt winding that is to supply the 226 tubes, must have a tap brought out from the exact electrical center of the winding.

"B" CURRENT FOR A. C. RECEIVERS

We have seen that it is possible to use a transformer to step up the voltage as well as to step it down and these two functions can be performed by the same transformer. It is common practice to do this in electric receivers. In addition to the low voltage windings already mentioned, a high voltage secondary winding-ing is placed on the same transformer. This ordinarily has about five to six times as many turns as the primary and is center-tapped so that there is available from 250 to 300 volts alternating current on each side of the center tap.

This high voltage alternating current is first rectified into a pulsating direct current, then sent through a filter circuit consisting of chokes and condensers to take out the pulsations and smooth it into usable direct current, and after that it is applied to a resistance network to cut the voltage down to the amount required for each of the "B" circuits in the receiver.

Fig. 9.—A typical filament heating transformer suitable for heating the filaments of the tubes in the conventional type of electric set. The two binding posts at the top give 1½ volts. The middle row, 2½ volts with a center tap and the lower row, 5 volts with a center tap. The size can be judged by comparing it with the electric plug beside it.

Figure 10 shows a standard circuit used to accomplish these results and we will study it very carefully because if you understand it thoroughly you will know how all "B" supply circuits work since they vary only in minor details.

At the left is a transformer such as is used in thousands of electric receivers. Note the four low-voltage windings and the high-voltage winding. The 1½ volt, 2½ volt and one of the 5-volt windings are used to supply the "A" current for the tubes in the radio receiving circuit. The remaining low-voltage (5-volt) winding is connected to the filament terminals of the socket in which the type 280 full-wave rectifier tube is inserted. The ends of the high-voltage winding are connected to the two plates of the 280 tube (the G and P binding posts of the X-type socket). As soon as the current is applied to the primary of the transformer, the twin filaments in the 280 tube heat and current starts to flow first from one plate and then the other, the center tap of the 5-volt winding always being positive with respect to the center tap of the high-voltage winding.

This high-voltage pulsating direct current first flows into and charges the condenser C1. Then it starts to flow through choke A. The choke consists of an iron core with a coil around one leg containing a large number of turns of wire. The electro-magnetic action of a choke is such that it violently resists any change in the amount of current flowing through it. As long as a steady direct current flows through a choke, it offers no more resistance to the flow than would an equivalent amount of wire wound around a wooden spool, but as soon as the rate of flow starts to change, the magnetic field goes into action and does its best to prevent the change. It makes no difference to

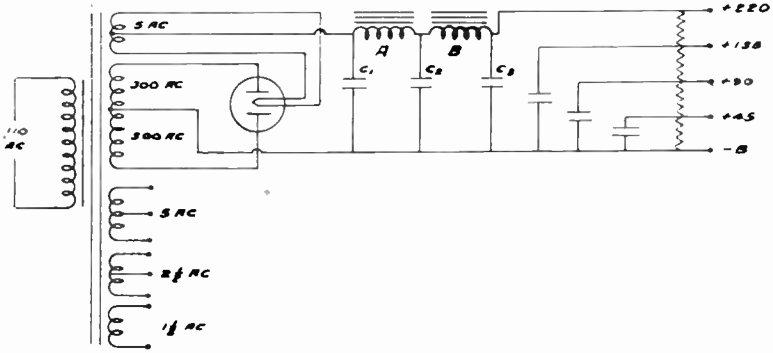

Fig. 10—Circuit diagram showing power transformer and "B" supply unit.

the choke whether you try to increase the flow or to decrease it. The choke is dead set against any change.

The choke in the world of electricity is the equivalent of the "stand-patter" in politics. He is the fellow who always is opposed to any change no matter what it is.

As a result of the opposition of choke A, the flow of current from condenser C1 into C2 is impeded and the peak voltage of the pulsation is removed. The same thing happens again as the current flows from condenser C2 into C3 because of the effect of choke B so by the time the current reaches the end of the resistance, it is practically smooth direct current.

There is nothing mysterious about the action of a filter circuit such as this. Any degree of filtering action can be obtained by increasing the capacity of condensers C1, C2 and C3 and the inductance (ability to resist change in current flow) of the chokes A and B. Of course, the larger the chokes and condensers are made, the more expensive they become, so the manufacturer of the low-priced set is forced to use the smallest chokes and the least amount of condenser capacity that will give reasonably satisfactory filtering action. From this you would expect to find that the amount of hum produced in the loudspeaker by a low-priced set would be more pronounced than that produced by a very high-grade outfit and this actually is the situation.

However, it is well to remember that elaborating the filter system beyond a certain point is not worth while even in the highest priced receivers. A lingering trace of alternating current hum always creeps into the receiver due to capacity pick-up between wires and the A. C. operation of the filament circuits.

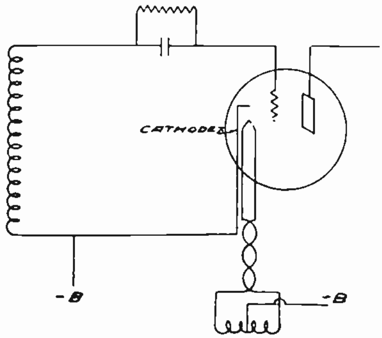

Fig. 11—Detector circuit using 227 type vacuum tube.

As long as the filter system of the "B" circuit is adequate to prevent adding appreciably to this residual hum, additional condenser capacity or the use of larger chokes would represent money spent uselessly.

OBTAINING THE VARIOUS "B" VOLTAGES

In Figure 10 you will note that after the current has passed through the filter it reaches the resistance that is used to obtain any desired voltage below the maximum.

Theoretically, the voltage measured from any point on the resistance to the minus or negative end is proportional to the resistance between that point and the negative end as compared with the value of the entire resistance. Thus, if 180 volts is applied to the ends of the resistance, a very high resistance voltmeter would register 90 volts between the negative end and the mid-point on the resistance. This is true no matter what value in ohms is the resistance of the unit that is connected across the 180-volt terminals.

In practice, however, this result is not obtained because the effect of drawing current from the taps lowers the voltage obtained below the no current voltage at that point. And the greater the resistance of the whole unit, the greater the drop will be for any given current drain.

That is why, in the "B" supply circuit diagrams you examine, you will find that the values of the resistances between the various taps do not agree with the theoretical voltage drops. The 90-volt tap is always nearer the high-voltage end than the negative end and so on.

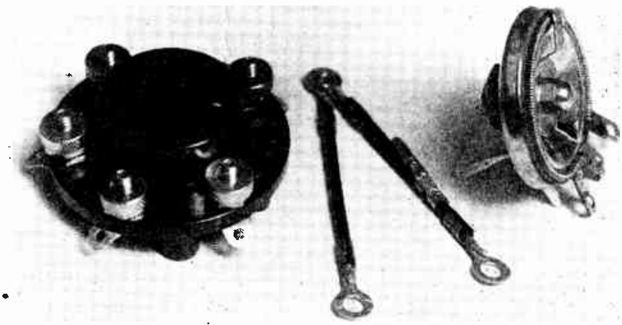

Fig. 12.—The socket at the left is the UY type which takes the type 227 A. C. heater tube. It has five holes. The one slightly separated from the others is the grid connection. At the center is an ingenious arrangement for securing a neutral grid-return for use on filament heating transformers not equipped with center tapped windings. It consists of two exactly equal wire wound resistances fastened together at one end flexible enough so that it can be fitted to the filament terminals of any socket. At the right is a low resistance potentiometer designed for use in balancing out the hum on the 226-type tubes.

You will note that a condenser always is connected between each voltage tap and the negative end. These act as small current reservoirs and steady the voltage. Without them, the tone quality would be affected, especially on the low notes, and the radio-frequency stages would have an uncontrollable tendency to oscillate because each voltage change in any stage would be impressed on the other stages.

All "B" supply circuits are, in principle, exactly like the one in Fig. 10, so that once you have mastered what goes on in this circuit, you will have a good working knowledge of all others. Sometimes only one large choke is used and all sorts of variations exist in the resistance network. You will find by a careful study, other resistance arrangements are merely different paths to the same goal—the matter of obtaining lower voltage by putting a resistance in the path of the current.

OBTAINING "C" BIAS IN ELECTRIC RECEIVERS

In your study of battery operated radio receiving circuits, you have found that the grid circuit, which is connected to the grid of the tube, has its other end always connected to one side of the filament, either directly to the filament terminal of the socket or by way of the filament wiring.

In electric receivers, the same procedure may be followed only with the detector tube which is of the type 227 heater variety. However, the grid-return wire in this case is connected to the cathode terminal as the cathode supplies the electron flow, and not the filament which is merely a heating element and takes no part in the action of the tube. The cathode also is connected to minus B. By this arrangement, the conventional grid leak and grid condenser can be used. Figure 11 shows a type 227 tube in a detector circuit. Note that the center tap of the filament transformer secondary is connected to —B terminal so as to place a difference of potential between the cathode and filament to minimize hum.

With tubes such as the type 226 used in the radio and first audio amplifier stages, and the type 171A used in the last audio stage, where the electron emitting filament has alternating current passing through it, the grid-return must be made to the filament at a point where there is no alternating current voltage. A center tap on the 5-volt winding that furnishes current for the 171A tube supplies the required no voltage point for this tube.

In the case of the 226 tubes, however, it is necessary to use a potentiometer in order to obtain an adjustable center point on the 1½-volt winding. This is needed to balance out any hum that may arise from slight irregularities in the construction of the 226 tube and variations in the A. C. power supply.

Theoretically, the same necessity for balancing exists in the case of the 171A tube, but in practice it is not necessary, because any hum introduced in the last stage is not amplified many times as is the case when the hum is introduced in the first audio stage.

Now that we have found out how to make the grid-return connection without introducing an appreciable amount of A. C. hum, we are ready to find out how to develop the required "C" voltages and to apply them to the grids of the radio and audio amplifier tubes.

In your previous studies, you have learned that whenever a current of electricity is forced to travel through a resistance that voltage is used up in the process, and that a voltmeter connected across the terminals of the resistance will indicate the amount of voltage that is used. In other words, when you pass a current of electricity through a resistance, an amount of voltage is developed at the terminals of the resistance which is determined by the value of the resistance in ohms multiplied by the amount of the current in amperes.

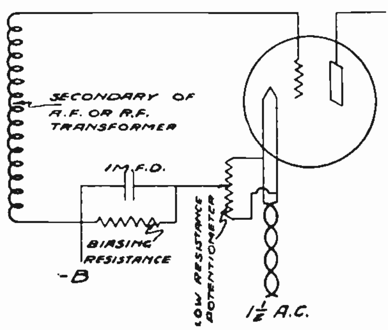

Fig. 13—Circuit of A. C. tube showing connections to "C" biasing resistance.

So, all we have to do to obtain a "C" voltage for our electric receiver is to pass some current through a resistance and the desired "C" voltage will appear at the terminals of the resistance provided, of course, that the resistance is of the right value in ohms.

The only current we have available for passing through the resistance is the plate current of the tubes, so we place the resistance where the plate current will be forced through it in its travel between the plate and the filament. This means, of course, that whatever "C" voltage we develop in this way will be subtracted from the effective plate voltage, but that is no disadvantage since we can increase the plate voltage to make up for the loss.

Figure 13 shows the circuit for a single tube. Note that the "C" biasing resistance is connected between minus B and the movable arm of the potentiometer that is connected across the A. C. filament winding. We could substitute the center tap of the low voltage winding for the movable arm with exactly the same result, as the resistance of the potentiometer is so low that it can be neglected in the calculation of "C" bias voltages. Also, coil A may be either the secondary of a radio-frequency transformer or of an audio transformer. The result as far as the "C" bias is concerned is the same in either case.

The plate current necessarily must flow through the resistance in traveling between minus B and the filament. The direction of flow is such that the end of the resistance connected to the filament is positive with respect to the other end which is connected to the grid of the tube by way of the secondary winding.

Now, suppose we want to find the value in ohms of a resistance which will properly bias a type 226 A. C. tube. We have, for instance, decided to operate the tube on 90 volts B. We find, on looking up the rating of the tube, that the "C" voltage should be minus 6 when the plate voltage is 90. If we don't know what the plate current should be under these conditions, all we can do is to put an adjustable resistance in the circuit and keep changing it until we have the "C" voltage reading 6. But if we also know what the plate current should be, we can divide the rated "C" voltage by the rated plate current and the result will be the value of the biasing resistance in ohms. Assuming that the plate current of the type 226 tube should be 3 ma. at 90 volts B with a 6-volt C bias. Dividing 6 by .003, the value of the plate current in amperes gives us 2000 ohms as the correct biasing resistance. It so happens that the 2000 ohms biasing resistance which is correct for a single 226 tube operated on 90 volts B also is correct for a 171A tube operating on 180 volts B. The 171A tube requires 40 volts C bias and the plate current is 20 ma. Forty volts divided by .02 amperes gives 2000 ohms. In the one case, the 2000-ohm resistance produces a 6-volt C bias and yet exactly the same resistance produces 40-volt C bias in the second case because of the heavier plate current.

When more than one tube is biased by the same resistance, the value of the resistance must be lowered in proportion to the increase in the plate current. Thus in a receiver using three 226 tubes in the radio-frequency stages, the biasing resistance should be one third of 2000 ohms which would amount to 666 ohms. Similarly, when two 171A tubes are used in a push-pull circuit, the plate current is doubled and the biasing resistance is halved to 1000 ohms.

When a biasing resistance is common to more than one tube it should be by-passed by a 1 microfarad condenser to prevent interaction and the consequent tendency to oscillation, and for best results, every biasing resistance should be by-passed.

VOLUME CONTROL ON A. C. SETS

Controlling the volume of a battery set is easy. Decreasing the filament current of one or more of the radio-frequency amplifier tubes by means of a rheostat gives complete control from full volume to absolute silence.

In A. C. sets, this simple procedure cannot be followed for two reasons. First, because it would be necessary to use a complicated double rheostat so as to add resistance to both sides

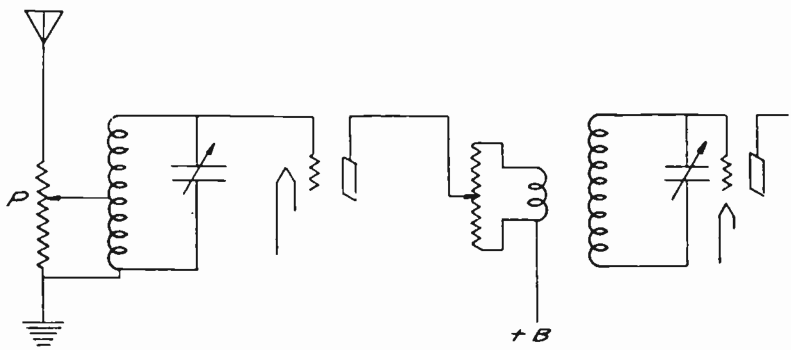

Fig. 14.

of the A. C. filament winding at the same time. Second, because the balance between plate voltage, C bias and plate current would be disturbed resulting in a critical control that would be particularly bad on tubes that respond slowly to changes in filament current.

The best practice is to allow all the tubes to operate at maximum efficiency and then "kill" the signal either before it reaches the first tube or as it passes from one radio-frequency stage to another. In some very sensitive receivers, both methods are resorted to.

The first method is carried out by fitting a high resistance, non-inductive, non-capacitive potentiometer in the antenna circuit as shown in Fig. 14. The reason why the potentiometer must have little capacity between its terminals or in the resistance element is because on strong local signals, capacity of this type will permit the radio signals to pass to the radio receiver around the resistance by way of the capacity.

When the volume is controlled between two of the radio-frequency stages, the usual method is to fit a potentiometer across the plate coil. The signal can then be shunted around it and thus not affect the grid coil of the following stage.

Now that we have studied the peculiarities of alternating current operated tubes which distinguish them from battery type tubes, we can proceed to investigate the circuits of a number of electric receivers and see how the A. C. tubes are used in actual practice.

MANUFACTURE OF A. C. RECEIVERS

Before we take up the examination of the actual circuits of a number of factory built receivers, it will be well to look into some of the factors that govern the design and production of radio receivers and every other manufactured product for that matter.

First and foremost is the cost of production. The shadow of the dollar sign hangs over every step in the making of a radio receiver. The radio manufacturer is not in business for his health any more than the maker of any other product. He must make a profit or cease operations, and if he is to make a profit in a highly competitive market, he must economize at every point where economy is possible.

Naturally, the fiercest competition is between the makers of the lowest priced receivers, and least in the higher priced classes where the difference of a few dollars in the selling price is of less relative importance.

This explains why, in spite of advertising claims to the contrary, a low-priced radio set is not as good as one that costs a lot more money, assuming, of course, that each of the sets compared is the product of a reliable manufacturer who is turning out the best set he can for the price at which he sells it.

In this lesson, we are interested in this matter only in so far as it applies to A. C. sets. So let us examine the ways by which a manufacturer of A. C. sets may reduce his costs without seriously impairing the product.

Really high-grade audio transformers are available today that will reproduce audio frequencies with considerable intensity below 60. Cheaper audio transformers can be substituted that will not respond to frequencies below 200. This means an economy in the cost of the audio transformers, but what is still more important to the maker of an A. C. set, the use of the cheaper transformers will permit him to use smaller chokes and

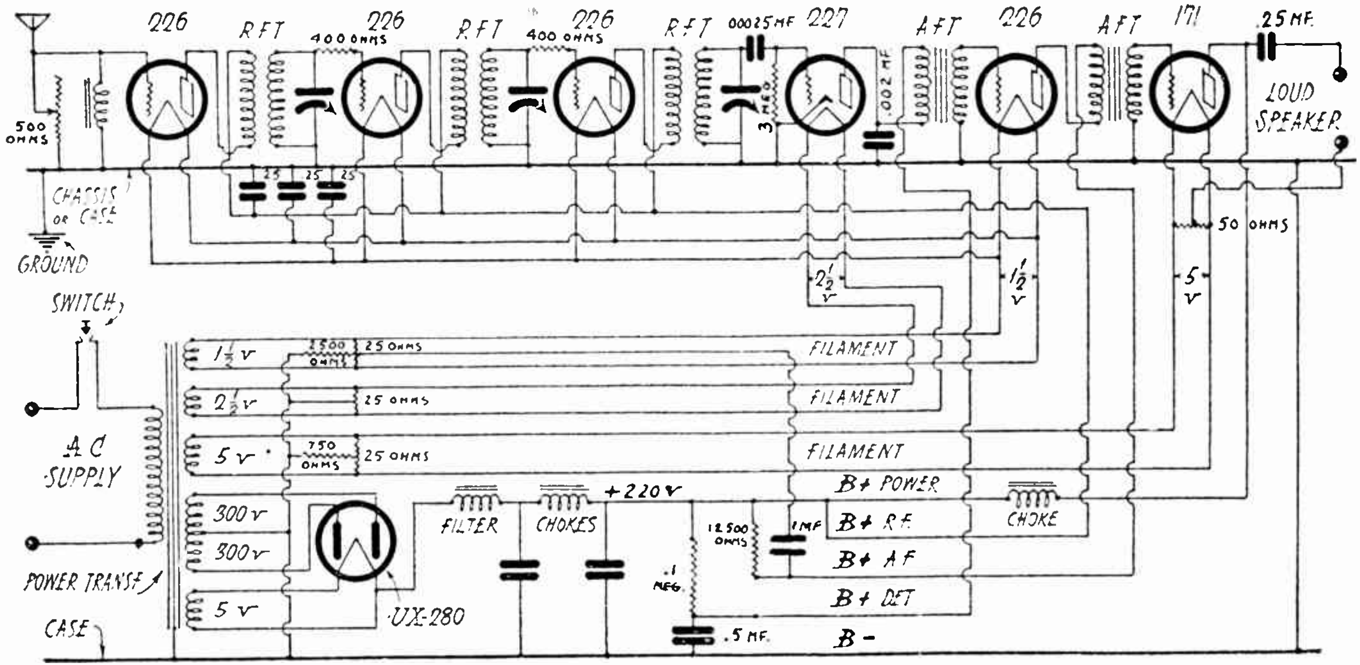

Fig. 15.—Circuit of Atwater Kent Model 37 Receiver.

lower capacity condensers in the "B" supply filter system because the cheap transformers will not reproduce the alternating current hum of either 60 or 120 vibrations.

Curiously enough, a receiver with poor audio transformers may appear to be capable of giving more volume without distortion than can be obtained from a set using high-grade transformers. This is because the low notes require more power to reproduce in sound waves.

Another possible change that brings manifold economies is to operate the 171A power tube at 135 instead of 180 volts. The lower voltage imposes less strain on the filter condensers and cheaper condensers can be used. An indication that the power tube is being operated at less than its full rated voltage is the rating of the resistance that is used to obtain the C bias. If materially below 2000 ohms for a single 171A tube, you can be sure that the "B" voltage also is below 180.

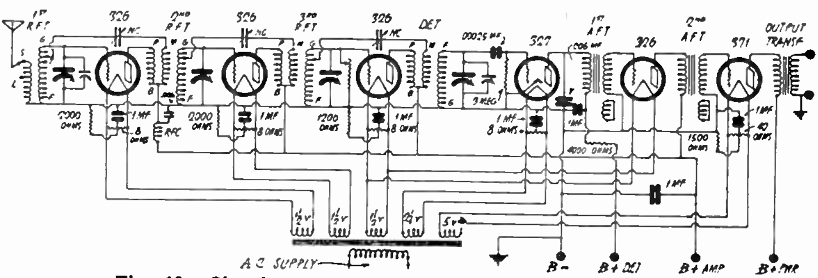

Fig. 16.—Circuit for A. C. Bremer-Tully Counterphase 8.

Of course, you must understand that an almost limitless number of minor variations can be made in individual circuits. Not all of these are for the sake of economy. In most cases, they are made to secure maximum results under the conditions existing in the particular circuit.

FACTORY BUILT A. C. RECEIVERS

The circuit of the Atwater Kent Model 37 A. C. receiver is shown in Fig. 15. This receiver has a 3-stage tuned radio-frequency amplifier using type 26 A. C. tubes, a type 27 detector, and two stages of transformer coupled audio-frequency amplification, using a —26 and a —71 tube. The latter is impedance coupled to the loud-speaker and has its filament operated from a 5-volt winding on the power transformer.

Filament balance in the radio-frequency and first audio-frequency stages is obtained by means of a center tapped fixed

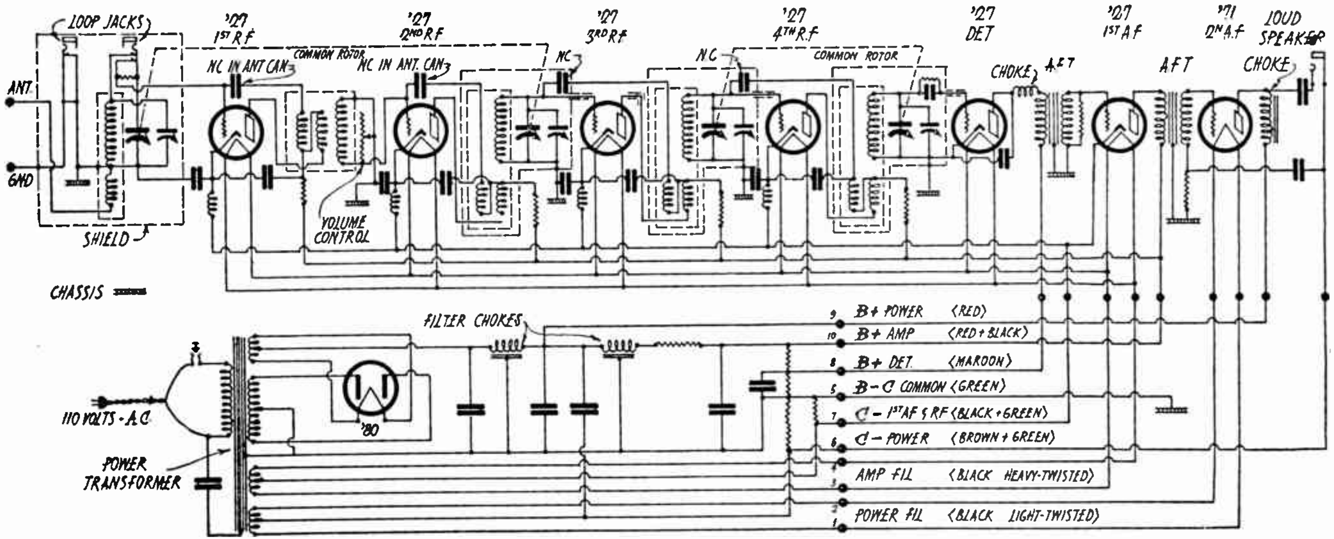

Fig. 17.—Circuit of the Fada 7-tube A. C. Receiver.

resistance located in the power unit, and in the case of the power tube, —71, a balancing resistor for the loud-speaker return lead is shunted across the filament circuit in the receiving set, and another center tapped resistor is placed across the filament lead, for the negative B connection, in the power unit. Fixed resistances cut down the effective "B" voltage from 220 volts to 45 and 90 volts, for the detector, radio-frequency and first audio-frequency tubes, and a total of 180 volts is supplied to the power tube, with 40 volts negative bias through the voltage drop in the resistance placed in the negative "B" circuit. The volume control on this receiver is obtained by means of a 500-ohm potentiometer shunted across the radio-frequency choke, which is placed between the antenna and ground connections, with the grid of the first radio-frequency tube connected to one side of the choke. The filament circuit of the radio-frequency amplifier is by-passed with .25 mfd. condensers to prevent oscillation due to the presence of resistance in the grid-return lead to the radio-frequency tubes.

In Figure 16 is shown the circuit diagram of the Bremer-Tully Counterphase 8 A. C. receiver, which is a 6-tube set, having three stages of neutralized radio-frequency amplification, detector and two stages of audio. Radio-frequency amplifying tubes are balanced individually with center tapped 8-ohm resistances and a C bias for each tube is obtained by the voltage drop in the "B" negative connection to the center tap of the 8-ohm resistance. A 1 mfd. condenser is connected across the C biasing resistance in each stage and in the first radio-frequency amplifier, a .006 mfd. fixed condenser is connected between the positive B terminal of the first radio-frequency amplifier and the center tapped resistance. No positive bias is placed on the detector tube heater element, but a system of A. C. balance is installed, consisting of an 8-ohm center tapped resistance with a 1 mfd. condenser between the center tap and the cathode. No circuit is shown for the "B" voltage supply but it is practically the same as for any other factory built receiver.

Figure 17 shows the circuit diagram of the Fada 7-tube A. C. receiver, together with the power equipment. This receiver supplies four stages of tuned radio-frequency, with either loop antenna or outdoor antenna. The radio-frequency stages are of the neutralized type and by the use of an elaborate system of shielding, together with other precautions, such as radio-frequency chokes in the leads to the cathode of each A. C. tube in

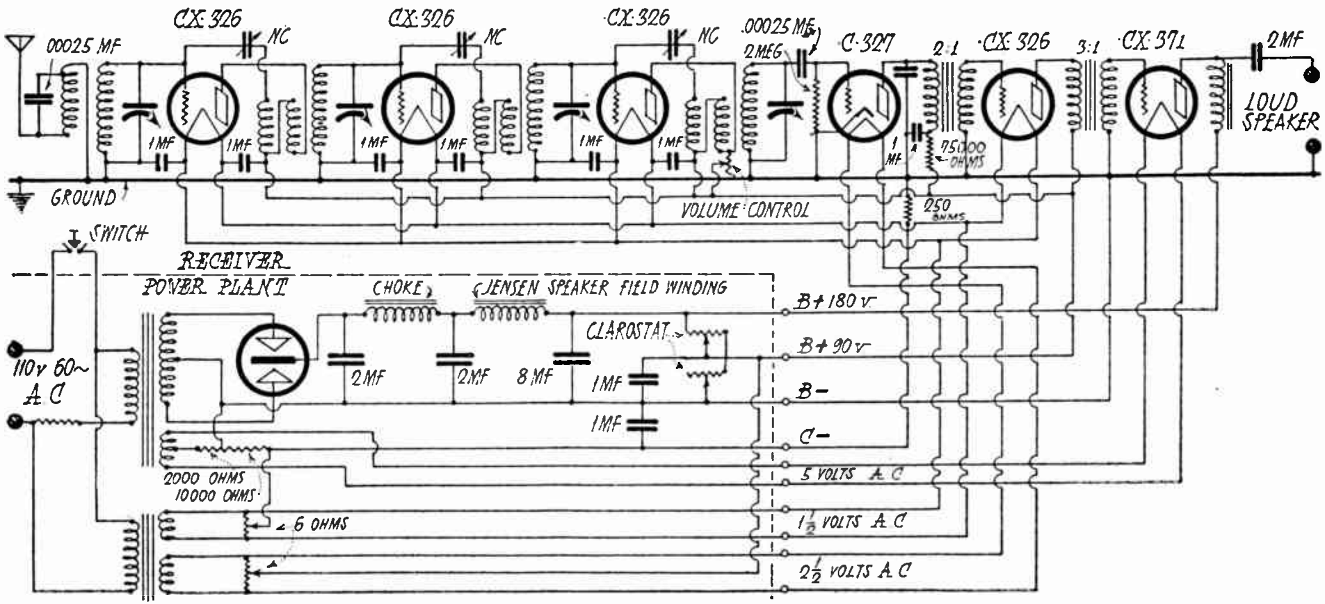

Fig. 18.—Circuit of the Gilfillan A. C. Model 60 Receiver.

the radio-frequency amplifier, a non-oscillating receiver is produced. Volume control is obtained by shunting a variable high resistance across the secondary of the first radio-frequency transformer. The power unit consists of a full-wave type 380 rectifier tube, supplying 180 volts for the 71 power tube and the various intermediate voltages for the radio-frequency, audio and detector tubes. It will be noted that all the tubes in this receiver, except the power tube, are of the heater type; only two windings for filament supply are contained in the power transformer.

Figure 18 shows the circuit diagram of the Gilfillan A. C. receiver, Model 60, which is a 6-tube Neutrodyne. The volume control, instead of being in the antenna circuit like a good many

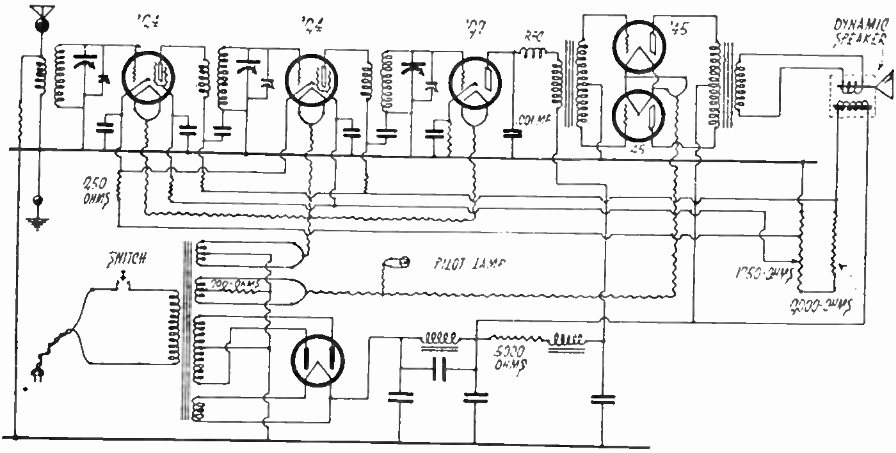

Fig. 19—Circuit diagram of Philco Receiver, Model 65.

A.C. receivers, consists of a 2000-ohm variable resistance shunted across the primary of the last radio-frequency transformer so as to control the input to the detector tube.

The circuit diagram of the Philco Model 65 A. C. five-tube receiver is shown in Figure 19.

Two —24 A. C. screen grid tubes are used as R. F. amplifiers, —27 power detector with plate rectification and two —45 tubes in push pull. Each R. F. stage and detector are tuned by one of the gang of three condensers.

Transformer coupling is used in both R. F. stages and in the detector circuit. An R. F. choke is in series with the detector plate and the primary of the A. F. input transformer, and a .001 mfd. feedback condenser by-passes the R. F. in the detector output to ground. A variable resistor with one fixed tap is connected across the D. C. output of the rectifier tube and serves as a volume control and C bias voltage divider, providing the variable screen grid voltage and the cathode voltages for the R. F. tubes. The plate voltage for these tubes is supplied from the maximum positive output less the drop encountered in the field of the dynamic speaker. The grid bias for the detector tube is obtained from the voltage drop through a resistor which separates the cathode and ground.

The grid bias is supplied to the —45 tubes by the drop from a 700-ohm resistor in the power pack. This resistor is connected between the center tap of the filament secondary and ground.

TEST QUESTIONS

Number your Answer Sheet No. 24—3 and add your **Student Number**

1. Is it possible to use raw alternating current applied directly to the "B" and "C" circuits of an A. C. receiver?
2. Why is it not possible to successfully use alternating current, of the correct voltage, on the filament of the ordinary direct current tube?
3. Draw a diagram showing the construction of the heater type tube, naming the four elements of the tube.
4. What is the filament voltage and filament current of the 226 and 227 type tubes?
5. Describe briefly the changes that are necessary before the 110-volt alternating current can be applied to the "B" circuits of a receiver.
6. Draw a diagram showing the "B' supply circuits of the ordinary A. C. receiver.
7. Draw a diagram showing the way the 227 type tube is connected in a detector circuit.
8. Why is it not possible to control the volume of an A. C. set by means of a filament rheostat in the radio-frequency circuits?
9. Describe two good methods of controlling the volume of A. C. receivers.
10. Explain fully how the use of the cheaper grade of audio transformers can lower the manufacturing cost of A. C. receivers.

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THE SCREEN GRID VACUUM TUBE

The screen grid vacuum tube is one of the major contributions that science has made to the radio industry. This tube is new in the sense that its development to the stage of a practical device suitable for production in large quantities is comparatively recent. Prior to the advent of the screen grid tube, the three-electrode vacuum tube working into a carefully designed amplifier circuit, such as the neutrodyne, formed the only satisfactory means for obtaining amplification at radio-frequencies.

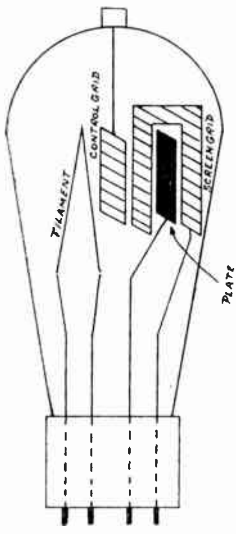

Fig. 1 — Illustrating the general make-up and method of connecting electrodes to terminals in the D.C. screen grid receiving vacuum tube.

The screen grid tube has, however, opened up an entirely new realm of possibilities and not only does it give greater amplification per stage but also it makes this amplification possible without neutralization or stabilizing grid resistors.

The fundamental principles of the screen grid tube were discovered and investigated several years ago by Schottky, a German scientist. Two American research workers are, however, responsible for the tube in its present form. Messrs. Hull and Williams of the General Electric Company research laboratories;

continued the research begun by Schottky, improved the screening and produced a tube which enabled them to achieve almost to the theoretical limits of amplification. This particular tube though was a laboratory device, not suited to economical manufacture. Further work finally led to a production model which retained a surprisingly large proportion of the excellent characteristics of the earlier tube.

Before explaining the properties of this tube it should be pointed out that all tubes having two grids are not necessarily screen grid tubes. For many years there have been vacuum tubes with more than one grid. European manufacturers in

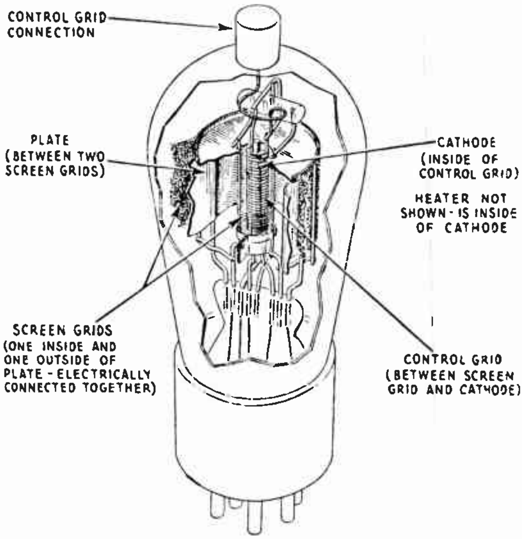

Fig. 1(A)—Cross-sectional view showing the construction of an A.C. screen grid vacuum tube.

particular have been supplying two-grid and three-grid tubes and have developed several interesting circuits around such tubes. The two-grid and three-grid tubes of ordinary design are very different in action and construction from the screen grid type, for in the usual multi-grid tube such as has found wide application abroad, the several grids have been used as control grids. The screen grid receiving tube of the type described in this book is distributed by the Radio Corporation of America under their models UX-222 and UY-224 and by the E. T. Cunningham Co. as their CX-322 and C-324. Other manufacturers also furnish these tubes with the same or similar identifying numbers.

Figure 1 shows the general arrangement of the parts in a screen grid receiving tube. Instead of the usual three, there are four electrodes: the filament, the control grid, the screening grid, and the plate. It should be noted that the control grid is a name which has been adopted in place of grid. This has been required by the fact that there are now two grids: (1) the control grid, which has the same function as the grid of an ordinary three-electrode tube, and (2) the screening grid, a new electrode which gives certain remarkable properties to the tube.

While the general external appearance is similar to that of an ordinary tube it will be found, upon examination, that the internal arrangement is quite different. The four prongs which extend through the base are used for connection into a standard UX socket in the usual way except that the "grid" prong must be connected to the screen grid circuit wire. A fifth connection,

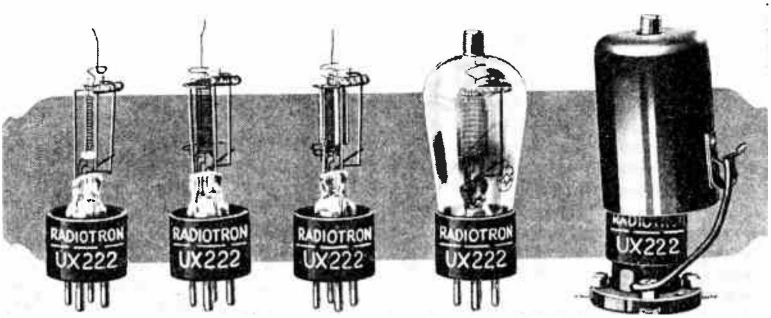

Fig. 2—Step by step construction of a D.C. screen grid vacuum tube.

that of the control grid, is brought out through the glass top to a small cap (see Fig. 2D). By referring to Fig. 2, a general idea may be obtained of the construction of the screen grid tube. The filament is a coarse spiral and forms the central element (Fig. 2A). Surrounding the filament and spaced from it by a few thousandths of an inch is the control grid which is made up of a fine spiral mesh (see Fig. 2B). The plate is an open-ended cylinder of thin sheet metal placed outside of the control grid (see Fig. 2C). The screening grid is in three sections; the first is a fine spiral mesh between the control grid and plate, the second a spiral mesh surrounding the plate, while the third is a flat metal disc which connects the upper of the two mesh sections. Fig. 2D shows the outer spiral mesh and the metal disc portions of the screen grid but the inner mesh is hidden by the plate. The object of the screen grid is to shield electrically the control grid from the plate. To accomplish this and to obtain the necessary degree of shielding requires the most accurate and careful mechanical construction of the electrodes located within the small space within the tube.

A more recent type of screen grid tube designated as the UY-224 has appeared on the market. This is essentially the same in electrical and constructional characteristics except that it is an A. C. tube having an indirect heater type filament. The base construction is of the standard UY five-prong type and the control grid is brought out through the top of the tube in the customary cap. (See Fig. 1A.)

"A" AND "B" BATTERIES

The screen grid vacuum tube of the battery type requires for its operation a filament or "A" battery and a plate or "B" battery. As in the three-electrode tube the "A" battery is used

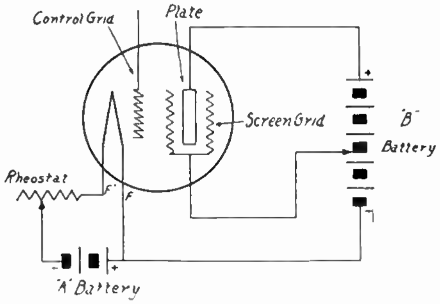

Fig. 3—Screen grid vacuum tube connections to "A" and "B" batteries.

to heat the filament to incandescence, while the "B" battery furnishes the energy which increases the effect of the radio waves. In addition, the screen grid must be kept at a voltage higher than the filament. This is most conveniently done by tapping the plate battery at a point which will give from ¼ to ⅓ the full plate voltage. A diagram of the screen grid vacuum tube with the necessary battery connections is shown in Fig. 3.

The A. C. screen grid tube employs alternating current on the heater. As with three-electrode tubes, twisted wires should be used leading from the transformer to the heater terminals. In addition to the usual voltages, it is of material help in reducing hum to make the heater slightly negative with respect to the cathode. The manner in which voltages are supplied to the alternating current tube is illustrated in Fig. 4.

COMPARISON WITH THREE-ELECTRODE VACUUM TUBE

Before proceeding further, it should be thoroughly understood that the action of the filament, plate and control grid is exactly the same as for similar electrodes in the older tubes. The filament emits the electrons, and acts as the current carriers of the plate current between plate and filament. The control grid is the device which regulates the amount of plate current which flows between the plate and filament.

INTER-ELECTRODE CAPACITY OF THE THREE-ELECTRODE VACUUM TUBE

Since the electrical characteristics of the battery and A. C. screen grid tubes are quite similar, the theoretical discussion will apply to both. In Fig. 5 is shown a diagram of a three-

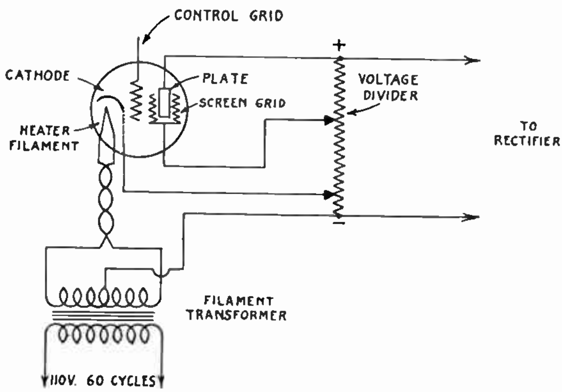

Fig. 4—A.C. screen grid tube current supply connections.

electrode tube illustrating the capacities which exist between the various elements. Of particular importance is the capacity C2 existing between the grid and the plate. This capacity in the average three-element tube has a value of from 6 to 15 micro-microfarads.

In the early days of vacuum tube amplification at radio-frequencies, this small capacity was of little importance because the frequencies in use were in the low range. With the advent of broadcasting on frequencies higher than 500 kcs. and, later with the discovery that frequencies higher than 3000 kcs. were worth while for long distance communication, the problem of grid plate capacity became one of utmost importance.

It will be recalled that the reactance of a condenser to the passage of alternating current depends upon the frequency of the current. At low frequencies the reactance is very high and a small capacity such as exists between the grid and plate of a vacuum tube of the three-element type will pass a negligible amount of current. As the frequency is increased, however, the reactance of the capacity becomes smaller and consequently larger currents are passed. When using ordinary tubes as radio-frequency amplifiers, it is found that the reactance of C2 at frequencies higher than 500 kcs. becomes so low that sufficient energy is passed from the plate circuit to the grid circuit to cause instability or oscillation. Reduced signal, poor quality and howling are some of the bad effects which result from this feed-back condition. Balancing or neutralizing schemes are necessary to counteract the feed-back which is so detrimental to radio-frequency amplifying circuits. A balancing circuit shown in Fig. 6 introduces a small condenser CB in the circuit. This

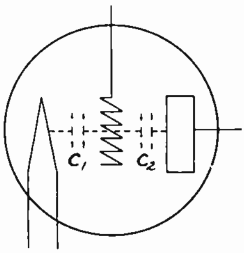

Fig. 5—Diagram of inter-electrode capacities in the three-element vacuum tube.

condenser is connected at one side to the grid and on the other side to a point on the plate coil which is below the effective ground tap. The condenser CB, when properly adjusted, carries a current equal to and opposite in phase from that passing through C2, hence the two currents neutralize or balance out, thus preventing oscillation and instability. It should be noted, however, that balancing counteracts but does not prevent feed-back.

DEFECTS OF BALANCE CIRCUITS

At best, balancing is merely a way out. It does not eliminate the cause of the trouble and makes for circuit complication. It is virtually impossible to achieve a balance which will be correct for a wide range of frequencies such as is met with in broadcast reception. In such a case the balance for the middle frequency is obtained and certain instability exists at the terminal frequencies. At the very high frequencies (above 3000 kcs.) it is difficult to obtain a balance no matter how carefully the circuits are laid out and adjusted. Furthermore, whenever a tube is changed it is frequently necessary to re-balance, since the grid plate capacity of the replacement tube is usually different from that of the tube which has been removed.

GRID PLATE CAPACITY OF THE SCREEN GRID TUBE

In the screen grid tube the grid plate capacity has been almost entirely eliminated and has a value between 0.01 and 0.1 micro-microfarads, or from 0.01 to 0.001 of the capacity present in the three-electrode tube. This low grid plate capacity has been obtained by inserting a screen or "shield" between the control grid and the plate. In Fig. 7 the screen grid tube is shown in diagrammatic form. The screen grid completely surrounds the

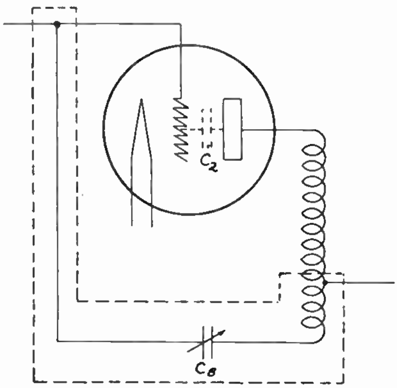

Fig. 6—Sketch of three-element tube and balancing circuit to neutralize the inter-electrode capacity. C2 represents the grid plate capacity and CB the equivalent balancing capacity.

plate and the lines of electric force which in the three-electrode tube run from plate to grid are now intercepted by the shield. The screen grid is kept at "ground" potential by means of a large capacity (C) which is connected on one side to the screen grid and on the other to the filament, thus providing a low reaectance by-pass for the radio-frequency potentials impressed on the screen grid. Hence, only a few of the lines of electric force pass through the screen to the control grid with the result that the capacity is very small. Since the control grid plate capacity is almost negligible, it follows that changes in the plate circuit will have no appreciable effect on the control grid circuit. Hence there is no path for the feed-back. Consequently, there is no instability or oscillation to hamper the radio-frequency amplifier performance. The practical elimination of the control grid plate capacity virtually does away with the necessity for balances and the intricate circuits associated therewith. Also, radio-frequency amplification may be obtained with the screen grid tube at frequencies as high as 100,000 kcs.

CHARACTERISTIC CURVE

Another interesting feature of screen grid tube performance may be discovered by examination of a characteristic curve. In Fig. 8, the plate current is plotted against plate volts with a fixed control grid and screen grid bias. Between the limits of 90 and 145 volts on the plate which is the limit of operating voltage, there is a change in plate current of only 0.1 milliampere. In the ordinary three-electrode tube, a similar change of plate voltage would cause a current variation of nearly 9 milliamperes. The practical value of small current variation due to voltage changes

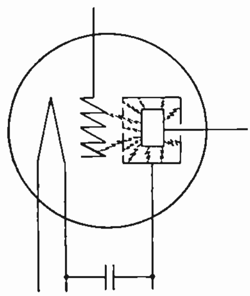

Fig. 7—A diagram showing the manner in which nearly all of the electrostatic lines of force between the control grid and plate are intercepted by the screen grid with the result that the control grid plate capacity is reduced to the vanishing point.

on the plate is readily seen when modern radio circuit power supply systems are considered. The majority of the new broadcast receivers, as well as many older types, make use of plate or "B" current supplied through rectifiers or filters from house lighting power. Such a power supply is subject to changes in voltage which, of course, affect the plate voltage. With ordinary tubes, the variation of plate potential by even a few volts causes signal fading. The screen grid tube remains unaffected by small voltage changes and is unlikely to reflect, except in limited degree, fairly large variations in the plate supply.

RADIO-FREQUENCY AMPLIFICATION

One of the major improvements to be found in the performance of the screen grid tube is the exceptional sensitivity resulting from its high amplification factor. Fig. 9 shows the amplification to be expected from each of the three types of tubes at various frequencies: (a) three-electrode, (b) high mu,

(c) screen grid. Laboratory amplifiers have been built which used several special screen grid tubes. These amplifiers proved so sensitive that the effect of electrons striking the plate of the first tube has been heard as a roaring noise in the loud-speaker connected to the output stage.

The high amplification comes about as follows: Due to the absence of control grid plate capacity of appreciable value, the plate resistance of the commercial screen grid tube is extremely high. By reason of its very high value, which may be considered as infinitely large, the screen grid tube alternating current plate resistance may be neglected as a factor in determining the amplification. Hence, the amount of voltage amplifi-

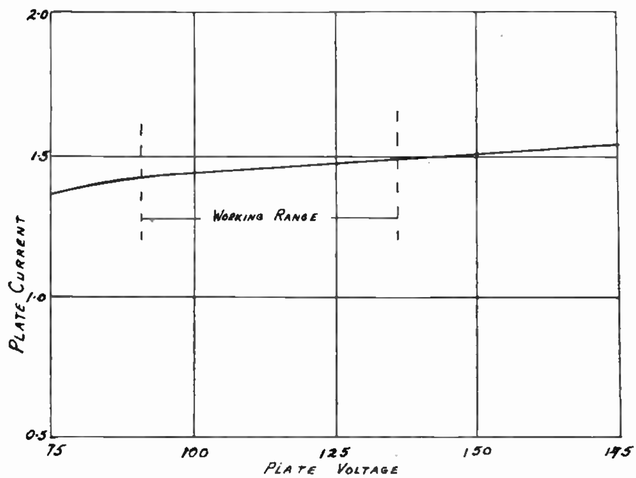

Fig. 8.

cation obtainable depends on the amount of resistance which can be placed in the external plate circuit of the tube times the mutual conductance of the tube itself. The mutual conductance has a constant value for any one grid potential, therefore, the amplification of the screen grid tube is in proportion to the amount of resistance in the external plate circuit. Fig 10 shows graphically how the amplification factor increases with the plate circuit resistance.

In theory the nearer the external plate resistance matches the internal plate resistance of the tube, the better the circuit and tube function together. This condition holds for three-electrode tube where the highest amplification from stage to stage is obtained when the tube and circuit resistances are equal. In screen grid tube circuits, this rule must be modified. It is, of course, necessary to couple each stage of amplification to the following tube. By doing so, the resistance of the plate circuit is decreased by an amount depending on the tightness of the coupling. If the coupling is made in a manner which permits of high plate resistance (above 200,000 ohms) it will be found that

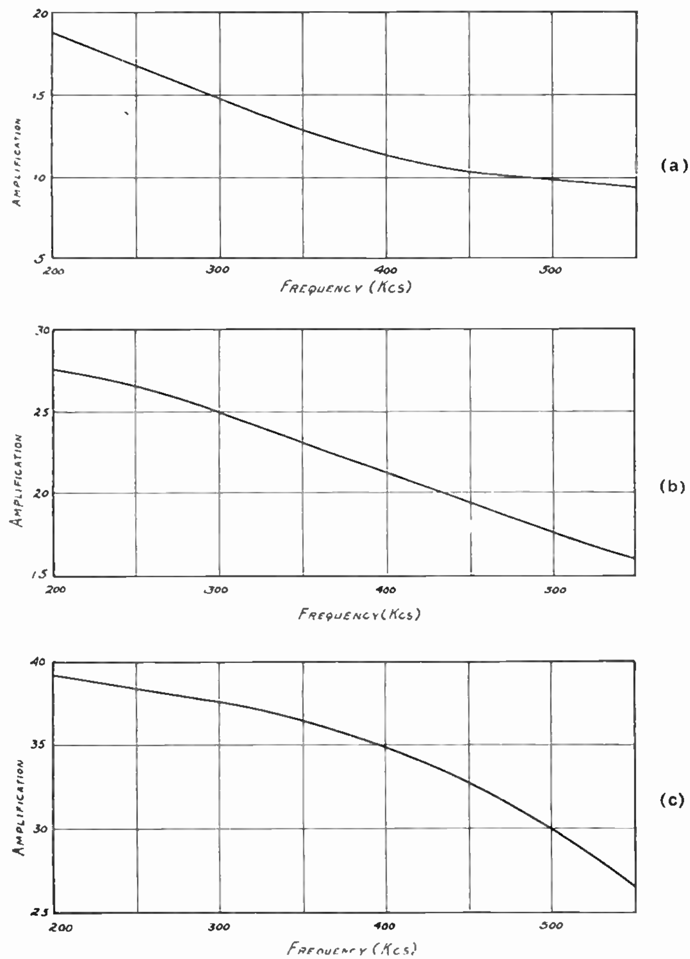

Fig. 9.

the grid of the following tube will get but little excitation and consequently the overall efficiency of the amplifier will decrease, though one stage may be operating at a very high rating.

Furthermore, it has been found that even the small grid plate capacity existing in the commercial type of tube is sufficient to cause a certain amount of feed-back which, in these highly sensitive tubes, results in instability. For this reason, the tuned plate circuit is not very satisfactory when applied to screen grid tube circuits in the broadcast frequencies. Without the most careful shielding and separate batteries for each stage, it is virtually impossible to realize the full amplification of these tubes and it has proved better to be content with somewhat less amplification in order to take advantage of circuit simplification. For this reason transformer coupling is widely employed. Four or five turns in the plate circuit are coupled closely to a tuned grid circuit. This arrangement gives excellent stability, good amplification, and is convenient to handle. The impedance of the plate circuit is considerably lower than that desirable for

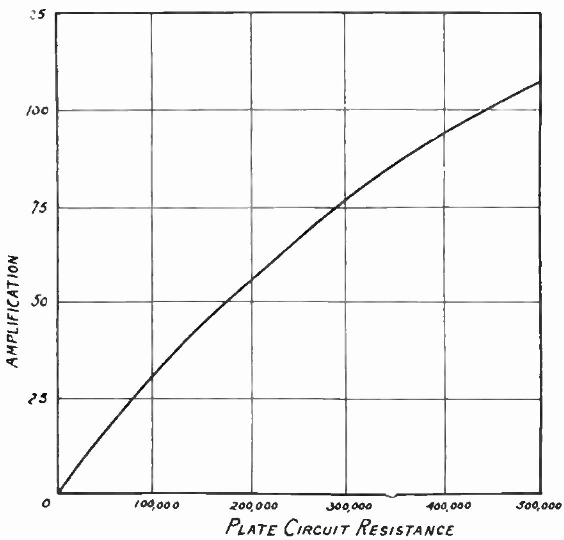

Fig. 10—Note the direct increase of amplification with increase in the plate circuit resistance.

the most efficient operation of these tubes but better all around performance is obtained.

SUMMARY

The outstanding features of the screen grid tube as explained above are:

(a) The practical elimination of the troublesome grid plate capacity.

(b) The small changes in plate current due to changes in plate voltage.

(c) The high amplification attainable at both radio and audio-frequencies.

THE SPACE CHARGE GRID

A further use of this adaptable tube requires a different connection from that specified in the preceding description. Fig. 11 shows the tube hooked up as a "Space Charge Grid" amplifier. In this case the inner grid is given a positive potential, while the outer grid performs the functions of the control grid.

It will be remembered that a heated filament emits electrons. If, as in the case of an electric light bulb, there is nothing to prevent, the electrons will be attracted back to the filament at the same rate as they are emitted. In the three-electrode vacuum tube the plate is given a positive charge and some of the electrons (negatively charged) which are emitted by the filament are attracted to the plate. For a given plate voltage, a certain number of electrons are attracted to the plate while the rest rejoin the filament. As the plate voltage is increased, more electrons

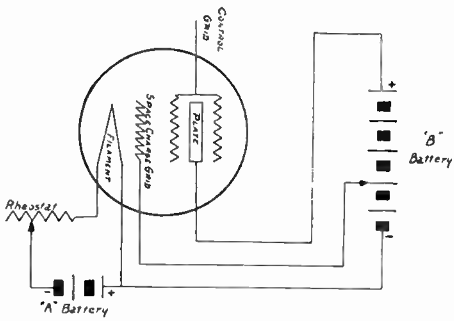

Fig. 11—The UX-222 vacuum tube with the necessary "A" and "B" battery connections for use as a "Space Charge" amplifier.

are attracted to the plate. The reason that all of the electrons emitted by the filament do not go to the plate is that the "Space Charge" between the two elements limits the electron flow. The space charge is the repelling effect of the electrons upon themselves and since the electron cloud is most dense near the filament the space charge is highest in that location.

Now, if an electrode be introduced very close to the filament and a positive potential placed upon it, this electrode will exert a great attraction upon the electrons in the cloud around the filament and cause a material reduction in the space charge. The inner grid of the new tube, when hooked up as in Fig. 11 serves just this purpose. Its positive potential neutralizes the space charge and imparts a tremendous velocity to the electrons leaving the filament. Because of the grid structure, only a few of the electrons are actually intercepted by the inner grid. The great majority pass through the space between the openings to come under the controlling influence of the outer grid which is now acting as the control grid. If the control grid happens to be positively charged, the electrons which have come through the inner grid are further accelerated and proceed to the positively charged plate. Should the outer (control) grid be negatively charged the electrons would, of course, be repelled and would not reach the plate. The practical results of the space charge grid connection may be summed up as:

(a) That the plate current for a given plate voltage is much increased.

(b) That the mutual conductance of the tube is increased.

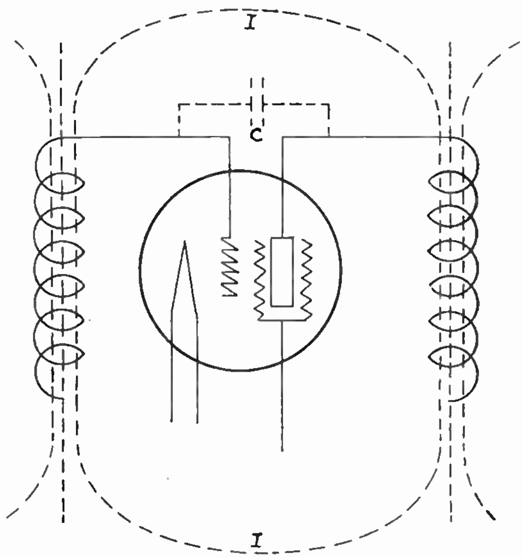

Fig. 12—Diagram of the capacity and inductive coupling which may exist in the external circuits of a screen grid amplifier. Under these circumstances, the advantages of the small internal capacity of the tube are lost. Proper shielding of the coils and condensers will eliminate these external circuit couplings.

The grid plate capacity has reappeared with this type of hook-up, however, making the tube of no use as a radio-frequency amplifier. It is in the audio-frequency circuits that the space charge grid finds its field of usefulness and very high amplification per stage can be obtained at the audio-frequencies. It will be improbable that more than one stage of space charge audio amplification followed by an output tube will ever be necessary for ordinary purposes.

PRACTICAL APPLICATION OF THE SCREEN GRID TUBE

Having discussed the means by which the screen grid tubes accomplish their extraordinary performance, it remains to show the methods and circuits required for utilizing the tube in practice. First of all comes the necessity for the thorough shielding of all external circuits. The manufacturer in making the screen grid tube has done an excellent job in eliminating the capacity between the control grid and plate. His work will be nullified, however, if circuit capacities are permitted to act in the same manner as the old grid plate capacity. Without proper external shielding, the screen grid tube is valueless. In Fig. 12 the couplings which may exist in the external circuits are depicted.

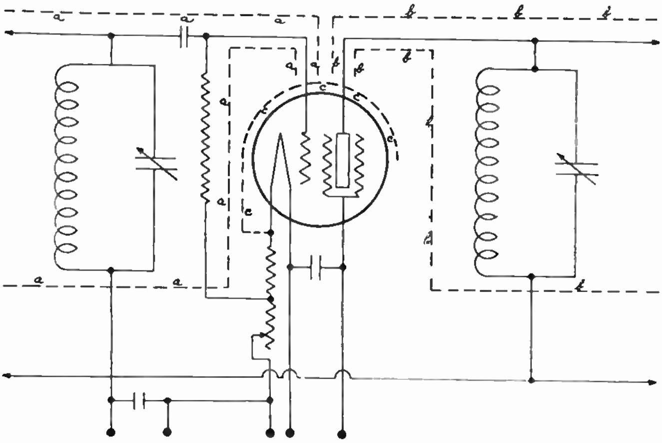

Fig. 13—Sketch of the shielding required for the most efficient use of the screen grid vacuum tube.

Since they couple plate and control grid circuits together, it can be understood that feed-back is again possible and that balancing or neutralizing methods will be required once more. Thus one of the prime factors in the excellence of the screen grid tube will have been lost through careless assembly or wiring.

The screen grid tube is a very fine and sensitive device. It is not pretended that this tube can be used in a "haywire" hook-up with any degree of success. The circuits to which the tube is connected must be carefully laid out and shielded from one another and from the tube in order that the full possibilities of this new tube may be realized. In Fig. 13 a single tube is shown connected to the eternal circuits necessary for a single stage of radio-frequency amplification of the tuned plate circuit type.

The dotted lines represent the shielding which should be used for the effective action of the amplifying unit. In Fig. 13 a-a-a is the shielding around the control grid circuit. Notice that it completely surrounds the tuning coil and condenser of the input circuit and effectively confines all of the radio-frequency field within the limits of the shield. An extension of the shielding in the form of a small metal tube may lead to a point close to the control grid terminal so that only a fraction of an inch of unshielded connecting wire will be exposed. The plate circuit shield represented by b-b-b is as thorough as that of the grid shielding. Once more all of the elements of the radio-frequency circuit are confined within the shield which extends to within a short distance of the plate terminal at the tube socket. The shielding shown as c-c-c is a metal jacket fitting closely over the glass bulb of the tube, but having a hole with an insulated bushing at the top through which connection is made to the control grid. The

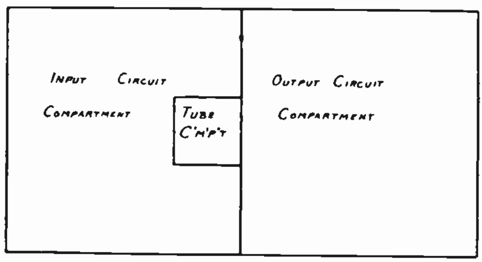

Fig. 14—The box layout which ensures proper shielding.

shielding for the plate and control grid circuits is in the form of a metal box or compartment for each circuit. In addition, it is desirable to have a separate small special compartment for the tube itself. The general layout of the compartments may be along similar lines to that shown in Fig. 14.

Shielding is also helped by keeping the control grid and plate wires as far apart as possible. This has been made relatively easy by the construction of the tube which brings the control grid out of the top and the plate out of the bottom of the tube assembly. A further aid is to make the control grid and plate connecting leads as short as possible in order that the capacity may be decreased and the coupling losses to the shield reduced. If these cautionary shielding measures are carried out, a long step towards satisfactory screen grid tube operation will have been taken.

KEEPING THE SCREEN GRID AT GROUND POTENTIAL

It is important that the screen grid be kept at "filament" potential with respect to radio-frequency currents. From the foregoing explanation of the action of the screen grid, it will have been seen that the duty of the screen is to intercept the electrostatic lines of force between the plate and the control grid. If, however, the screen grid is at a higher radio-frequency potential than the filament, a charge will be induced on the control grid and feed-back will take place. The resistance of the "B" battery, especially when low, or the choking action of long or small wires may be the means for keeping the screen grid at a high radio-frequency potential with respect to the filament. To avoid this condition a large capacity condenser, about 0.5 microfarads, is connected between the screen grid and the filament. To assure that this condenser will act efficiently in by-passing the

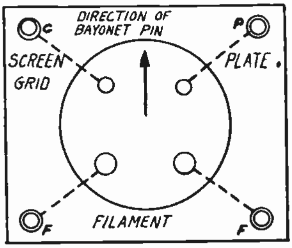

Fig. 15—The terminal arrangement of the D. C. screen grid tube when used in a standard socket.

stray radio-frequency energy, the location should be as close to the tube socket as possible with short leads to the socket terminals. By so doing the radio-frequency energy chooses the low impedance path represented by the condenser. Thus, long wires or battery circuits in which there may be considerable potential drop at high frequencies are avoided and the screen grid is thoroughly grounded.

SELECTIVITY

The trend of radio receiver design is always along the lines of increasing sensitivity, better selectivity and improved quality. The advent of the screen grid tube solves beyond question the problem of sensitivity. With amplifications of from 20 to 40 per stage obtainable at the broadcast frequencies, one or two stages of efficient screen grid amplification will satisfy the desires of most broadcast listeners. The increased sensitivity has resulted in no loss of quality and as a matter of fact, the quality will usually be improved because of the elimination of feed-back and the absence of regenerative circuits. In the matter of selectivity, however, the application of the screen grid tube does have certain limitations. It has been quite the custom to rate the sensitivity of a radio receiver in terms of the number of tubes employed on the radio-frequency amplifying stage. It is quite as correct to regard the selectivity of a receiver as a function determined by the number of tuned radio-frequency stages. In other words, several stages of radio-frequency amplification are desirable not only for the sake of sensitivity but also for the necessary selectivity. Under the present conditions of broadcast reception, the general custom has been to demand a selectivity such as will be produced by two well-designed tuned radio-frequency stages (three tuned circuits) or one radio-frequency stage (two tuned circuits) with regenerative detector.

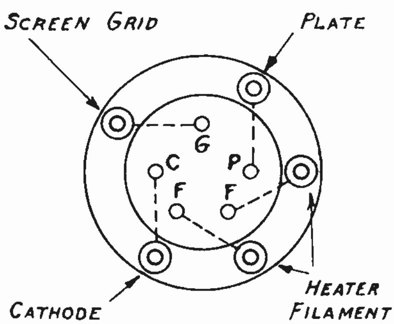

Fig. 16—The terminal arrangement of the A.C. screen grid tube when used in a UV socket.

The screen grid tube when employed in properly designed circuits will give a considerable increase in sensitivity over that possible with ordinary three-electrode tubes at no sacrifice in selectivity. To achieve this end, however, special attention must be paid to the tuning and coupling circuits. Coils of ample dimensions, good quality condensers and parts, the elimination of stray couplings with their increased resistance and the employment of loosely coupled circuits are some of the requirements to be met.

NOISES

A new problem in the elimination of the many kinds of noises which interfere with radio reception is opened up by the use of multi-stage screen grid amplifiers. Further, while the grid plate coupling is reduced to a low value a certain amount is still present which, in multi-stage amplifiers, will cause trouble. Hence, it is recommended that no more than two or three screen grid stages be employed in any receiver intended for ordinary purposes.

CHARACTERISTICS OF THE UX-222 OR CX-322 SCREEN GRID TUBE

The arrangement of the electrode terminals of the battery type screen grid tube is as follows: Standard UX base with two large and two small prongs. The electrode connection to each base prong may be easily ascertained by reference to Fig. 15 where, it will be noted, the arrangement is the same as for all UX tubes except that the screen grid prong is in the position usually occupied by the prong connected to the control grid of the three-electrode tube. The control grid of the UX-222 tube terminates in the metal cap on the top of the tube. Table No. I summarizes the battery requirements and amplification data for this tube.

TABLE NO. I

Characteristics of the Battery Type Screened Grid Receiving Tube

"B" Battery Volts	"C" Battery Volts	Plate Mils	Mutual Conduct-ance	Amplification Factor	"A" Battery Volts
135	1.5	1.5	350	300	3.3

CHARACTERISTICS OF THE UY-224 OR C-324 A. C. SCREEN GRID TUBE

The base layout of the A. C. screen grid tube is of the standard five-prong UY type with the exception that the screen grid is attached to the terminal marked "grid." The electrode connection to each base prong for this type of tube may be readily found by reference to Fig. 16. The control grid of the UY-224 or C-324 tube terminates in the metal cap on the top of the tube. Table No. II summarizes the voltage requirements and amplification data for this tube.

TABLE NO. II

Plate Volts	Negative Grid Bias	Plate Mils	Mutual Conduct-ance	Amplification Factor	Heater Volts
180	1.5	4	1050	420	2.5

NOTE:—The UY-224 or C-324 tube may be used in battery circuits provided the necessary filament and plate potentials are supplied from the D.C. source.

TYPICAL CIRCUITS FOR THE RECEIVING SCREEN GRID TUBE

The extreme sensitivity, high plate resistance and low internal capacity of the screen grid tube requires special circuits and arrangements in order that these excellent characteristics may be utilized to the fullest extent. In Fig. 17 is shown a screen grid receiver of an approved type. Two screen grid tubes are used as radio-frequency amplifiers while the detector is a three-electrode tube. The audio stages may employ any of the standard circuit arrangements and tubes. From a study of Table No. 1 it is noted that the voltage across the UX-222 filaments should be 3.3 volts while the negative bias on the control grid should be 1.5 volts. Inasmuch as the voltage for the UX-201A tube filaments must be 5 volts for best

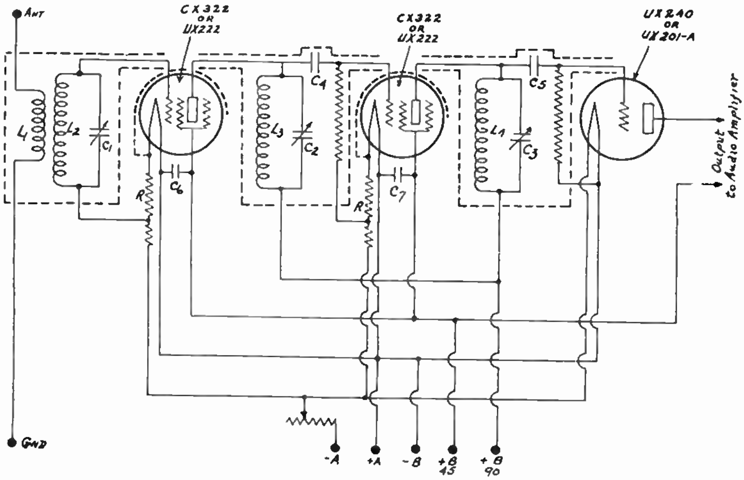

Fig. 17—Circuit showing D.C. screen grid used as R.F. amplifier.

operation it is necessary to insert a resistor "R" in series with each UX-222 filament in order to reduce the voltage to the 3.3 volts required. The resistance of "R" should be 15 ohms. By using a tapped resistor as shown or by using two resistors, one of 10 and one of 5 ohms, placed in series with the larger resistor nearest to the filament, it is possible to get the correct control grid bias from the drop in voltage across "R" thus avoiding the use of a "C" battery. Another type of circuit shown in Fig. 18 employs one screen grid radio-frequency amplifier feeding into a tuned three-electrode regenerative detector. This circuit while very sensitive and selective is likely to be rather unstable if not put together with extreme care. It should be noted that in this case the plate current of the screen grid tube is supplied through a radio-frequency choke "L."

THE SCREEN GRID TUBE AS A DETECTOR

The present trend of receiver design is towards the attainment of the utmost fidelity in the reproduction of the broadcast signals. To attain this end it has been found most desirable to have the amplification concentrated at radio-frequencies since distortion is most likely to occur in audio circuits. By the use of screen grid tubes, a very considerable gain in radio-frequency amplification may be obtained but this gain is not of itself sufficient to eliminate any audio stages provided a three-

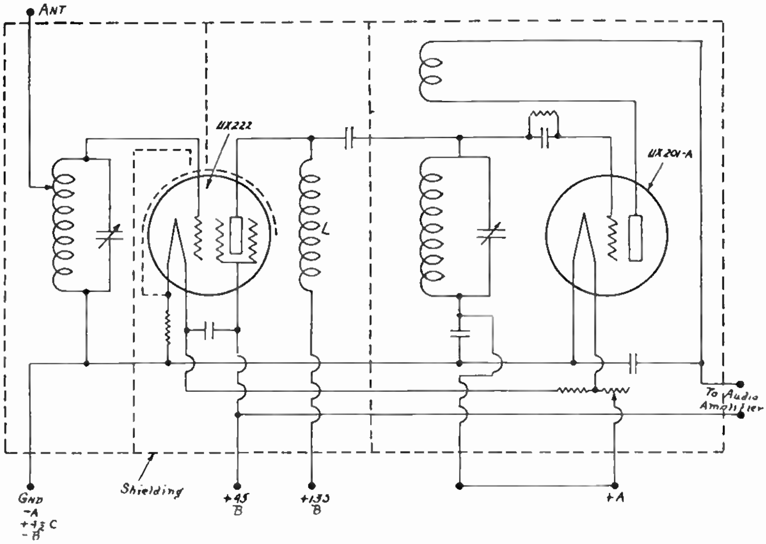

Fig. 18—Circuit diagram using D.C. screen grid as R.F. amplifier with a three element regenerative detector.

electrode detector is employed. If, however, a screen grid tube is used as a detector a very considerable amplification is obtained in the tube itself and the output of this tube may be used to directly excite a power tube feeding into a loud-speaker. The most efficient circuit for coupling the plate of the screen grid detector to the power tube is resistance coupling which is also very desirable from the standpoint of fidelity of reproduction. With this arrangement two audio transformers and one tube are eliminated and the major causes for audio distortion are thus no longer present. In order to handle the large voltages impressed on the grid by the powerful radio-frequency amplifier, it is necessary to use grid bias detection in the screen grid detector as shown in Fig. 19. The plate circuit employs a 250,000 ohm resistor and a .01 microfarad coupling condenser as shown. In order to compensate for the drop across this large resistor it is desirable to raise the plate supply voltage to 200 volts. In Fig. 20 is shown a modern screen grid broadcast receiver suitable for battery tubes (UX-222). A similar circuit is shown in Fig. 21 for an alternating current broadcast receiver employing two radio-frequency screen grid tubes, one screen grid detector and a power tube in the output stage.

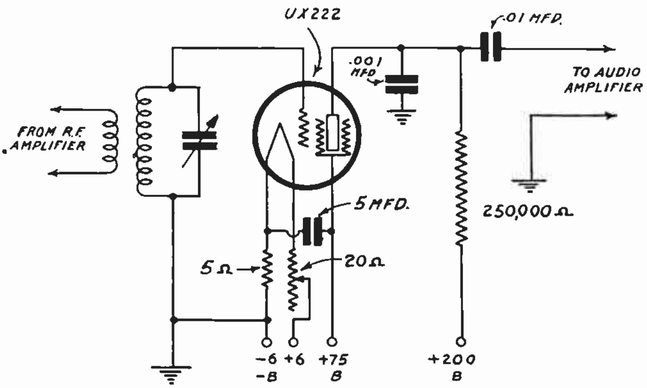

Fig. 19—The screen grid tube circuit for grid bias detection.

HIGH FREQUENCY RECEIVERS

The foregoing diagrams have applied to receivers to be used in the broadcast frequencies. Standard parts and known circuits which need but slight modification to be applicable to the screen grid tube make the task of changing over existing sets or building a new receiver with screen grid tubes a comparatively easy one for the broadcast set builder. In the amplification of frequencies higher than 3,000 kilocycles, however, the situation is not and has not been so easy. It is only with the use of screen grid tubes that amplification has been obtained at all the very high frequencies. Even with the screen grid tube, it is necessary to take careful steps in the wiring and assembly and to provide filters in the battery and telephone leads.

The receiver illustrated in Fig. 22 is sufficiently sensitive for any purpose on short wave-lengths. The construction details will be considered at some length because of the excellent results which may be achieved on the higher frequencies from a well-made short wave receiver of this type.

The first question to be considered is the shielding. This must be absolutely complete except where wires enter the various compartments. A metal box should be secured and the compartment joints should be soldered or tightly screwed to angle pieces. Wire holes should not be larger than necessary to clear the insulation. The cover should fit tightly over the box and have angle pieces screwed or riveted on so that slots are formed into which the shielding walls can fit and make a good shield joint between compartments. The amplifier tube should be located in a separate small compartment as shown in order that the several circuits may not be coupled together through their wires which connect to the screen grid amplifier tube. A series

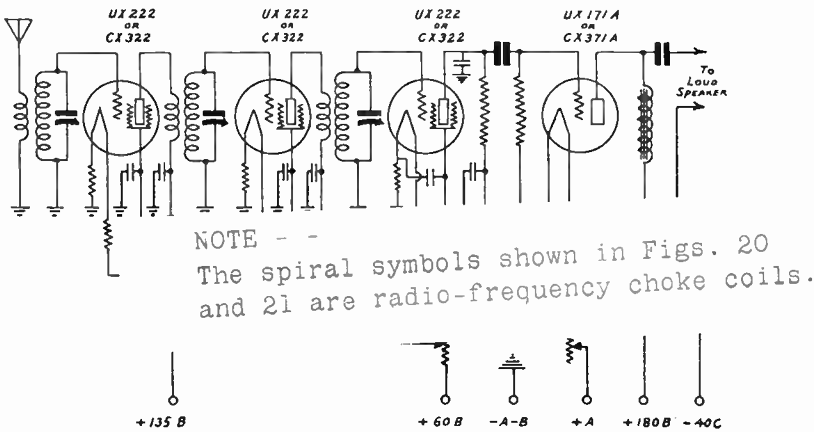

Fig. 20—Schematic circuit diagram of D.C. screen grid receiver.

of small compartments should be built under the receiver proper —these sections to take the different battery wires and introduce a filter between the battery and the receiver. Only a small coil and "postage stamp" condenser are in each of these filter sections so that these compartments need only have limited space.

All wires from the filter compartments to the points where they are connected to the tube, coils or condensers inside the receiver compartment should be covered with a copper braid for shielding purposes as a further precaution against stray couplings.

Taking the circuits in order: Condensers C1 and C2 are of the variable type and should have a capacity of about 150 micro-microfarads. A good vernier dial should be provided to secure easy tuning. Over the wave-length band of from 30 to 50 meters, the coil L1 should be made up of twelve turns of number 12 cotton-covered wire wound to make a two and one-half inch diameter coil of the self-supporting type. Turns should be spaced the width of the wire by means of string. The whole assembly should be boiled in paraffin after completion. L2 is the antenna coupling coil and should be made of two turns of ordinary annunciator wire two and one-half inches in diameter and placed so that the coupling to L1 is quite close. C8 is an insulating capacity intended to separate the negative filament from the grounded shield while permitting an easy path to ground for the radio-frequency currents in L1 and L2. The capacity of C8 should be about .001 microfarads and the condenser should be of the postage stamp mica variety. The high

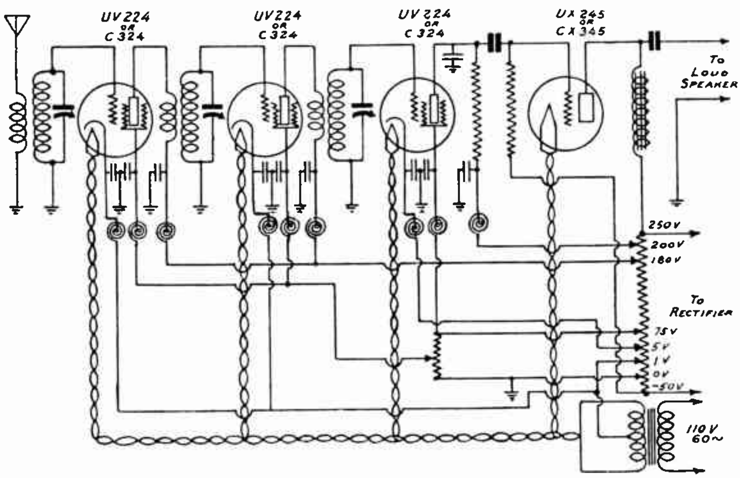

Fig. 21—Schematic circuit diagram of A.C. screen grid receiver.

potential wire from the tuning circuit L1 C1 passes through the upper part of the shield and goes directly to the control grid cap on the screen grid tube. R1 is a small fixed resistor in series with the negative filament of the screen grid tube. The resistance of R1 is 10 ohms and it supplies the necessary voltage drop for proper filament voltage and grid bias for the tube. C3 is the screen grid filament by-pass condenser, an item all too frequently left out in these circuits, yet a most important part if the best operation is desired. As noted before C3 has a capacity of .5 microfarads and may be a paper condenser. The plate of the radio-frequency amplifying (screen grid) tube connects through to the coil L3 and condenser C2 which make up the tuned plate circuit of the amplifier tube. For the 30 to 50 meter band, L3 may be a two and one-half inch diameter coil similar in construction to L1 but having eight turns only. L3 is at high D.C. potential because it is part of the plate battery circuit, hence an insulating mica condenser of .001 microfarad capacity is connected between the low potential end of L3 and the low potential end of condenser C2. The low potential end of C2 is also grounded to the shielding. C4 is a mica condenser having a capacity of .00025 microfarads and is the capacity which couples the circuit L3 C2 to the grid of the detector tube. The three megohm resistor R2 acts as the leak for the grid of the detector tube and also by reason of its being

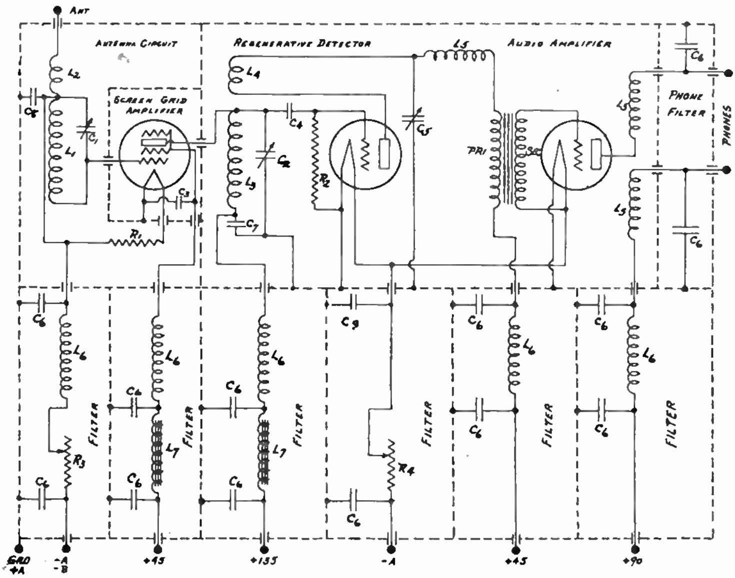

Fig. 22.

connected to the positive filament provides the positive bias, necessary for rectification, to the detector grid. L4 acts as the tickler and is an inch in diameter with eight closely wound turns of number twenty-six cotton covered paraffined wire. The condenser C5 is a small variable type and controls regeneration. Inductances L5 are radio frequency chokes which prevent high frequency currents from circulating in the audio-frequency circuits. These chokes may be made from 200 turns of number thirty wire either in a universal winding or in a home-made thin coil shaped like a disc. Condensers C6 are paper dielectric .1 microfarad capacities which act as by-passes in the various filter circuits. Inductances L6 are the radio-frequency chokes contained in the filter circuits and should be formed of a single layer winding of number forty enameled wire two inches long on a half-inch thick paraffined dowel stick. R3 and R4 are variable resistors used to control the filament current in the vacuum tubes. R3 should have a resistance of 20 ohms and R4 a resistance of 6 ohms.

The arrangement of the circuits should be similar to that shown in the diagram. In particular the filter circuits should have their apertures through which the receiver wires pass as close to the connecting element as possible.

L7 is an iron-core audio-frequency choke of good commercial design. The two chokes L7 prevent modulation and microphonic noises by "ironing out" the plate current.

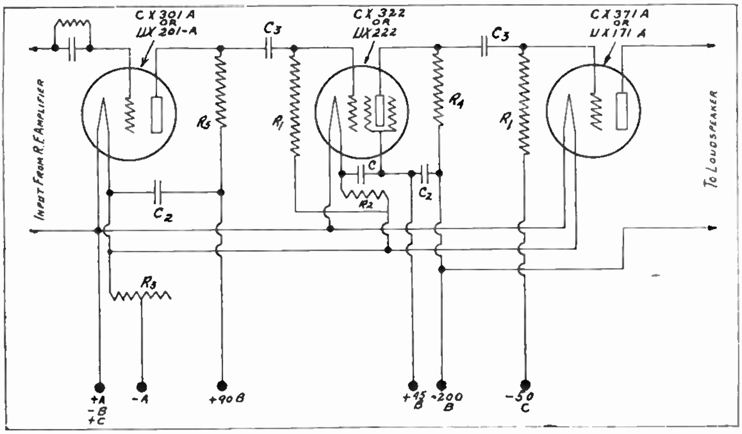

Fig. 23—Circuit showing screen grid tube used as A.F. amplifier (resistance coupling).

C9 is a .5 microfarad paper condenser which by-passes the radio-frequencies which may be impressed on the filaments of the audio tubes.

The importance of suitable filter circuits on high-frequency receivers can hardly be over-emphasized. Especially should a sensitive receiver of the type described have all the battery and phone leads pass through filters. By the use of filters the major part of the interfering noises found in a high-frequency receiver are eliminated. It is possible, however, under favorable conditions to secure good results with the receiver described even without the filter circuits. If, for reasons of economy or simplicity, the filters are not desired, the receiver may be built without them. In such a case the wiring diagram will be identical with that shown in Fig. 22, except that all lower compartments with their associated circuits are left out and the wires from the receiver are brought directly out to the batteries.

THE SCREEN GRID TUBE AS AN AUDIO AMPLIFIER

So far the practical application of this tube has had to do with radio-frequency circuits only. The tube has excellent characteristics as an audio amplifier also provided only that the amplifier is to be used in a quiet location since these tubes are very microphonic in audio circuits. Where a high amplification is desired, an arrangement like that shown in Fig. 23 may be employed. It is advisable to use only one stage of screen grid audio amplification and to place that stage immediately after the detector tube in order that the power output of the tube

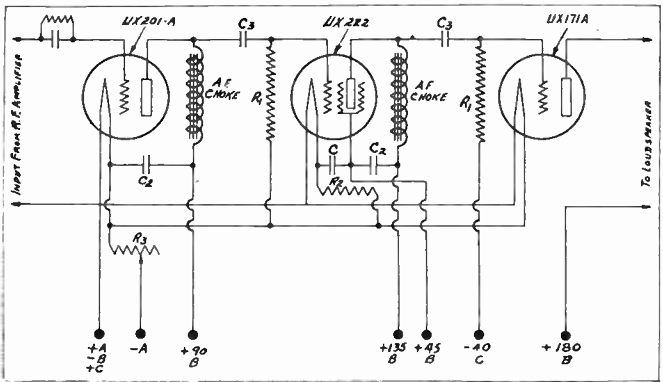

Fig. 24—Screen grid tube as A.F. amplifier (impedance coupling).

may not be exceeded. In Fig. 23 only the circuit from the detector tube through the audio stages is shown—the radio-frequency amplifier may be of any conventional type or may include a screen grid stage. As in the radio-frequency case a screen grid tube used as an audio-frequency amplifier must be carefully shielded and special pains must be taken to keep the control grid and the plate leads well separated and individually shielded. It is also desirable to have a large capacity by-pass condenser between screen grid and filament. Referring again to the diagram of Fig 23, the plate of the detector tube works into a resistive load and is supplied with plate current through resistor R5 which has a value of from 25,000 to 100,000 ohms. C2 is a by-pass condenser from the low potential end of the resistor R5 to ground and the value of the capacity is about .02 microfarads. The filament resistance combination R2, R3, is similar to that which has been described before and serves to reduce the voltage across the tubes to the proper amount as well as to furnish the correct grid biasing potential. In this case R2 has 10 ohms resistance, and R3 has 6 ohms resistance. R3 is, of course, variable as shown. C3-C3 are coupling condensers between tubes and should have a capacity of .01 microfarads. R_1-R_1 are grid leaks and should have a resistance of approximately three megohms. R4 should be a resistor of about 250,000 ohms (¼ megohm).

A modification of the above circuit and one which works very satisfactorily is shown in Fig. 24. In this audio amplifier and detector and screen grid tube, high resistance loads are composed of iron-core chokes. These chokes should have an

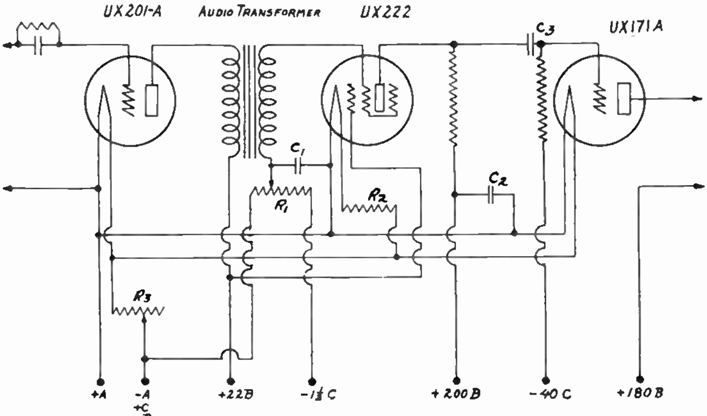

Fig. 25—Screen grid tube as A.F. amplifier (combination transformer and resistance coupling).

inductance of twenty or thirty henries for best operation. By placing large condensers across these audio chokes, it is possible to tune at specific audio-frequencies, a feature that is sometimes very desirable for code reception.

THE SPACE CHARGE GRID AUDIO-AMPLIFIER

A third method audio amplification which is simpler in its application makes use of the tube as a space charge grid tube. It will be remembered that the space charge grid method does not prevent feed-back and, hence, is of no value in radio-frequency circuits. It is, however, applicable to audio-frequency use and is, possibly, somewhat easier to handle than an audio-frequency screen grid amplifier. The constants of the tube as a space charge amplifier are somewhat different from those of the tube as a screen grid amplifier. Table No. 11 summarizes in tabular form the characteristics of the tube for the space charge grid arrangement. In this hook-up it is also important to remember that the grid connected from the socket base becomes once more the control grid and metal cap from the top of the tube is the space charge grid.

In Fig. 25 is a diagram of a detector and two-stage audio-amplifier in which the first audio stage is of the space charge grid type. Referring to Fig. 25, the output from the detector is fed into an audio-frequency transformer in the usual manner. Any good audio transformer may be used in this place. The secondary of the transformer connects, on one side, to the control grid (a socket terminal) while the other or low potential

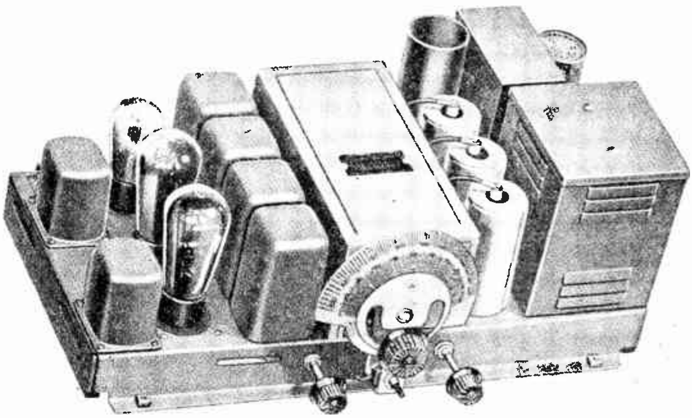

Fig. 26—Typical chassis of a screen grid receiver.

end of the secondary connects to a potentiometer R1 placed across a single dry cell. It is advisable to by-pass the potentiometer battery with a condenser C1 having a capacity of one microfarad. The space charge grid (top of tube) is brought directly out to a battery supply of plus 22 volts. Across the plate circuit of the tube is placed a resistive load of from .1 to .3 megohms and the resistor is by-passed to ground at its lower end through a 1.0 microfarad condenser C2. The coupling from the space charge tube to the following tube is taken care of by C3 which is a good quality mica condenser with a capacity of about .01 microfarads. Note that the plate voltage for the space charge tube is 180 volts. In other respects the amplifier resembles those that have been described before.

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Number Your Answers 25—4 and Add Your Student Number.

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In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Show by diagram how the "A" and "B" batteries are connected in the tube circuits of the screen grid tube.
2. Where is the control grid placed and what is its duty in the screen grid tube?
3. What is the screen grid and where is it placed and why?
4. What are the principal advantages of the screen grid tube over the three-electrode tube?
5. What should be done to keep the screen grid at ground or filament potential?
6. How does a space charge grid tube work?
7. What are the advantages to be gained from the use of the space charge grid tube?
8. Tell why shielding is so essential in circuits using the screen grid tube.
9. Why is the screen grid tube of such great value as a radio-frequency amplifier?
10. Draw a simple diagram of a receiver using a screen grid radio-frequency amplifier.

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SUPER-HETERODYNE SUGGESTIONS

Some Practical Ideas for Improving the Reception Obtainable With This Popular Circuit

The Super-Heterodyne circuit is much misunderstood and consequently leads to too great expectations. The amplification produced by an eight-tube set can be but little greater than that given by three stages of tuned radio-frequency detector and two stages of audio, such as might be secured from a six-tube neutrodyne.

The first two tubes of a super, the oscillator and first detector, act merely as frequency converters, changing the incoming frequency to that to which the intermediate frequency amplifier

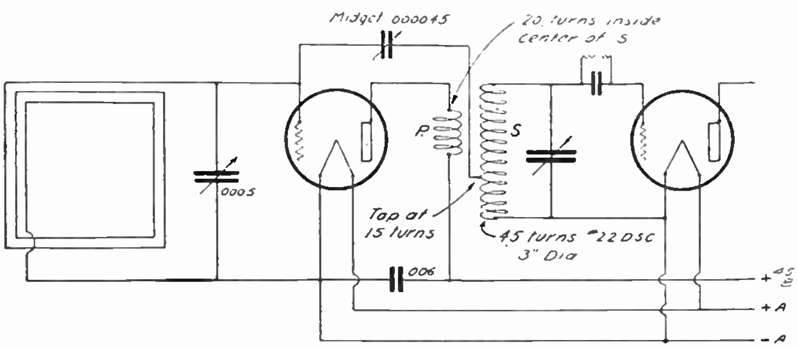


Fig. 1—Diagram illustrating method of adding one stage of tuned radio-frequency between the loop and the first tube.
(Pick-up coil not shown in this diagram.)

is tuned, only a limited amount of amplification being supplied by the first detector. The Super-Heterodyne differs from other radio-frequency circuits in that it tunes the incoming wave to the intermediate R.F. stages, whereas the others tune each R.F. stage to the incoming wave.

Therefore, "why the super-het?" The answer is found in the fact that the lower the frequency (the higher the wave-length) at which a radio-frequency amplifier is used, the greater its amplification. By amplifying wave-lengths between 1,000 and 10,000 meters (300 Kcs. and 30 Kcs.) the Super gives greater amplification than another circuit amplifying between 200 and 600 meters (1500 Kcs. and 500 Kcs.). It is also more selective, more stable, and easier to operate. It makes better use of the small amount of energy supplied by a loop than other sets can do with the larger amount of energy supplied by an outside aerial.

Several improvements can be made in the Super-Heterodyne sets as ordinarily constructed. The first is the use of a larger loop to collect more energy. A loop having 3 to 5 feet to a side is none too large. It should never be less than 2 feet to a side if good results are to be secured.

Another practical improvement is the reduction of the B battery voltage to the R.F. amplifiers. The heavy current that these tubes take, if the set is operated with a potentiometer giving a positive bias to the grids, can be greatly reduced by cutting the B potential to 45 or even 22 volts.

An expensive but useful addition is a shield that completely encloses the set. This prevents, if properly installed, any pick-up by the wiring of the set itself and in that way often provides a worthwhile gain in selectivity. The shield is equivalent to a metal box that completely includes the apparatus and should be installed when the set is built.

An outdoor antenna is sometimes used. If the set is shielded it is possible to get a degree of selectivity entirely unexpected. Loose coupling should be used with the coils that tune the antenna and secondary adjusted permanently in one angular relation that does not give maximum signal strength but good signal strength with satisfying selectivity. The secondary coil, which replaces the loop, is outside the metal shield and, although it will pick up directly, its main pick-up from the antenna coupling coil will result in soul-satisfying distance.

The addition of a stage of tuned R.F. amplification ahead of the set itself is also practicable. It is particularly useful in the event of a bad location where a loop must be used or where the size of the loop is limited and a definitely better pick-up than now possible would be of great value. The details of such a unit are shown in Figure 1. This adds a third tuning control to the set, but it prevents the set from radiating, which too many Super-Heterodynes do—very effectively.

Despite what has been said from time to time, the addition of a stage of intermediate amplification, making four instead of three as in Fig. 2, is useful if done properly. Two of the R.F. stages are controlled by one potentiometer and two by another

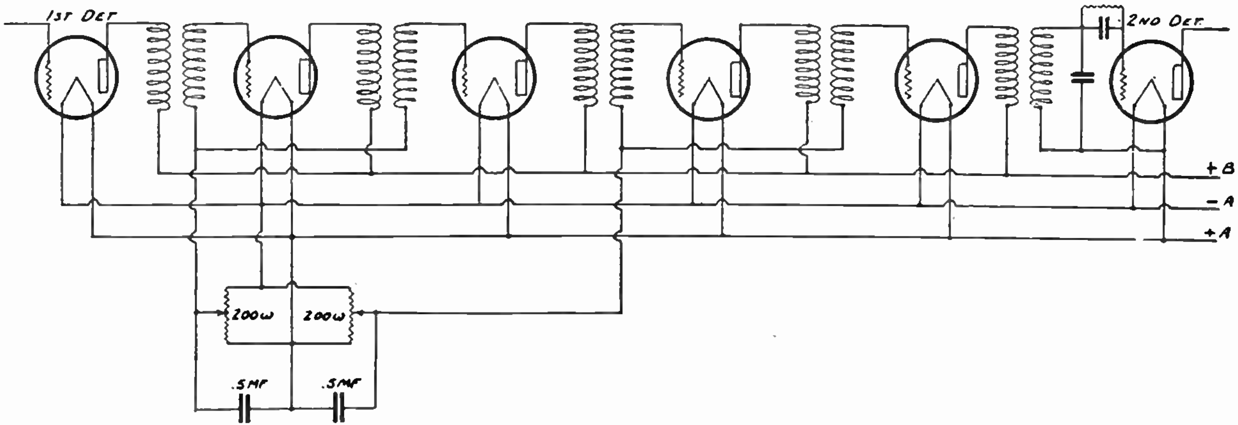


Fig. 2—Diagram showing method of controlling four intermediate stages.

This is apparently adding one control, but in actual operation the one potentiometer is set for a position close to oscillation and the other will be found to control all four stages. Only one of the potentiometers is put on the panel while the other is mounted with the other parts and adjusted by test to the proper point. Thereafter the panel potentiometer will be found very effective for controlling the intermediate frequency oscillating point to a nicety.

The addition of regeneration to the set is an easily accomplished thing that is included in a number of Super diagrams. The circuit of the Super-Heterodyne provides a certain amount of feedback from the loop circuit in the first detector by the use of a .00005 mfd. variable condenser which serves as a feedback control while tapping the loop, which provides the necessary inductive coupling to the grid circuit.

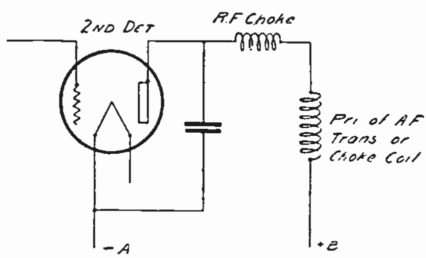


Fig. 3—Use of Radio-frequency Choke in Second Detector.

A word here about one thing may save someone some trouble. When using a circuit, where the first I. F. T. is an untuned one, this first IFT cannot be tuned if regeneration through the loop tap is desired. If a tuned transformer becomes the first one, the capacity used to tune the primary of this acts as a by-pass of that energy that should be fed back and no regeneration results. One fan, who preferred his tuned I. F. T. to come first, tried this and discovered that he had lost the sensitivity due to regeneration. The only remedy of this condition is a R.F. choke in the lead from the plate of the first detector to the plate connection of the first amplifier transformer. This should consist of 350 turns lumped on a small spool.

The most frequent fault in Super construction is the use of incorrect by-pass condensers. A Super handles two kinds of radio-frequency current: that having the frequency of the incoming signal and the oscillator, and that having the much lower frequency of the intermediate radio-frequency amplifier. The first require relatively low capacity R.F. by-pass condensers and the second relatively large. It is not unusual to see an .005 mfd. fixed condenser across the potentiometer of a 30 Kc. Super. This capacity is supposed to by-pass the R.F. around a 400 ohm potentiometer when its own reactance at 30 Kc. is 1,061 ohms. A .5 mfd. condenser having a reactance of about 10.6 ohms at 30 Kc. would be far more effective. Remember that reactance varies inversely as the frequency and also inversely as the capacity.

A peculiar by-pass condition is met in the second detector. To use a capacity much greater than .002 mfd. would result in rather bad distortion. This is particularly true where high primary impedance audio transformers are used. Yet .002 is inadequate because its reactance is in the order of 2,654 ohms at 30

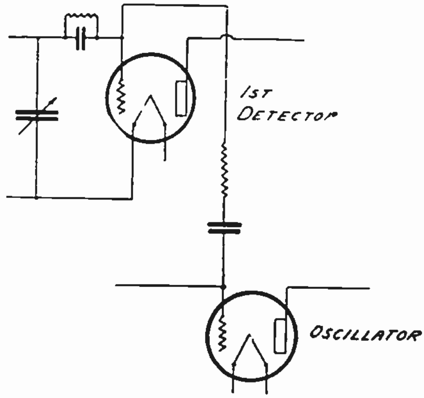


Fig. 4—Coupling Oscillator and First Detector by means of Resistance.

Kc., that being our illustrative frequency which puts a large part of the intermediate R.F. into the audio amplifier, and often results in instability because there can be feed-back from the loudspeaker to the first detector or the antenna circuit. Also, it sometimes happens that this R.F. causes howling in the audio amplifier. The remedy is a choke inserted as in Fig. 3. This R.F. choke can well consist of the secondary of one of the intermediate R.F. transformers with the primary left free. By purchasing an old I. F. T. whose resonant point is at a lower frequency than that of your intermediate R.F. you will be safe. Actually, every manufacturer should include a R.F. choke for this purpose in his Super kit. The choke should be a closed iron-core and it could be made quite small. A R.F. choke in the position as shown in Fig. 3 must not be too large or it will cause distortion by reducing the amount of the higher audio frequencies that reach that audio amplifier. Too low an intermediate R.F. would require too large a choke, so the only remedy is to choose the I. R. F. at a fair compromise. Between 3,000 and 6,000 meters is excellent for the purpose. On an unshielded Super-Heterodyne the use of a choke as in Fig. 3 is an absolute necessity for perfect performance.

The proper use and isolation of the energy of the oscillator of a Super-Heterodyne is important. The detector tube, upon which is impressed the oscillator and signal energy, operates best when the signal energy and oscillator energy inputs are the same. This points to the need of an adjustment that should be made for each signal, but this is not practically necessary. The man searching for supreme DX should have such an adjustment, but the man desiring a good and sensitive all around

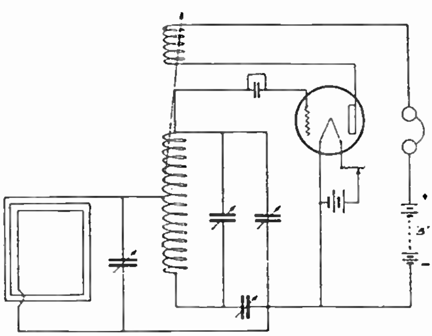


Fig. 5—Super-Autodyne Detector Oscillator.

receiver does not want a multiplicity of adjustments. However, such an adjustment, if provided, can be left fixed for the more normal receptions while always ready for the sympathetic touch of the searcher for distance.

Before going into the arrangement of the oscillator, the more ordinary and familiar methods of limiting the detector's pick-up from the oscillator will be of interest. There is the method of coupling the grid of the oscillator to the grid of the detector through a resistance and a capacity. This is shown in Fig. 4 and is used in some types of Super sets. There is the usual idea of a two to five turn pick-up coil run from the detector to the oscillator or vice versa. In some sets there is an oscillator-coupler with a rotating coil for pick-up containing anywhere from 10 to 40 turns. Although an adjustment of the coupling of the pick-up to the oscillator coils is possible, it is often true, due to jamming of parts or else the size of the pick-up coil, that anywhere between the limits of rotation of the coil pick-up is much the same and the adjustment proves useless. This had led many to the false conclusion that an adjustable pick-up is of no value although a correct trial would convince them otherwise.

Then there is the arrangement of Pressley's used by McMurdo Silver in the Super-Autodyne in which the detector and oscillator become one tube. This is an arrangement that can be made every bit as good as the separate frequency-converter arrangement if the tickler is arranged to be controllable from the panel so that the degree of oscillation can be adjusted to an exactness. It has seemed odd to me that such an arrangement has not been suggested before, for in practice, to the man that likes to push his set to its limit, it works out very well. The Super-Autodyne converter is shown in Fig. 5.

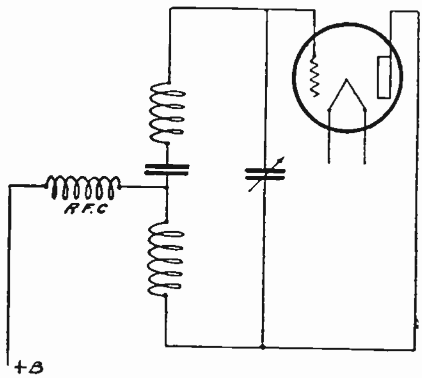


Fig. 6—Diagram showing method of localizing Oscillator Current.

If the isolation of the oscillation energy is provided for, it is not difficult to arrange the proper use of it for beat purposes. The trouble in most cases is in not properly isolating the oscillator current within the oscillator or circuits where no harm can result from its presence. This isolation can be accomplished fairly well by simple means. It is necessary to see that the detector circuits are well separated from the oscillator and associated apparatus. It is a good idea to build the oscillator coil in some form that has a limited field. This can be done by making the oscillator coil very small in diameter, 2 inches or less, wound with fine wire, or by using a special form of coil such as the Toroid, the Binocular or the D coil.

For instance, the ordinary oscillator circuit using a two section coil would, on a 2 inch diameter, require a coil of 70 turns of No. 30 d. s. c. wire, 35 turns in each section, wound in the same direction, and to be tuned with a .0005 mfd. variable condenser.

The losses that occur in an oscillator are unimportant since it always has many times the power needed. To further keep the oscillator energy within reason no more than 22½ volts should be used as B battery. It has been known for a loop of a Super to pick up energy directly from the oscillator, because the field of the loop and oscillator coils were so large that no other means of pick-up was necessary, even this being too much. J. L. MacLaughlin in the one-control Super keeps energy from the oscillator circuit from getting into the B battery by means of a choke coil as illustrated in Fig. 6. This should not be necessary where a sufficiently large B battery by-pass condenser is used, .1 mfd. or more.

Probably as good an arrangement as possible is to remove the oscillator tube and components to the end of the set farthest from the first detector and try out the set without any pick-up direct and intentional. If the set works well without an apparent pick-up, then the pick-up is from the wiring and other parasitic feeders. If there is no pick-up, arrange the pick-up coil with a variable shunt resistance according to Fig. 7, the pick-up coil being from 3 to 6 turns, 3 generally being enough. If the variable resistance has a good range, the adjustment of pick-up provided will take care of any condition of incoming signal-strength. The pick-up coil should have about 6 to 9 turns when the variable shunt resistance is used since the pick-up can be reduced to any desired strength. A variable grid-leak with a range of ½ to 5 or 6 megohms would be excellent for use in place of the resistance R in the coupling method as used in some types of Super sets as it would allow a very nice control of the pick-up energy. In this latter case some capacity effect would likely result but it can be partly eliminated by carefully mounting the variable resistance with a fairly long control shaft.

The best method of protecting the set from any pick-up from the oscillator, other than that intended, is to shield the oscillator circuit completely. As was said before, losses in the oscillator are of not much importance, so it can be crowded to get compactness.

Air-core intermediate R.F. transformers are not always desirable for Super-Heterodyne use. They are too sharply tuned, in the main, and when they prove to be not so sharply tuned they often prove also to be ineffective. Tubes whose capacity vary, differences in wiring capacity from stage to stage, and small similarities can affect the amplification of a sharply tuned transformer. The iron-core transformer is not sharply tuned and is justly the favorite at present. In any case the transformer should be inclosed within a shield unless it has an open iron magnetic circuit. The transformer with a good shield will not interact with its teammates, an important virtue. A closed iron core often makes in effect as good a shield as an inclosing can.

Sometimes exceptional pick-up results with a Super that is credited to the circuit rather than to outside influences. Particularly is this true where unusual results are secured with a

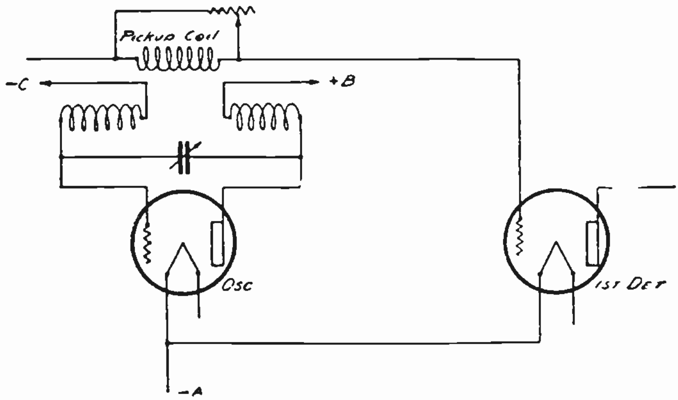


Fig. 7—Variable Resistance Pick-up Control.

very small loop and a normal circuit. In one case, the pick-up of the wiring in a house was the entire foundation of his (the owner's) success with a Super. He could hear anything worth hearing until the place was remodeled and the wiring run in grounded conduit. A similar case will be found with smaller set owners who are unable to surpass a light-socket antenna plug with a good outdoor antenna.

Another peculiar situation due to house-wiring occurred with one Super owner who was getting excessive interference from a local station. It was another case of open wiring. The house-wiring was practically on the wave-length of the local station and was thus full of quite a bit of energy from it. A strong signal field existed about this set so that in spite of everything that could be easily done, it was impossible to get away from interference from the local jazz generator. The owner was disgusted because he had built what was supposed to be a highly selective set and it had proved otherwise. The problem was solved by the use of three or four high capacity fixed condensers connected across the A.C. wiring in several widely spaced positions. Then the local station's strength dropped, insofar as excess was concerned, to a reasonable point and the set was able to tune it out.

Since the above case points to how easy it is to misjudge a set or circuit there is one other thing to be said in relation. That is, comparisons between circuits and sets are seldom made fairly. A particular instance was a man who built a conventional "Super" set that performed very nicely in a good location and of which he was very proud. Later he built another arrangement with a little different kind of oscillator circuit and a new "dyne" name. This he praised very highly as being much better than his original set. He was told that a tremendous difference was impossible with the same parts and but a rearrangement of the oscillator connections. Then we looked things over. The whole reason for the better performance lay in a loop whose

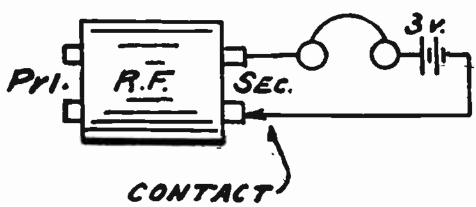


Fig. 8—Testing Secondary of I. F. Transformers; Primary tested in the same manner.

dimensions were nearly 6x6 feet in place of the 3½x3½ feet previously used.

Now that we have made several valuable suggestions which should be given careful consideration in the design and construction of the Super-Heterodyne receiver, it seems fitting to turn our attention to the matter of testing out the set and defects that may develop in its building.

We will first give a list of the ordinary troubles that may develop in the receiver and then follow it by a more detailed discussion of the individual tests for some of these more important troubles.

The following points should be carefully checked before proceeding with the operation of the receiver.

Test all of the batteries, or power units.

Clean and test all battery connections.

Make sure that the tubes are making good contact in the sockets and check all battery polarities for reversals.

Make sure that the leads to the condensers are in good condition.

Also check up on your loop aerial and make sure that there is not an open or short circuit in your aerial circuit.

Plugs not making good contact with the jack.

Variable condenser shorted.

Defective or burned out transformer or poor connections to same.

Defective Vacuum Tubes, or Rectifier Tube.

Potentiometer defective.

Fixed Condensers shorted.

Defective grid leak or condenser.

Grid condenser of too high a capacity or grid leak of the wrong value.

Parts of the apparatus touching the panel shield.

The power supply voltage too high.

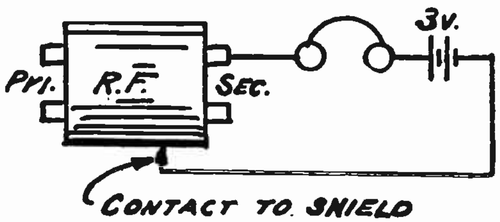


Fig. 9—Testing Secondary for Grounds; Test Primary in same manner.

ADJUSTING YOUR SUPER-HETERODYNE

How to Find and Remedy Possible Trouble in the Home-made Instrument

After you have carefully wired up your Super-Het, as per specifications, you may find that it will not "perk" at first. Such troubles can usually be remedied if you know what to look for.

First be sure that your sockets and intermediate frequency transformers are all right. Test out each instrument for shorts, open circuits, or grounds with a pair of phones and battery as in Figs. 8 or 9. The transformers should give a loud and distinct click when the circuit is made and broken through both the primary and secondary circuits. If shielded, test for grounds to the shield.

See that the condenser terminals make good contact. A rubbing contact, if dirty, may not be good. In soldering, be sure that the wire isn't held mechanically but makes an excellent contact as well. Stray noises, very difficult to locate, frequently come from this source, especially if in the detector or oscillator circuits. Polish up all socket contacts with fine sandpaper. Rub the tube terminals on a clean piece of fine sandpaper. The lead oxide film isn't very deep and is easily removed. The thoroughness with which the various instruments are tested may mean the difference between success and failure.

Now let us suppose that you have assembled the set, and are ready for a try out. It has been found that a meter in the positive B supply lead to all the tubes is one of the most helpful things for testing any set. The meter need not be calibrated, but may be a high voltage voltmeter minus the series resistance, as only comparative readings need be made.

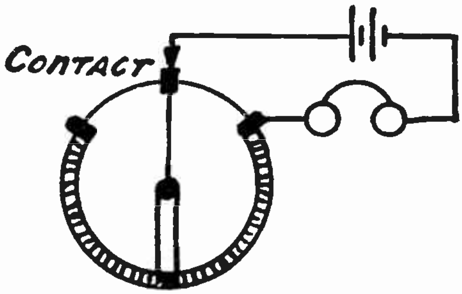


Fig. 10—Diagram illustrating the method of testing a Potentiometer or Rheostat.

The first thing to test is whether the filament circuit is right. Place one tube in a socket, and see if it lights. If so, try this tube in each of the other sockets, then disconnect the "A" battery.

Next connect the "B" battery or eliminator, without the meter for the moment, and short the filament leads momentarily by inserting a screw-driver between the socket contacts. If a large or unusual spark is produced, trace out the trouble. Make contact for an instant only or the batteries will be run down quickly. If the proper size voltmeter is available, it would be better to use it. If these circuits test all right, place tubes in the sockets, leaving out the audio-frequency ones for the time being.

Now plug the head-set in the detector circuit, and connect the meter in the "B" supply lead to the set. Take readings for each tube, and if there is one that seems to give unusual values, discard that one for the time being. The tubes should all be tested in the same socket, as the position in the circuit will give varying space currents.

Test the potentiometer, if one is used, by turning the arm until a click or hiss is heard in the phones, and noting the action of the meter as the tubes go in and out of oscillation, for future reference. If no click or meter kick is observed, check the R.F. wiring, and if OK check the contacts on the potentiometer. There should be a circuit between its three posts regardless where the arm is placed. This is tested out by the means of battery and phones, Fig. 10. A grating noise as the potentiometer arm is turned indicates poor contacts on the wire, which should be cleaned. If the R. F. tubes are oscillating, touching and removing the finger from the grid terminal will each give a distinctive click, also the meter will give an upward kick when the oscillations are stopped.

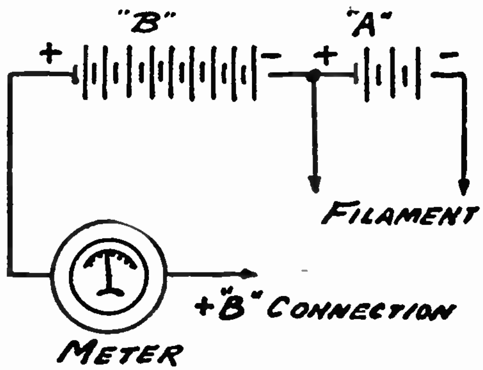


Fig. 10-A—Diagram illustrating method of connecting a Meter in the Battery Circuits.

The next circuit to test is that of the oscillator. If the grid of the oscillator is touched, a distinct click should be heard, and the meter should act in the same way as with the R.F. tubes, when oscillating. If the condenser is varied, a number of whistles should also be heard as it is turned through its various values.

The commonest faults of the oscillator are: too few turns on the plate feed-back (follow directions carefully); reversed plate leads; shorted or open coils, or poor contacts; or poor by-pass condensers. With an open plate coil, no space current will be shown on the meter. Lack of oscillations is shown by little or no change in the meter when the grid of the tube is touched. The filament adjustment, while not critical, must be above a certain value for oscillations to take place. I have found that nine-tenths of the troubles in a Super-Het occur in the wiring of the oscillator circuit.

Now if the oscillator and R.F. tubes are working properly, tune in signals, and try out the tubes in various positions. Some tubes are good R.F. amplifiers, some good A.F. amplifiers, some good detectors, and some are distinctly no good.

Don't overlook your grid leak or condenser or any by-pass condenser. They may be way off capacity, shorted or otherwise defective.

Cut out the by-pass condensers and then connect them one by one until the trouble is found. The only test for these condensers is a comparative one made by listening to the strength of signals. Any decrease in signals will show a defective condenser, wrong capacity or incorrect position. Your meter will generally show up a defective leak, especially if its value is low, for then a positive potential is put on the grid of the detector tubes, and an abnormal plate (space) current results. A little testing will show just what to expect. A reversed "C" battery will also cause a tube to show an excessive plate circuit.

The actual tuning in is greatly simplified by the use of a meter. By noting the action of the meters as the loop (or secondary) and oscillator condensers are varied, the resonance point may be determined. The meter gives a distinct dip as resonance is passed through, which may be easily recognized after a little practice. The relative dip of the meter will also indicate, more or less, the strength of oscillations at that particular setting. A small change generally shows weak oscillations. With a little observation, and general knowledge of the tubes under varying conditions, it should not be difficult to correct and adjust the faults that usually occur.

As a summary the following is given:

No plate current—
- (1) Defective tubes.
- (2) Open plate circuit—
  - (a) Poor tube contact.
  - (b) Opened transformer.
  - (c) Defective wiring.

Abnormal plate current—
- (1) Positive potential on grid—
  - (a) "C" battery polarity reversed.
  - (b) Detector grid leak too low.

Low plate current—
(1) Poor contacts.
(2) "C" battery too high—follow instructions. See note.
(3) "B" battery weak or filament low.

Note.—With correct "C" battery connections the plate current is very low, as compared to when it is not used. Test this out for yourself.

A buzzing sound—loud and persistent—shows an open grid circuit.

SHOOTING TROUBLE IN THE SUPER-HET

A Super-Heterodyne receiver which is not operating properly may or may not be as sensitive as a good three tube regenerative receiver—it depends on how really awful the re-

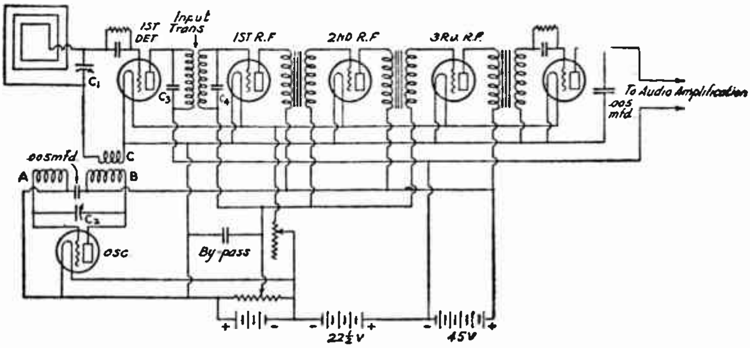


Fig. 11—Standard Super-Heterodyne Circuit using a Loop.

generative receiver is! Many people own and operate "Supers" and take pleasure in boasting of reception over distances of a thousand miles when the Super is operated with an outside aerial, but look surprised when asked what results have been secured with a loop. The idea of a Super operating with a loop! Well, folks, that is exactly what a Super—a **good** Super—is supposed to do. If your Super has to be operated with an antenna in order to accomplish reception over a distance of a thousand miles, you can be sure that either your Super is no good, or that you are located in a very thoroughly shielded "pocket" such as a steel building. If the former is the case your Super needs a considerable amount of ironing out.

Some Don'ts

Let's start out with a clean slate and eliminate a lot of undesirable things. First of all there is this "second-harmonic" principle. If you are using a detector oscillating at twice the working wave-length so that its second harmonic is used to make the intermediate frequency, which gives you trouble, use a non-oscillating detector plus a **separate** oscillator. It may take several long months to make a second-harmonic Super work, and it always operates with more distortion than a separate oscillator would cause.

Next is the matter of reflexing. The plain Super-Heterodyne is hard enough to put into operation. Why add a hundred per cent more trouble at the start by trying to reflex any of the tubes? Reflex sets are OK when they work, but no two of them work alike. It takes hours and hours of tinkering to do any kind of a reflex job. All manner of reversing of connections and substitution of various by-pass capacities are necessary. When the tubes are finally tied down to the point at which oscillation ceases, nine times out of ten distortion occurs somewhere and we are a lot worse off than we would be if we had forgotten the reflexing and used an additional tube.

Getting Started

Assume that your Super is not working at all. It has been assembled according to blue prints, all connections are soldered and are actually making contact, the tubes have been tested and found to be OK, the "B" batteries are OK with other tests already given and still the set will not make any music.

In Fig. 11 there is shown a standard Super-Heterodyne circuit. If yours differs radically from this one be certain that there is some excuse for the difference.

The Super can be divided into five component parts, all of which must operate satisfactorily alone before the Super, as a whole, can be expected to function. There is No. 1 an oscillator or tuner, No. 2 a 1st detector, No. 3 an intermediate frequency amplifier, No. 4 a second detector, and No. 5 an A. F. amplifier in **every** standard Super-Heterodyne. Each of these can be tested separately and if there is any trouble it can be readily located. It would be wonderful if this point could be driven home. No matter what affects a set the thing can be found more easily by going after one thing at a time. This goes for transmitters also. Don't tear the receiver down because the tube gets hot, sit down and think it over, then change **one** thing at a time and watch what happens.

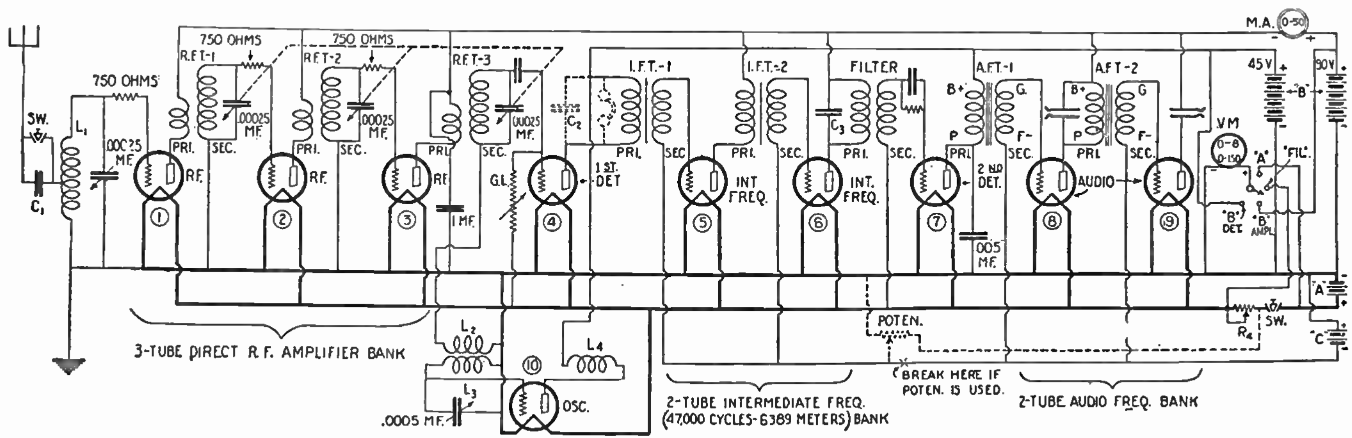


Plate I—Schematic circuit diagram for Navy model C-10 Super-Heterodyne receiver using plug-in coils and having a range from 600 meters down to 50 meters. This receiver has three stages of tuned radio-frequency ahead of the detector which eliminates radiation.

The Oscillator

The coils A and B of the oscillator inductance (Fig. 13) should be wound in the same direction, and the grid of the oscillator tube should be connected to the **outside** end of coil A and the plate to the **outside** end of coil B. If these connections are reversed, the oscillator will not operate and the whole set will be dead. The oscillator tuning condenser C2 is connected across the grid and plate of the oscillator tube. The rotary plates of this condenser must be connected to the plate, otherwise the hand capacity effect will be bad when varying this condenser. The by-pass condenser across the inside ends of coils A and B should have a capacity not less than .005 mfd., and should be mounted as near the coil as possible so that the leads from the condenser to the coil will be short. Coil C is the pick-up coil, which is coupled to the oscillator coils. If no means are provided for varying the coupling between coils B and C, coil C should consist of only one or two turns wound directly over coil B (Fig. 13).

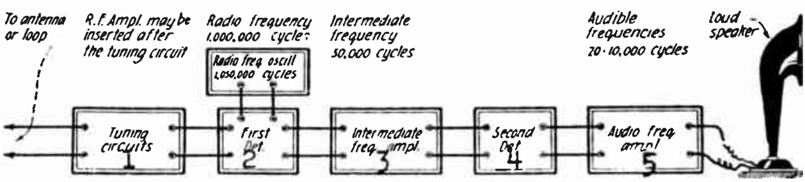


Fig. 12—This illustrates the five essential parts of a Super-Heterodyne receiver:

Parts 1 and 2 act as a frequency converter, making the short-wave signal into a long-wave signal. The intermediate frequency (or long wave) amplifier is then able to handle this signal.

3—The intermediate frequency (also called supersonic or long wave) amplifier which amplifies the long-wave signal passed to it by 1 and 2.

4—The second detector that converts the long-wave signal into A. F. passing it on to No. 5. No. 5 amplifies the audio frequency and feeds it into the head-set or loud-speaker.

The only possible sources of trouble in the oscillator circuit are (1) a short circuited or open circuited by-pass condenser. If there is a short on the by-pass condenser, the "B" battery will also be short circuited, (2) a shorted turn in either coil A, B or C. One shorted turn will quite likely keep the oscillator from oscillating. (3) A high resistance connection in the oscillator tuning condenser or a short circuit in this condenser. The latter condition will also cause a short circuit on the "B" battery. (4) Loose springs in the tube sockets which cause an open circuit or a bad connection between the tube pins and the external circuit. (5) Reversed grid and plate connections.

The First Detector (Part 2, Fig. 12)

The circuit of the first detector is shown in Fig. 14. If you live close to a high-power broadcasting station, it is possible to pick the station up on the loop and the first detector alone. Open the plate circuit of the detector tube at point "x" (Fig. 14) and connect a head-set in series with the plate and the primary of the input transformer. Remove all of the tubes except the first detector. By pointing the loop in the proper direction, tuning the loop with the condenser C1 and listening carefully, the local station should be picked up.

If you are not close to a broadcasting station it will be necessary to use either a buzzer-driven wavemeter or a home-made source of modulated power. The buzzer-driven coil and

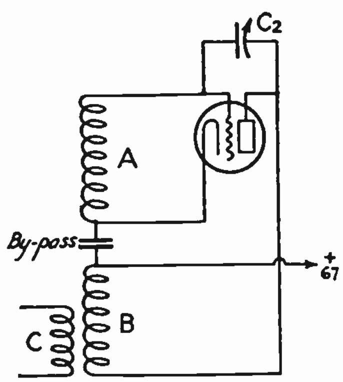


Fig. 13—Diagram of Oscillator connections.

condenser combination shown in Fig. 15 will function over the whole broadcast band. Place the coil near the loop and in inductive relation to it, connect the battery to the buzzer and set the shunt (tuning) condenser across the coil (C in Fig. 15) at about one-half maximum capacity. Now listen with the head-set, varying the tuning condenser across the loop (C1, Fig. 14). Somewhere near 50 degrees on the dial of the loop tuning condenser, the signal from the buzzer should be picked up. If it is not, retune the wavemeter, setting the condenser at a lower capacity, and again try to pick up the buzzer signal in the head-set. If it cannot be heard there is some serious trouble in the first detector circuit.

See that the variable condenser C1 is OK. It must not be open or short circuited. The pick-up coil C must not have any shorted turns. The primary of the input transformer must not be open circuited. Test it with a head-set and battery. And lastly see that the grid condenser is OK and that the grid leak is of the proper value and is not open or shorted.

Testing the Detector and Oscillator

(Parts 1 and 2, Fig. 12)

When the first detector has been put into operation and the oscillator circuit has been carefully checked and found to be OK, the two can be tested together. Start the buzzer once more. Insert the oscillator tube in its socket and listen, again, in the plate circuit of the first detector. Tune the buzzer signal by

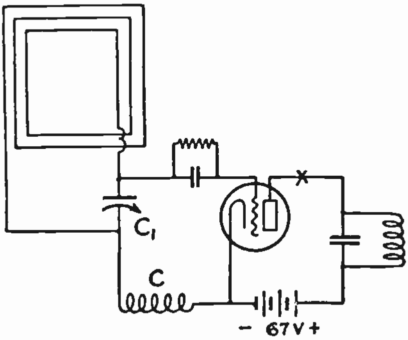


Fig. 14—Diagram of the First Detector.

means of the loop tuning condenser and then vary the oscillator tuning condenser (C2, Fig. 13). At a certain setting of the oscillator condenser, the buzzer signal will become muffled and will sound just as a spark signal sounds when the regenerative control on a regenerative receiver is advanced until the tube oscillates. Check this oscillation condition at both the lower and upper ends of the loop tuning condenser by setting the loop condenser first at 100, varying the buzzer condenser until the buzzer signal is picked up in the head-set, and then varying the oscillator condenser until the buzzer signal becomes indistinct and muffled. Then set the loop tuning condenser at about 5 or 6 degrees and repeat the above process, making certain that the oscillator muffles the buzzer signal at this condenser setting.

THE INTERMEDIATE FREQUENCY AMPLIFIER AND SECOND DETECTOR

(Parts 3 and 4, Fig. 12)

The intermediate frequency amplifier and the second detector are usually tested at the same time. If the intermediate frequency amplifier is properly wired and if the tubes are OK and the battery voltages correct, there is very little likelihood of trouble. When the potentiometer slider is turned completely to the left (or to the right, depending on how its terminals are wired) the intermediate frequency amplifier will go into oscillation. This oscillation will generally be accompanied by several long wave telegraph stations, as the coils of the intermediate amplifying transformers are large enough to pick up these high power signals without any antenna.

If the amplifier will not oscillate, test all of the sockets to see that the tubes make contact with the socket springs. See

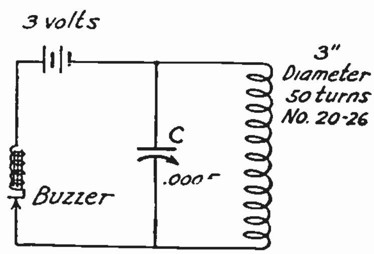


Fig. 15—Diagram showing Buzzer Arrangement for testing purposes.

that none of the connections between the transformers and the sockets are reversed (it is particularly important that the intermediate frequency transformer terminals marked "G" be connected to the grids of the tube sockets). See that the condenser C4, Fig. 16, is not open or short circuited and that the by-pass condenser between the potentiometer slider and the positive "A" battery lead is properly connected and is not open or shorted. The grid condenser in the grid circuit of the second detector should have a capacity of .00025 mfd. and should be used with a grid leak having a resistance from 2 to 10 megohms. A rather large by-pass condenser must be used across the headset (or output circuit and the "B" battery), as the amount of radio-frequency current in the plate circuit of the second detector is usually quite large. A .002 mfd. condenser usually will not be large enough to by-pass all of the R. F.—use a .005 or .006 mfd. condenser to start with.

If the amplifier oscillates continually and cannot be stopped there are some undesired feed-backs between grid and filament or plate and grid circuits. All of the plate and grid leads from the transformers to the sockets should be run in as short and direct a manner as possible, taking care, however, not to parallel these leads. The transformers should not be mounted closer than 2 inches from center to center, unless they are enclosed in metallic cases which are connected to each other and to the negative of the "A" battery.

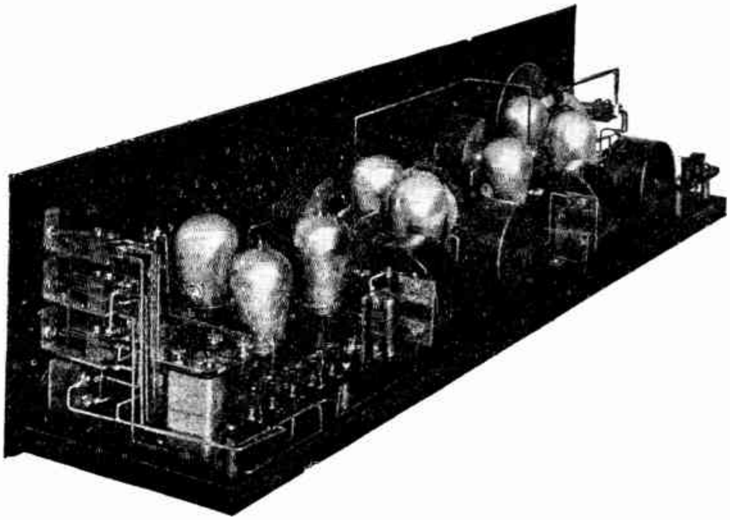


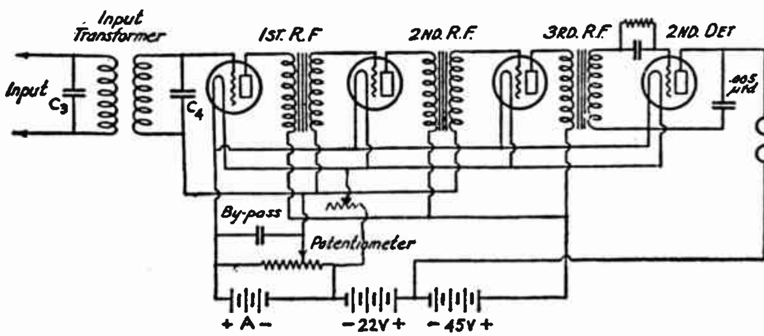
Plate II—This is a rear view of the panel showing the arrangement of the parts for an 8-tube Ultradyne receiver.

The Input Transformer

The intermediate frequency amplifier may be operating properly and still it will oscillate if the input transformer is not properly tuned; or if the proper coupling is not provided between the primary and secondary coils. There are some Super-Heterodynes that use the same type of I. F. transformer all the way through and still others that use a sharply tuned output transformer instead of a sharply tuned input transformer. The instructions here given can be readily modified by the student who is dealing with such a set.

For a 30 K. C. (10,000 meter) intermediate frequency no better input transformer can be constructed than one having a

1,250 turn honeycomb coil in the primary and a similar coil in the secondary circuit (Fig. 17). The outside end of the primary coil should be connected to the plate of the first detector and the outside end of the secondary to the grid of the first radio-frequency tube. The coils should be mounted so that the distance



THE INTERMEDIATE FREQUENCY AMPLIFIER

Fig. 16.

between them can be varied up to four inches. This rather loose coupling is not generally required, but under certain conditions the only way in which the proper selectivity can be secured is by loosening the coupling to this extent.

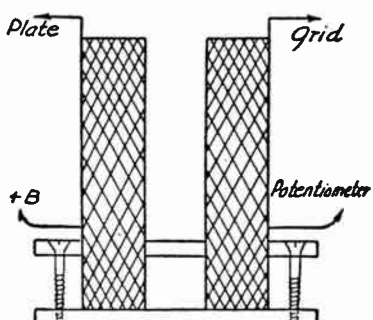


Fig. 17—This illustrates the connection for the four lead wires coming from the input transformer.

Both primary and secondary coils are shunted by .00025 mfd. fixed condensers. This value is rather critical. Do not rely upon the manufacturer's stamping of ".00025 mfd.", but try different condensers of this capacity until the correct one is found. Some of the small fixed condensers on the market—both paper and mica—have been made to fit the popular demand for a cheap condenser. When one pays for something cheap one generally gets something cheap. In a set so highly expensive as a Super-Heterodyne it is well to order special condensers that are guaranteed to have a capacity within 10 per cent. (or less) of their rating. They cost a bit more but they are worth the added cost. A change in this shunt capacity of only 10 mmf. will make a lot of difference in both the signal strength and the selectivity, as will also the coupling between coils.

THE AUDIO-FREQUENCY AMPLIFIER

With a single stage of audio-frequency amplification, the signals from stations within a distance of 500 miles will be uncomfortably loud. For loud-speaker volume for the average room

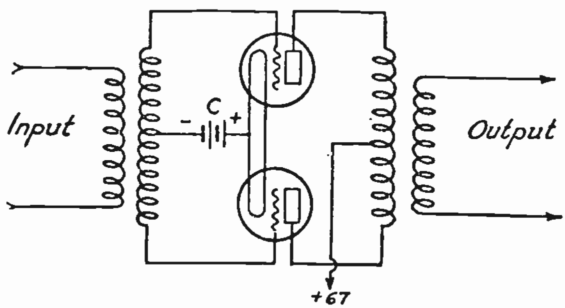


Fig. 18—Wiring diagram for push-pull audio amplifier.

a single stage of audio amplification is ample. If greater amplification is desired an additional stage may be added. This stage should be connected in the so-called push-pull fashion using two tubes and two transformers as shown in Fig. 18 in the one stage. If more than 45 volts are used on the plates of the audio tubes, a "C" battery will be needed. This "C" battery should have the proper voltage, depending on the plate voltage and type of tubes used.

Shielding

So far we have not mentioned shielding. Most people (and manufacturers, too) go at the shielding in such a half-hearted fashion that it might just as well be left out of the set entirely. The shielding, to be any good at all, *must* be thoroughly done. It is *not* satisfactory to merely enclose the whole intermediate

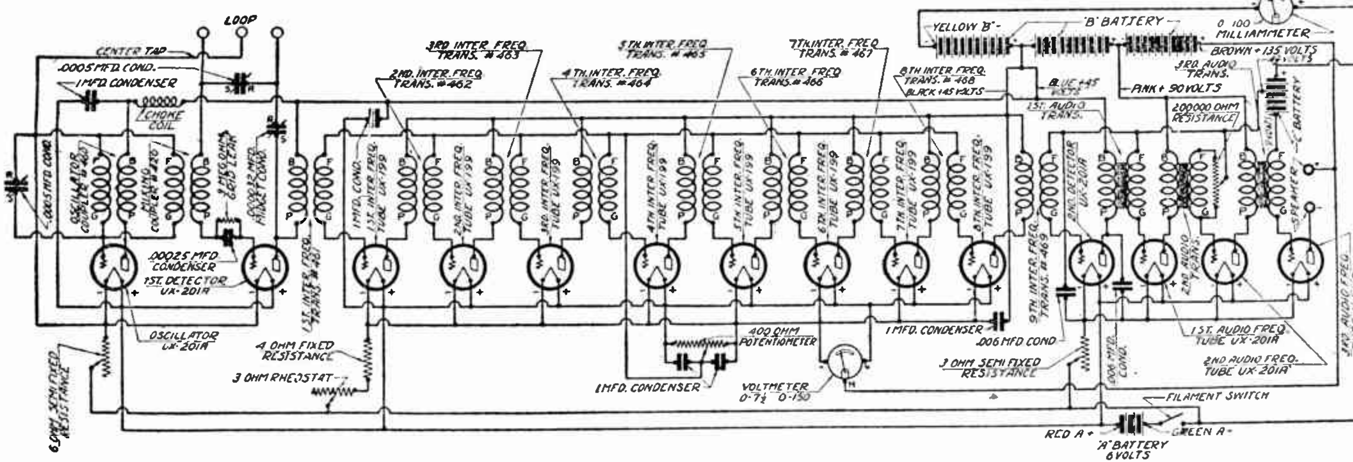


Plate III—Schematic wiring diagram, Melo-Heald Fourteen Super-Heterodyne.

frequency amplifier in a tin can—each component of the set should be shielded from the rest of the set.

The back of the panel, the baseboard, the inside of the cabinet and the top of the cabinet should be covered with a

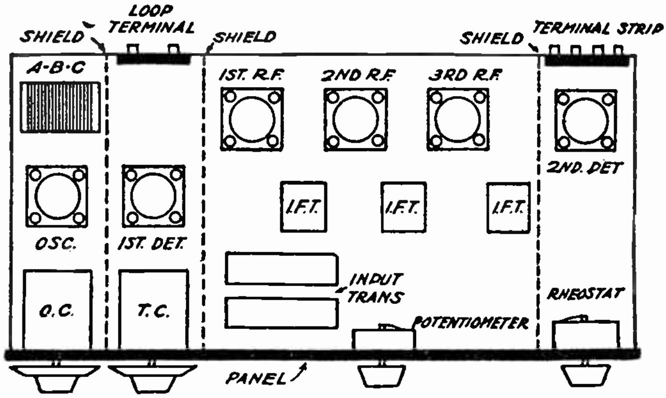


Fig. 19—Illustrates a neat form of lay-out and the method of shielding the parts of the set

sheet of 12 ounce copper. In addition partitions should be inserted between the oscillator and the first detector; between the first detector and the intermediate frequency amplifier, and between the intermediate frequency amplifier and the second

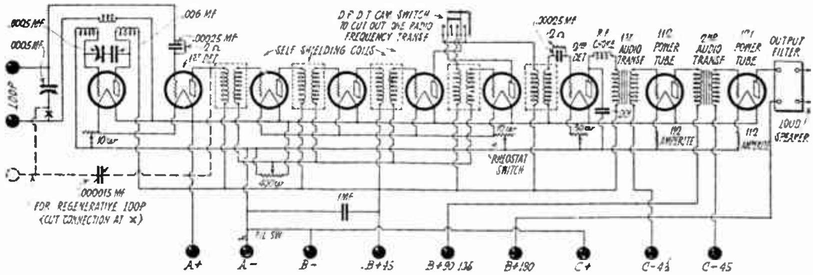


Fig. 20—Circuit diagram of Magnaformer 9-8 Super-Heterodyne Receiver.

detector. These partitions should extend from the base to the top of the cabinet and from the panel to the inside of the rear of the cabinet. The shielding for the baseboard can be tacked on with small escutcheon pins. The panel shield can be held in place by means of the two condensers (if the condensers are not alive—that is, if they are insulated from the panel), and also by means of the potentiometer and rheostat. Care must be taken that the holes for the shafts of condensers, rheostat, and potentiometer are large enough to avoid any contact between the shielding and the metal parts of the instrument.

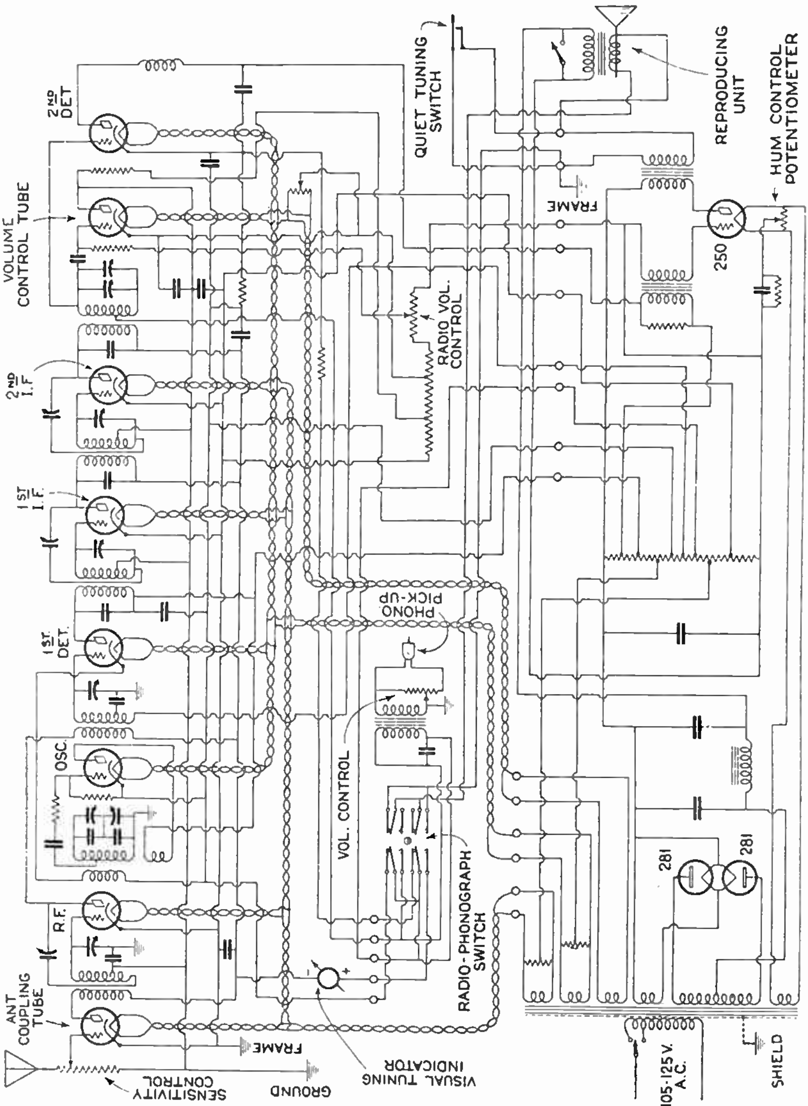


Fig. 21—Schematic diagram of the Radiola 64. A. C. Super-Heterodyne Receiver.

The upper shield forming the partition may be cut from this same copper in the form of squares or rectangles, and soldered in place against the baseboard and panel shield. See Figure 19.

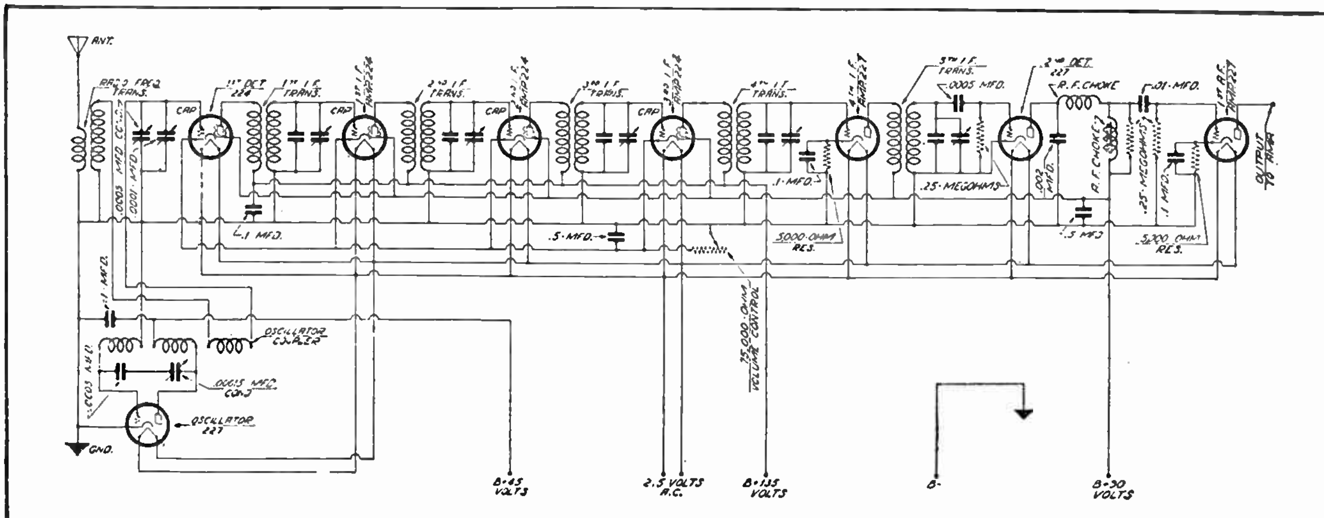


Fig. 22—Schematic diagram of Scott Screen Grid A.C. Ten Receiver.

The first compartment contains the oscillator, tuning condenser, the oscillator tube and oscillator coupler. The second compartment contains the loop tuning condenser, first detector tube and the terminals for the loop, while the third compartment holds the input transformer, the three intermediate frequency transformers and the three intermediate frequency tubes. The last compartment holds the rheostat, the second detector and the terminal strip for the "A" and "B" battery connections. All "A" and "B" and potentiometer wires should be run in a "cable" made of flexible wires, insulated, and laced together with string. The shielding material itself should be used as the negative "lead" of the battery. All connections going to the negative "A" should be soldered directly to the shielding.

If shielding is done in this manner, the volume and selectivity of the set will be increased fully fifty per cent.

TEST QUESTIONS

Number your Answer Sheet 26 and add your **Student Number.**

1. What improvement would you suggest for loop antenna used with a Super-Heterodyne receiver?
2. Show the wiring diagram for adding one stage of R. F. to the Super-Heterodyne set.
3. What kind and where can a R. F. choke coil be used in the 2nd detector circuit to prevent howling?
4. How may one protect the set from pick-up from the oscillator?
5. Show by diagram the method of testing a rheostat or potentiometer for open circuit or bad contact.
6. What happens when the grid circuit is open?
7. What is the advantage and also the disadvantage of reflexing the Super-Heterodyne set?
8. Name five sources of trouble in the oscillator circuit.
9. What causes an I. F. amplifier to oscillate continually?
10. What effect has shielding on the set and what kind of metal is used?

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RADIO BATTERY CHARGERS

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Pausing For Thought

A Personal Message from J. E. Smith

Concentration in study does not mean steady reading without pause. That may be concentration all right, but it is not a profitable kind of concentration. One should stop now and then and turn over in his own mind what he has been reading.

That is the only way to insure that the ideas he has gained, or thinks he has gained, are really clear to him. It is the only way, too, in which he can make them genuinely his own and be able in the future to apply them to circumstances in which he, himself, may be placed.

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RADIO BATTERY CHARGERS

The use of a storage battery for operating radio receiving sets requires some provision for charging the battery. Either you must utilize some Battery Service Station to which you can send or take the battery to be charged, or you must have a battery charger of your own. The latter plan is by far the most satisfactory and economical to the average man, and to meet his needs there have been a wide variety of chargers placed on the market, but before making your selection of a battery charger,

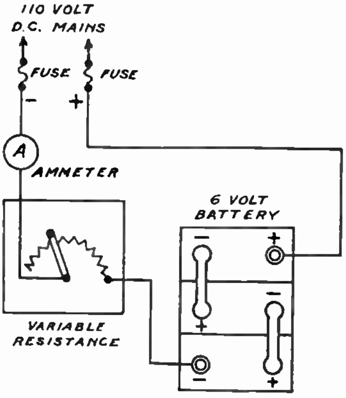


Fig. 1—Charging a 6-volt storage battery from a D. C. line using a variable resistance to regulate the charge rate.

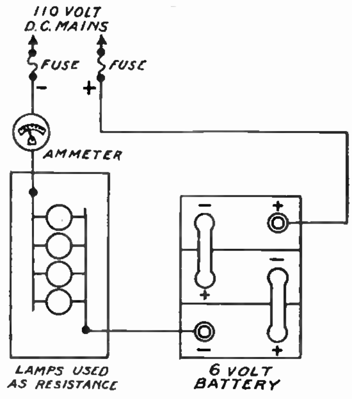


Fig. 2—Charging a 6-volt storage battery from a D. C. line using lamps for resistance to regulate the charge rate.

find out from your Electric Light Company whether you are being supplied with alternating current or direct current; also what is the voltage of the line and the frequency if it is alternating current.

CHARGING BATTERIES FROM D. C. LINE

Assuming that the source of supply is direct current, it is only necessary to procure a special resistance for the purpose (see Figure 1) which may be purchased or as an alternative, you may use a few electric light bulbs as shown in Figure 2.

SIMPLE METHODS OF DETERMINING POLARITY

In charging storage batteries, the positive terminal of the circuit must be connected to the positive terminal of the battery.

Unless the positive terminal of the charging circuit has previously been determined and marked, it becomes necessary to determine this before connecting it to the charging circuit. In case of necessity, one of the following simple methods may be used.

(A). Voltmeter. A voltmeter of the direct current type usually has one terminal marked with the plus sign. When this terminal is connected to the positive terminal of the circuit, the needle swings up the scale. Otherwise, the deflection of the needle is reversed.

Fig. 3—D. C. Trickle Charger having a constant charging rate of ½ ampere.

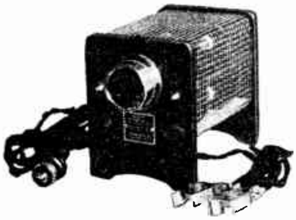


Fig. 4—D. C. 4-Ampere Charger.

(B). Ammeter. When an ammeter is connected in series with a circuit, it indicates current flowing through it from the terminal marked with the plus sign to the other terminal, the latter being the negative terminal of the circuit. A high resistance or other current limiting device must be connected in series with the ammeter.

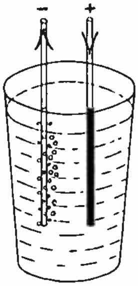


Fig. 5—Simple test for polarity of line.

(C). Electro-chemical. The passage of a current through an electrolyte decomposes it, and the character of this decomposition may be used to indicate the direction of the current flow. The simplest application of this principle for testing the polarity of low voltage circuits is to insert the two wires of the circuit in a raw potato and observe at which terminal the potato turns green. This is the positive terminal. The cause of the green color is the copper which is removed from the wire by the current. If this method is employed, care must be taken not to short circuit the source of current. Either a resistance must be connected in series or the ends of the wires must not make contact with each other.

Another application of the principle is to immerse the two wires in a glass tumbler in which is dissolved a small amount of ordinary table salt. The wire at which there is violent bubbling is the negative wire and should go to the negative terminal of the battery. See Figure 5.

(D). Compass indicator. If the north pole of the compass needle points away from the observer, when the compass is placed above a wire carrying a small current, then the direction of the

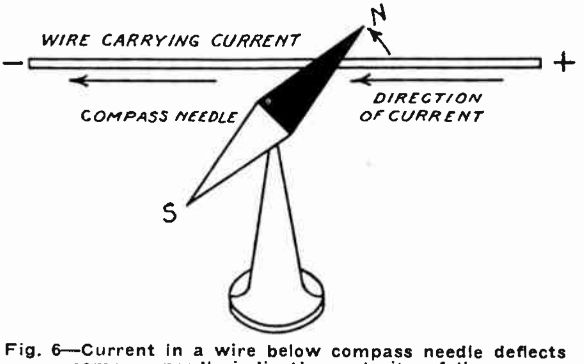


Fig. 6—Current in a wire below compass needle deflects compass needle indicating polarity of line.

current flow is from right to left, and the right end of the wire is positive with respect to the left hand end. See Figure 6.

(E). By using white filter paper immersed in a solution of sodium sulphate to which has been added a small quantity of phenol phthalein, the result is a colored paper which, if moistened, will turn violet when touched with the negative wire, but remains unchanged when in contact with the positive. The paper retains this property indefinitely and is sensitive to a very feeble current. Blue print paper may be used for the same purpose, a white spot developing around the negative pole when the paper is in contact with the wire, while the positive wire has no effect on it.

OHM'S LAW

In order to know how to connect and charge a storage battery, it is quite necessary to understand the relation between the electrical quantities associated with any ordinary electric circuit carrying a direct current. The flow of electricity in a circuit is called the current and is measured in a unit called the ampere; the electric force producing the current is called the voltage, potential, or electromotive force, and is measured in a unit called the volt; while the opposition offered by the circuit to the passage of electricity through it is called the resistance, which is measured in a unit called the ohm.

These three quantities, namely, electromotive force, current and resistance bear a definite relation to each other and this relation is expressed by the following simple equation, which is called Ohm's Law.

$$\text{Current} = \frac{\text{Electromotive Force}}{\text{Resistance}}$$

$$\text{Resistance} = \frac{\text{Electromotive Force}}{\text{Current}}$$

$$\text{Electromotive Force} = \text{Current} \times \text{Resistance}$$

As an example, if the voltage is increased, the resistance remaining constant, there will be a proportional increase in current, or if the resistance should be reduced, the voltage remaining constant, there will be a proportional increase in the current, etc. In other words, the current in the circuit may be varied by changing either the voltage acting on the circuit, or the resistance of the circuit.

It can be seen from the above that if the battery were connected directly across the line, there would be a short circuit as the internal resistance of a storage battery is very low. Therefore, to regulate the value of the charging current, it is necessary to insert a resistance in series with the battery.

A storage battery or accumulator, as it is sometimes called, is a number of cells in which a chemical action is first produced by an electrical current through the cells from some external source of energy, after which the cells are capable of delivering a current to an external circuit by means of a secondary or reversed chemical action. The process of storing electrical energy by sending a current through the cells from some external source of energy is called charging. When the cells are producing a current in an external circuit or supplying energy, they are said to be discharging.

The following discussion will be confined to the charging of storage batteries. As an example, suppose a 110-volt direct current circuit is available and it is desired to charge a small 6-

volt battery, such as those that are principally used with radio sets or automobiles.

All storage batteries have what is called a normal charging current and this current must be passed through the cells for a certain number of hours in order to fully charge them.

CAPACITY OF STORAGE CELLS

What does this mean? Just this, a 60-ampere hour storage battery will deliver (theoretically) 60 amperes of current for one hour, or one ampere for 60 hours, or 2 amperes for 30 hours, or its equivalent. Say you use three 201-A tubes and a 112 tube in your Radio receiving set. Each 201-A tube takes ¼ of an ampere of current, the 112 tube takes ½ ampere, the total current drawn in one hour is 1¼ amperes. Sixty divided by 1¼ is 48; the "A" battery should last 48 hours, theoretically.

Suppose you use the receiving set for 4 hours each day. At the end of 12 days the battery would be run down, but we don't want the battery to be completely discharged; when it is half discharged, the voltage starts to drop and we want to keep the voltage fairly constant. Therefore, we cannot wait until the 12th day to recharge it. The time to recharge is dependent upon the relative condition of the battery—it might be the sixth or the seventh day. We cannot rely on figures, such as those given, to determine the time for recharging, but we can tell the condition of the battery by testing the specific gravity of the electrolyte solution in the storage cells with a hydrometer.

TESTING CELLS WITH A HYDROMETER

By drawing some of the electrolyte out of a cell in the battery into a glass barrel, its specific gravity can be measured. The glass float inside the hydrometer barrel will float in the liquid, the figures on the stem of the float which appear on a level with the surface of the electrolyte indicate the specific gravity of the latter. See Figure 7.

The electrolyte from the cell of a fully charged battery should have a specific gravity reading between 1275 and 1300.* The three cells composing a 6-volt storage battery are isolated from each other, therefore, use the hydrometer on all three, not just one. Two of the cells might give a normal reading, when the third was undercharged. Don't overlook this fact.

If the electrolyte in one cell is low in its specific gravity reading, leave the battery on charge for a greater length of time

*The decimal point is not placed on the Hydrometer scale readings, but must be understood by the reader and inserted when recording readings. 1300 means 1.300.

and give this cell a chance to pick up; a slight excess charge will not harm the other two cells just so long as it is not continued for too long a period.

As to the lower limits, when the electrolyte drops to a specific gravity of 1.200, it is time for the battery to be recharged. It is best to start the charging even before it reaches this figure, say at 1.210. The battery is entirely discharged when the specific gravity falls to 1.150. Remember that an ordinary voltmeter reading either before or after a charge is not a suitable method for determining the condition of the battery.

Electrolyte, like most substances, expands with heat, affecting the hydrometer reading. To compare different hydrometer readings, therefore, the temperature should be about the same. It is a known fact that every three degrees increase in temperature decreases the hydrometer reading 1 point and this fact can be used in estimating what the hydrometer reading would be at normal temperature. The normal is taken at 78 degrees Fahrenheit. If the hydrometer reading at 100 degrees is 1.270, it would be 10 points more, or 1.280 at 70 degrees. When the temperature is much above or below normal, hydrometer readings should be corrected for temperature. Some hydrometers are a combination hydrometer and a thermometer, showing in red ink the temperature of the electrolyte, while at the same time giving the specific gravity reading in black ink. By specific gravity is meant the relative weight of any substance compared with water as a basis.

Now, in regard to charging the battery at a certain rate, assume that the charging current of the battery is 5 amperes, and its voltage 6. If the voltage of the source of energy is 110, the resistance that must be placed in series with the battery can be determined by means of the following equation, in which V is the voltage of the source of energy, E the voltage of the battery being charged, R the resistance of the circuit and I the current in the circuit.

$$R = \frac{V - E}{I}$$

Substituting the above equation, we have

$$R = \frac{110 - 6}{5} = 20.8 \text{ Ohms.}$$

The above resistance of 20.8 ohms represents the total resistance of the circuit and includes the resistance inside of the battery. The resistance of the leads and the resistance of the current regulating device connected in the circuit is called a rheostat. When speaking of the voltage of a battery as being so many volts, reference is made to the difference in electrical pressure between its terminals, which is different from the electrical pressure existing inside the cells. There is a certain resistance in ohms offered by the individual cells themselves to the passage of a current through it, and as a result, only a part

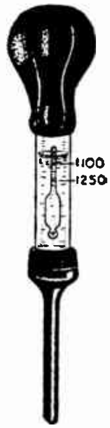


Fig. 7
—Hydrometer set.

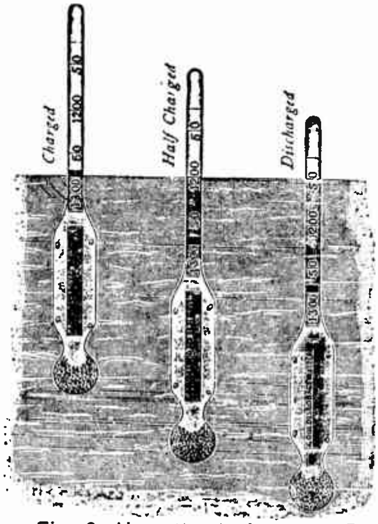


Fig. 8—How the hydrometer float checks the specific gravity of the battery.

of the electrical pressure existing inside the cells is available at the terminals when the cell is discharging, because some of the pressure is required to cause the current to pass through its internal resistance.

If a storage battery is being charged, a voltage must be impressed upon these cells that is greater than the voltage inside the cells in order that some voltage be available to send the current through the internal resistance. The voltage between the terminals of the battery is the same as the voltage inside only when there is no current through the cells. As the process of charging a battery continues, the voltage inside the cells increases and, as a result, there will be a decrease in the current, because the effective voltage acting on the circuit has been decreased, and the resistance must be decreased if it is desired to maintain the current constant.

In charging a single 6-volt battery from a 110-volt circuit as shown in Figure 1, the greater part of the energy supplied by the source of energy is expended in the resistance and the process is not at all efficient. The ratio of the input to the battery and the input to the resistance is the same as the ratio between the voltage over the battery and the resistance, respectively. This charging process can be made a great deal more efficient by connecting a number of storage batteries in series, and charging them all at the same time. The total voltage over the batteries

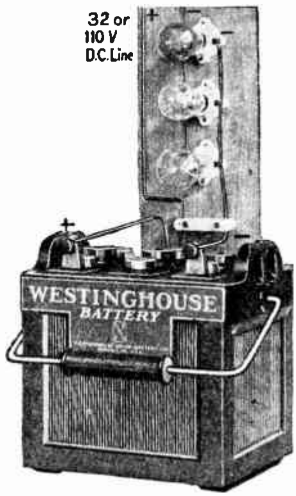


Fig. 9—Showing how to charge a 6-volt A battery from a 32 or 110-volt direct current line by means of a lamp bank. Adding lamps to the bank will increase the charge rate. Using lamps of larger wattage will also increase the charge rate.

in this case will be much greater and a much smaller resistance will be required. It is thus seen that the value of the resistance in ohms—that is, to be connected in series, will depend entirely upon the effective voltage and current required.

CONTROL RESISTANCES

If it is desired to charge a single 6-volt battery as was originally assumed, a very simple and inexpensive resistance may be made as follows: Obtain several porcelain lamp sockets; mount these sockets on a piece of board covered with asbestos, just far enough apart so that the lamps will not touch when placed in the sockets. On one end of the board mount a 10-ampere snap switch, a plug fuse block and four binding posts, and make the connections as indicated in Figures 2 and 9, using insulated wire. The charging current supplied to the battery may be regulated by screwing the lamps in or out of their respective sockets. If a larger current is desired, more lamps may be connected in parallel with those already in use. The completed board may be mounted on the wall and a small shelf provided for the battery, which will give a very convenient means of charging it.

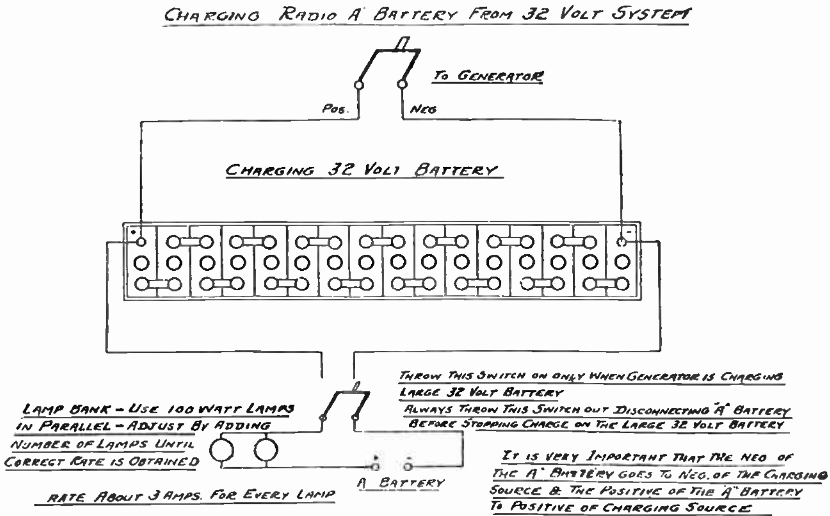


Fig. 10—Shows method of wiring for charging both "A" and "B" batteries from a 32-volt farm lighting unit.

To determine the number of amperes that will pass into the battery through a single lamp, divide the wattage of the lamp by the voltage. For example, the number of amperes that flow through a 110-volt 60-watt lamp is equal to 60 divided by 110 or 54/100 (.54) of an ampere, approximately ½ ampere. Four of these lamps in a bank would give a charging current of 2 amperes through a battery. For charging a battery from a 220-volt circuit, proceed as for a 110-volt circuit, but use 220-volt lamps of twice the watts used for 110 volts if it is desired to obtain the same number of amperes.

Storage batteries may be charged from a 32-volt farm lighting circuit. A lamp bank of 32-volt lamps may be used. Do not use only three or four cells of the farm lighting plant for this will unbalance the battery—that is to say, the amount of charge in the cells will then be unequal and when placed on charge, some of the farm lighting cells will be charged before the others or may be overcharged. There is no objection to charging a storage battery while the farm lighting cells are being charged by the engine generator, but the charge rate to the battery must be watched so that it does not exceed a maximum as the farm lighting cells become charged.

Applying the rule given under the 110-volt section, it is found that a 32-volt 100-watt lamp would pass a charging current of about 3 amperes to the battery. Two of these lamps would, therefore, charge the battery at about a 6-ampere rate, which is slightly higher than the given rate of 5 amperes but is close enough to be used. See Figure 10.

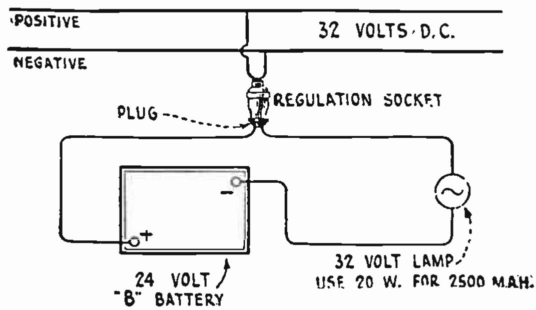


Fig. 11—Shows method of connecting lamps in series for controlling the amount of charging current.

CHARGING "B" STORAGE BATTERIES

To charge storage "B" batteries from a 110-volt direct-current source, the batteries should be connected directly across the 110-volt D. C. line with a 50-watt lamp in series so that only a fraction of an ampere of current will be delivered to the battery. When using this method of charging, a "B" storage battery having a voltage of anywhere from 22½ to 90 volts may be charged at the same time.

If the source of supply is a 32-volt farm lighting outfit, using a generator and storage battery, it will be necessary to separate the "B" battery (for charging purposes only) into 24-volt units using a 20-watt lamp for a 2500-MAH (milliampere-hour) battery and a 40-watt lamp for a 4500-MAH battery. See Figure 11.

MOTOR GENERATOR CHARGING UNIT

While the previous methods described are recommended for their simplicity, they are very inefficient. Thus, when charging a 6-volt battery at a 5-ampere rate from a 110-volt D.C. line, the power consumed by the resistances and dissipated as heat is 104 multiplied by 5 equals 520 watts while that consumed by the battery is only 6 multiplied by 5 equals 30 watts. Thus, the efficiency of the method is only approximately 6%.

Obviously, such a wasteful procedure would be impractical commercially. An excellent method for charging batteries which is not only satisfactory for the owner who charges his own batteries but equally for one who finds battery charging for his neighbors a fairly lucrative side-line, consists of a motor generator. An automobile generator, most of which can deliver about 15 amperes at 8 volts, is coupled or belted to about a 1/6 H.P. motor, driven from the main line. The motor is A.C. or D.C., depending upon the installation.

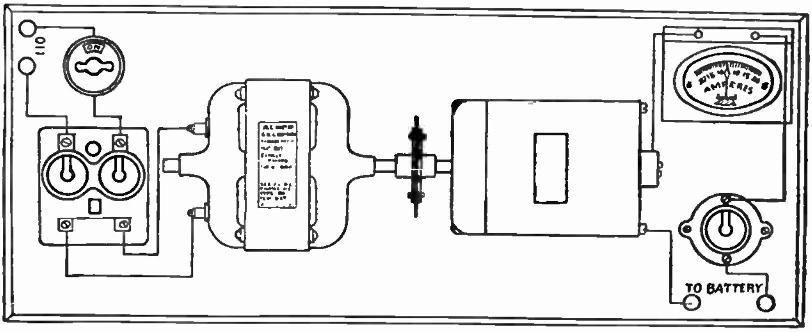


Fig. 12—This shows a motor-generator equipment for charging batteries.

The advantages of a motor generator charging set are:

(1) Highest efficiency.

(2) Quickest method of charging.

(3) Longest life (no bulbs, etc.).

Figure 12 illustrates the general lay-out of the complete equipment for a motor generator installation as used in connection with charging storage batteries, both for radio and automobile purposes. The 110-volt A.C. source is shown in the upper left-hand corner with a snap switch (just to the right) for starting and stopping the motor.

Just below the snap switch is shown the proper protective fuses which will open the circuit in case there is an overload or short-circuit on the generator. The machine to the left is a motor which is directly connected by a coupling to the generator. The voltage of this generator may be varied from about 4 or 5 volts up to a maximum of 35 or 40 volts by means of a field rheostat.

In the upper right-hand corner of the figure is shown a double reading ammeter and just below it is a fuse block, in which may be inserted different size fuses according to the charging current that is to be used. In case the 110-volt power should be accidentally cut off, the motor generator set will stop and the battery will discharge back to the generator armature causing a high value of current to flow in the circuit due to the very low resistance of the armature. The fuses or a circuit breaker will open the circuit under these conditions and avoid the battery being discharged due to this occurrence.

Its only disadvantage is the higher initial cost but if the battery charging is to be considered as a source of income, this factor dwindles. The size of the unit must, of course, be increased if the total charging load is in excess of the output of the generator.

A. C. CHARGERS

Rectifiers for Charging Storage Batteries

In many instances where only alternating current is available, the expense of the installation of a motor generator set and switchboard for charging purposes is not justified and other means must be provided. Since only direct current is suitable for charging, the alternating current must be changed to direct current before it passes through the battery. This changing of the alternating current to direct current is known as rectification and the apparatus or instrument by which the conversion is made is known as a rectifier.

An alternating current is one that is constantly changing in intensity and reverses its direction of flow periodically. Graphically, the fluctuation of an alternating current with time may be represented by the wave of Figure 13, which is drawn for a 25-cycle current. In this figure, the distance horizontally from the point marked "O" represents time after closing the circuit. The distance from this line to the wave represents the intensity and direction of the current flow at any particular instant. Thus at the instant of closing the circuit, the current is zero, 1/200 of a second later, the value of the current is represented by the line a-b in the positive direction. This means that in Figure 14 the current at this instance is flowing from A to B. After an interval of 1/100 of a second, the current is represented by the line c-d still in the positive direction. After an interval of 1/50 of a second, the current is again zero and during the interval from 1/50 to 1/25 of a second, the current passes through a similar set of values but in a reverse direction, namely, from B to A, Figure 14.

Thus, the current is shown as constantly varying or changing in intensity, and periodically once every 1/50 of a second, reversing its direction of flow. In 1/25 of a second, the current has passed through a complete cycle of values and entering upon its second set of values, which is an exact repetition of the first set.

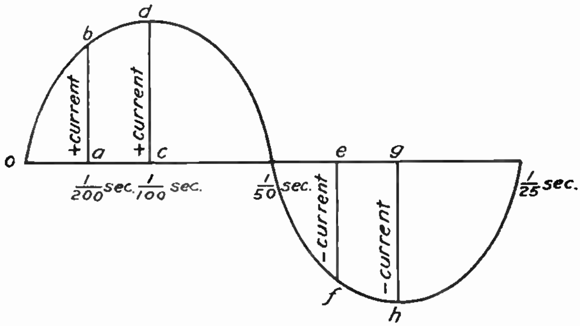


Fig. 13—An alternating-current curve.

It is evident that if the connections shown in Figure 14 are used, the battery will be charged for the first 1/50 of a second, and discharged for the succeeding 1/50 of a second. If, however, the connections at A and B are reversed every time the current in the circuit reverses, the current can be made to flow

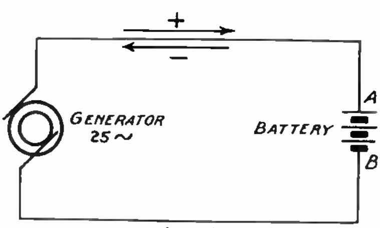


Fig. 14.

through the battery continuously in the same direction. Again, if the lower half of the current wave is suppressed, the flow of current through the battery will be in the same direction, although it will not be continuous. The current will continue to flow for 1/50 second and for the succeeding 1/50 second there will be no current.

Any device that will interchange the connections every time the direction of the current flow reverses, or opens the circuit when the current flows in the negative direction and closes it when it is in the positive direction is a rectifier. The illustration in Figure 15 shows three half waves or alternations. The function of the rectifier is to either cut off one side or the other of the wave as shown in the upper half of this diagram, which is

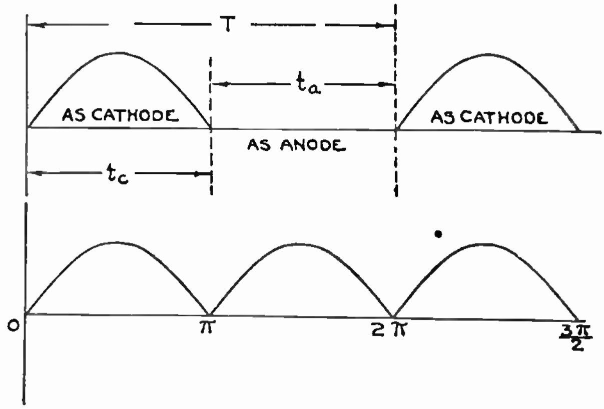


Fig. 15—The upper part of this figure shows half-wave rectification while the lower part shows full-wave rectification.

T = Period of one cycle.
Tc = Interval when rectifying metal is cathode.
Ta = Interval when rectifying metal is anode.

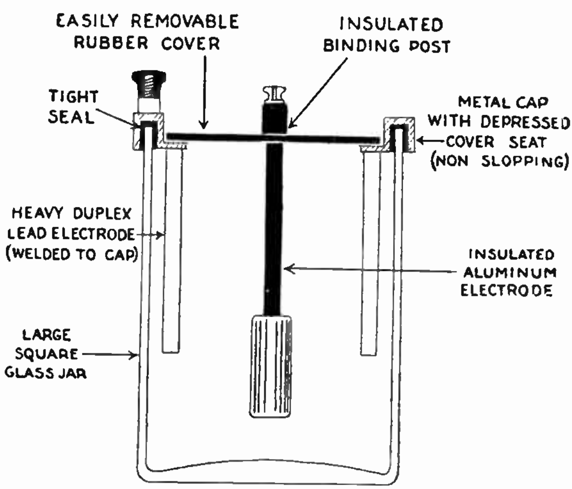


Fig. 16—This shows constructive details for a simple type of chemical rectifier.

called half-wave rectification, or put both sides of the wave on the same side of the zero line (as shown in the lower half of Figure 15) which is called full-wave rectification. Rectifiers are of many types, but most of them fall under one of three classes:

A. Chemical Rectifiers.

B. Mechanical Rectifiers.

C. Electron Rectifiers.

First, we have what is known as the electrolytic rectifier, wherein two plates of dissimilar metals are immersed in a solution and the entire arrangement is so made that current can only pass through it in one direction, whereby a rectifying action is obtained. Second, is the mechanical (vibrator) rectifier. This

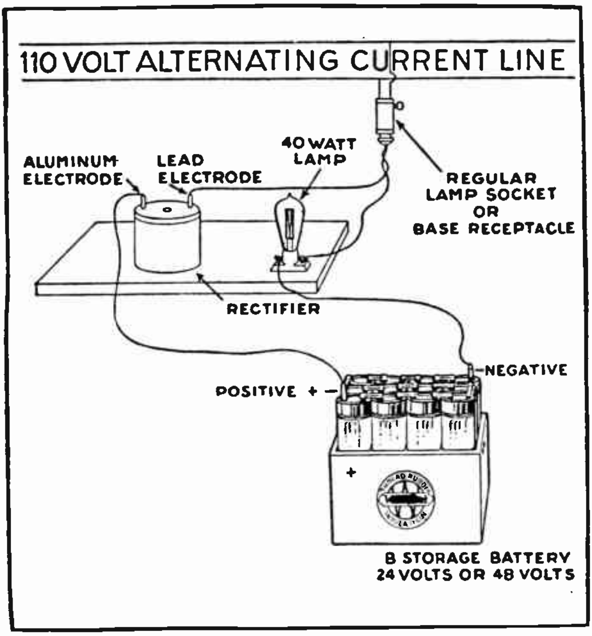


Fig. 17—This illustrates the use of half-wave rectification by use of one rectifier with a lamp in series to control the amount of charging current.

device may be connected in a circuit; when an alternating current is applied to the input circuit a pulsating direct current will be delivered by the output. The third type to be considered is that using a vacuum tube rectifying the alternating current. Let us now consider in detail these three types of chargers or rectifiers as they are often called.

DESCRIPTION OF A CHEMICAL RECTIFIER

The chemical rectifier is the simplest in construction, consisting of a positive plate of aluminum or tantalum and a negative plate of lead immersed in a saturated solution of borax, or a solution of ammonium phosphate as shown in Figure 16. (Use

¾ of a pound of ammonium phosphate to one gallon of water.) Before this type of rectifier can be put into use, the aluminum plate must be formed. This can be done by placing a 100-watt lamp in series with the rectifier cell across a 110-volt line. The deposit which forms on the aluminum plate that is responsible for the rectifying action permits the current to flow through it in one direction, but checks it in the other, thus giving half-wave rectification, as shown in Figure 15.

By connecting two cells as shown in Figure 18, it is possible to get full-wave rectification for charging a "B" battery and in the case of an "A" battery where the current is much larger, the rectifiers may be connected in parallel as shown in Figure 19. Since this type of charger cannot handle a heavy load without excessive heating and consequent poor rectification and lower efficiency, it cannot charge an "A" battery as quickly as the other types, but it is an excellent trickle charger for the "A" battery and a good "B" battery charger.

TRICKLE CHARGERS

A trickle charger is a device designed to maintain an "A" battery in a continual state of full charge. This charger is connected to the "A" battery through a special master switch that turns on the charger by the same operation which turns off the receiving set. Since this switch turns the set on and the charger off at one operation and turns the set off and the charger on at another single operation, the battery is being charged whenever the set is not in use.

Trickle chargers are designed to give a very low charging rate to the battery and generally not more than ¼ to ½ of an ampere. This charging rate is sufficient to keep the "A" battery fully charged at all times and yet is too low in amperage to harm the "A" battery even though the charge continues indefinitely. A trickle charging unit consists of a transformer for reducing the supply line voltage and a rectifier of the electrolytic, dry or bulb type. Such a unit is often built in one housing with a specially designed storage battery of small ampere hour capacity, but with an extra large space for the rectifier. Such a battery will handle an ordinary receiving set because it is charged immediately after each period of discharge.

Some trickle chargers on the market are provided with a regulating resistance by means of which the charging rate may be varied to care for the requirements of the battery.

Figure 23 shows a Kuprox dry metallic disc trickle charger. This charger utilizes an entirely new principle of rectification. It is a development of Dr. S. J. M. Allen, Professor of Physics at

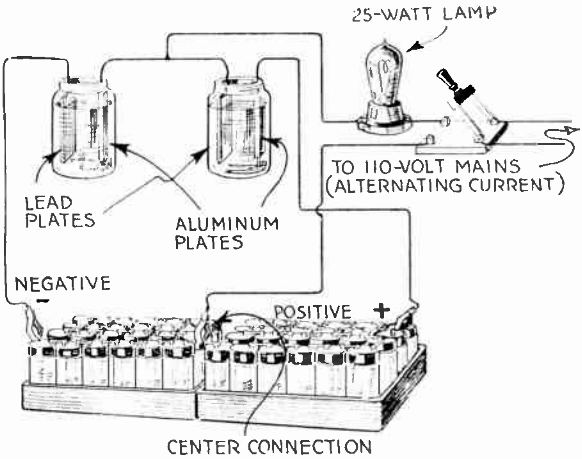


Fig. 18—Method of obtaining full-wave rectification by use of two rectifiers with a lamp in series for charging the "B" battery.

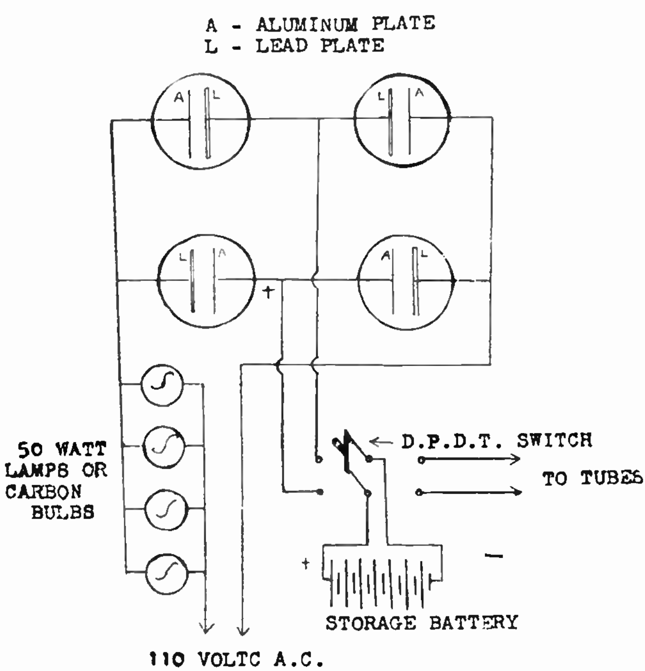


Fig. 19—This shows method of increasing the charging current by use of four chemical rectifiers and several lamps in parallel.

the University of Cincinnati. Ordinary sheet copper is first subjected to a special treatment and then punched into small discs about 1½″ square and 12 of these solid metal Kuprox discs, securely riveted together, constitute a rectifying unit of the charger. Rectification is due to a complete re-arrangement of the atomic structure within the Kuprox metal, which restricts

Fig. 20—Balkite Electrolytic Trickle Charger.

Fig. 21—Vesta Electrolytic Charger equipped with two taps for high and low charging rate.

Fig. 22—Vesta Dry Trickle Charger

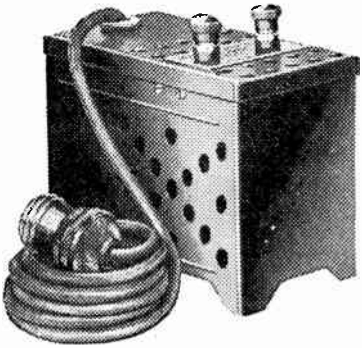


Fig. 23—Kuprox Dry Metallic Disc Trickle Charger.

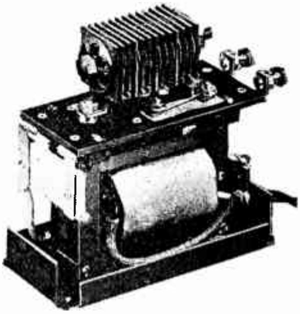


Fig. 24—Two Ampere Dry Charger. The dry rectifying unit can be seen on top of the transformer.

SEVERAL TYPES OF TRICKLE CHARGERS.

the transfer of electrons to but one direction. Since these electrons serve as the carriers of an electric current, it follows that any material possessing such characteristics will readily rectify an alternating current. Owing to this property, the Kuprox is purely an automatic type.

DESCRIPTION OF VIBRATING RECTIFIERS

The vibrating rectifier consists of a contactor operated in synchronism with the alternating current to be rectified. When

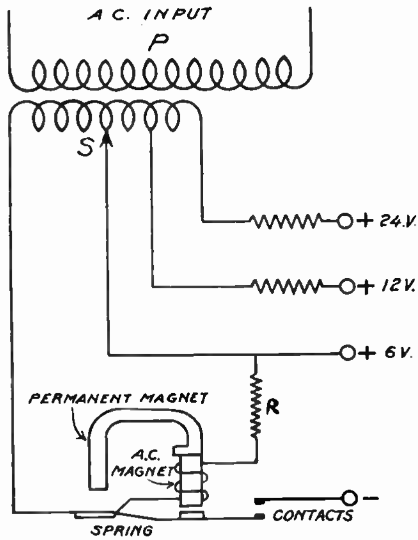


Fig. 25—Circuit diagram of a vibrating battery charger (Half-wave Type).

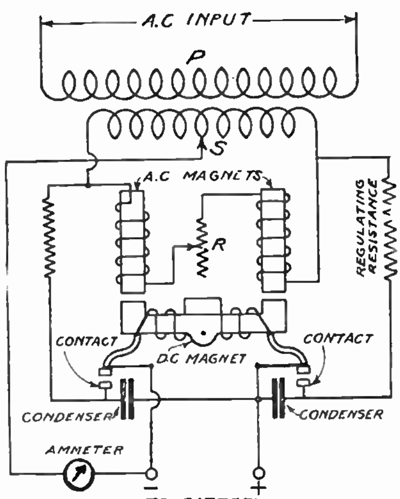


Fig. 26—Circuit diagram of a vibrating battery charger (Full-wave Type).

the contactor is allowed to make and break the circuit at the proper point of the wave, pulsations of current occur in the same direction; with a single contact as shown in Figure 25, half-wave rectification is obtained and with a double contact as shown in Figure 26, full-wave rectification is obtained. When the current from the supply line is of the correct polarity to charge the battery in Figure 25, the contacts close and the current flows through

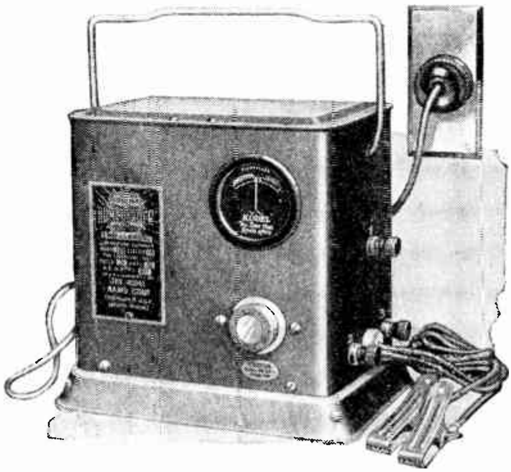


Fig 27—Kodel Home-Charger. Vibrating Type. This particular instrument is so constructed that it can be used for both "A" and "B" battery charging. For charging "B" batteries, the fuse plug is removed, and the suitable size incandescent bulb inserted in the socket.

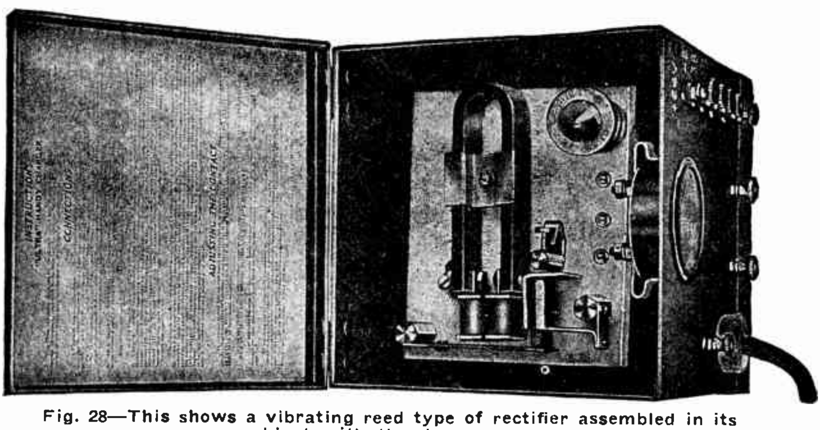


Fig. 28—This shows a vibrating reed type of rectifier assembled in its cabinet with the door open.

the battery, but when the supply line reverses its polarity, the contacts open and the battery cannot be discharged. On this diagram, taps are shown for charging the battery at several voltages.

The vibrator rectifier circuit shown in Figure 26 is built in such a way that the connections of the charging line to the battery are automatically reversed with the reversal of current flow in the power line. This reversal in the rectifier is brought about by a combination of two electromagnets and a spring. When the current flowing in the power line passes through the A.C. electromagnet in one direction, this electromagnet attracts one end of the D.C. electromagnet. When the current in the power line reverses, the other end of the D.C. electromagnet is attracted. When the magnets are acting together, they overcome the tension of the spring and close the vibrator contact permanently, charg-

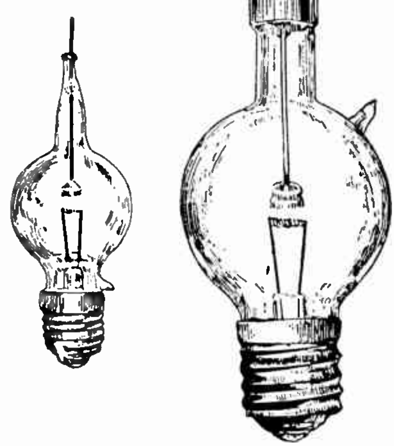


Fig. 29—Illustrates the small and large size of tubes for rectifying purposes.

Fig. 30—General appearance of a commercial one tube rectifier with two sides and top removed.

ing current can then flow through the battery. At the instant of reversal of current flow, the magnets balance each other and the spring opens the contact; a reversal of current cannot then flow through the battery and discharge it.

Some vibrating rectifiers have a spring whose tension must be adjusted in such a manner as to vibrate in step with the alternations of the power or supply lines. With this adjustment correctly made, the spring will open the circuit at the proper time. The spring adjustment on vibrating chargers is sometimes critical and the least movement of the regulating screw one way or the other will start or stop the charge. Other chargers of the same type are not at all critical and are easily handled. The adjustment should be made to give the greatest possible current in amperes without making the vibrator contact spark excessively. The vibrating contact rectifier is fundamentally a vibrating reed, whose frequency is the same as that of the current to be rectified, carrying a contact which engages the second contact for each vibration of the reed. The contacts complete a circuit from the secondary of a step-down transformer through the storage battery each time they touch.

The armature is polarized either by using a permanent magnet or by using an electromagnet energized by the battery being charged. The result of using a polarized armature whose period of vibration is the same as the frequency of the A.C. line is that

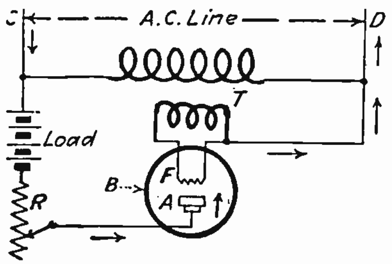


Fig. 31—Wiring diagram using one tube for half-wave rectification. The filament current is supplied by low voltage winding operated from the A. C. source.

the contacts touch at the point of each succeeding cycle and remain in contact for a portion of the half-wave so that the resultant current through the battery is shown by Figure 15.

DESCRIPTION OF THE ELECTRON RECTIFIER

The electron rectifier utilizes the phenomenon of electron emission from a hot tungsten filament. If such a filament be made to serve as one electrode in a highly evacuated tube along with a cold electrode having a positive potential with respect to the filament, electrons will flow from the hot filament to the cold electrode. If the cold electrode or plate remains negative with respect to the filament, the electrons emitted will be repelled by the negative plate and no current will flow. If an alternating potential be applied, electrons will flow only during the half cycle when the plate is positive. An alternating current is thereby rectified. Figure 31 shows the connections of a half-wave rectifier using an electron tube in its simple form. The equipment in this case consists of the bulb B with a tungsten filament F and a graphite plate A, transformer T for exciting the filament, rheostat R and the load which is shown as the storage battery.

Assuming an instant when the side C of the alternating current supply is positive, the current follows the direction of the arrows through the load, rheostat and bulb, and back to the opposite side of the alternating current line. A certain amount

Fig. 32—G. E. Tungar Trickle Charger.

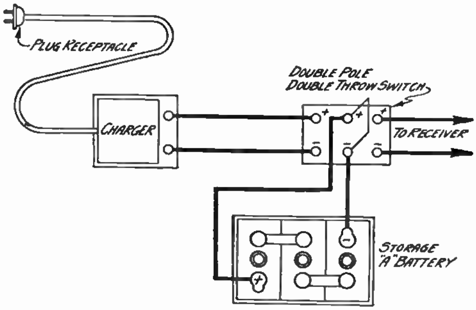
Fig. 33—Two-Ampere size.

Fig. 34—Five-Ampere size.

of the alternating current, of course, goes through the transformer T to excite the filament, the amount depending on the capacity of the bulb. When the alternating current supply reverses and the side B becomes positive, the current is prevented from flowing for the reason already mentioned. In other words, the current is permitted to flow from the graphite plate to the tungsten filament only during one-half the cycle.

The rectifier must include a transformer which serves to reduce the voltage usually from 115 volts to 30 volts for small outfits and to 75 volts for larger ones.

The electron rectifying tube used for battery charging resembles a large incandescent lamp with three terminals. See Figure 29. The elements are enclosed in a round glass bulb filled with argon, an inert gas. The trade name "tungar" is composed of the combination of the first syllables of "tungsten" and "argon." The bulbs are made in two sizes. The first charges a 6-volt battery at about 2 amperes, the latter at about 5 amperes. The smaller tube is mounted on a standard Edison screw base while the larger fits in a Mogul socket such as is used for extra large electric lights. The construction is similar in both tubes, for the filament connections come out through the Edison base, while the plate connection is brought out at the top of the tube.



A BATTERY CHARGING HOOK-UP.

Fig. 35—The wiring for the switch, the charger and the battery, from the lighting plug to the receiver in the quick change-over arrangement for battery and charger which is described above.

When in normal operation, there is a blue haze between the plate and filament in addition to the light from the filament and the plate will become just barely a dull red.

By using a transformer with the secondary coil tapped in the middle and using two tubes, full-wave rectification may be secured which will double the charging rate. The actual appearance of a complete rectifier unit using one tube and the two sides removed and the top cover lifted up is shown in Figure 30. Rectifiers are manufactured by the General Electric Company in three styles, all of the half-wave type, with different current and voltage capacities. All three types are for 115 volts, 60 cycle circuits.

CONSTRUCTION OF A TUNGAR CHARGER USING A 5-AMPERE TUBE

To construct the core, 230 pieces of .014″ core iron will be required. These pieces should be cut L shaped so that the legs are 6″ and 5¼″ long, respectively. See Figure 36. The coils are wound on cardboard or fibre forms 1⅝″ square and 2½″ long. Coil A consists of 73 turns of No. 10 DCC wire. To place the wire on the form, it will be necessary to insert a wooden block in the fibre form because of the large size wire used. When the 73 turns have been wound, the coil should be taped and 6 additional turns of No. 6 wire wound over the others. The wooden block should then be removed and the coil fastened securely. The end of the first coil and the beginning of the second are then connected together and the three wires brought out from the coil.

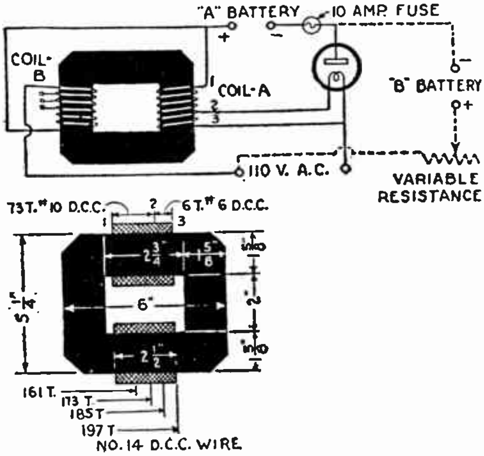


Fig. 36—A Tungar Charger which uses the five-ampere tube can be made with spare parts from the junk box of most amateurs.

The other winding coil "B" consists of 197 turns of No. 14 DCC wire wound on a fibre tube similar to the one used in the first coil. This coil is tapped at the 161st turn, the 173rd turn and the 185th turn. It should be taped in like manner to the other one.

The next point in constructing the transformer is the assembly of the core. This is done in staggered fashion. Insert the short legs of two of the pieces in the coil form and make the edges of the two meet. Two more pieces are then inserted from the opposite side; the complete core is now bonded. When all of the core pieces have been inserted, a clamp should be constructed to prevent the core from vibrating. This should be made of strip brass bent to the shape of the core and clamped tightly in place by means of screw holes. The other apparatus necessary to complete the charger comprises a 5-ampere tungar bulb, one large standard lamp socket and a 10-ampere fuse. This apparatus should be connected as shown in the diagram. The charger is then ready for operation. If it is desired to use it for charging "B" batteries, a 50-watt resistor capable of carrying at least ½ ampere is connected as shown in the dotted lines. A storage "B" battery of 50 volts can be charged in this way. The complete charger can be installed in a metal container if desired. If this is done, care should be taken to insulate all the apparatus from the container so that no short circuits can occur. The variable resistor and the switches can be mounted on one of the sides of the can, if desired, so that they can be easily varied.

Fig. 37—Half-wave Charger.

Fig. 38—Full-wave Charger.

Fig. 39—G. E. Tungar 4-Battery Charger.

When the charger has been assembled and connected to the battery for charging, inspection should be made of the initial performance. When charging a 6-volt battery the charging rate should be 5 amperes. On a 12-volt battery the rate should be about 2½ amperes.

Figures 37 and 38 show a half-wave and full-wave charger manufactured by the National Company of Cambridge, Mass. Figure 37 employs one Raytheon rectifier tube (cartridge Unit) for charging a battery at 2½ amperes rate. Figure 38 employs two of these Raytheon tubes, giving a 5-ampere charging rate.

Figure 39 shows the General Electric Tungar 4-Battery Charger. This outfit has a charging capacity of 1 to 4 three-cell

Fig. 40—Complete Rectigon—closed.

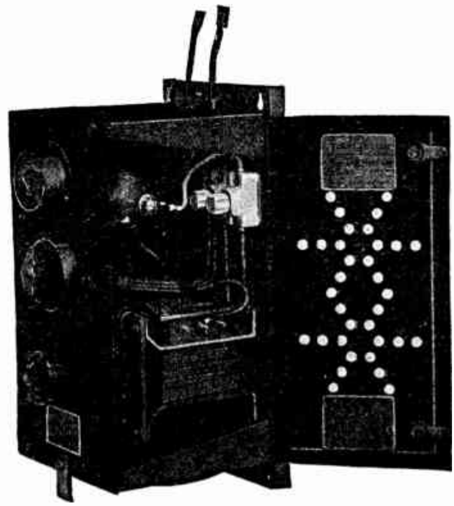


Fig. 41—Complete Rectigon—Open Showing internal parts.

Fig. 42—Westinghouse Rectigon Battery Charger, 115 volt, 60 Cy., A. C. 12 amperes. 6 to 75 volts, D. C., 3 to 30 cells.

batteries or their equivalent at a 5-ampere rate or less. It enables the Radio Service and Repair Shops to charge customers' batteries conveniently. The important parts of the G. E. Tungar are an insulating transformer, a regulating coil and a rectifying bulb. This unit is very simple to operate. To charge batteries, simply connect them in series with the Tungar and turn the handle on the front panel until the ammeter indicates the exact current desired. The handle serves the double purpose of turning

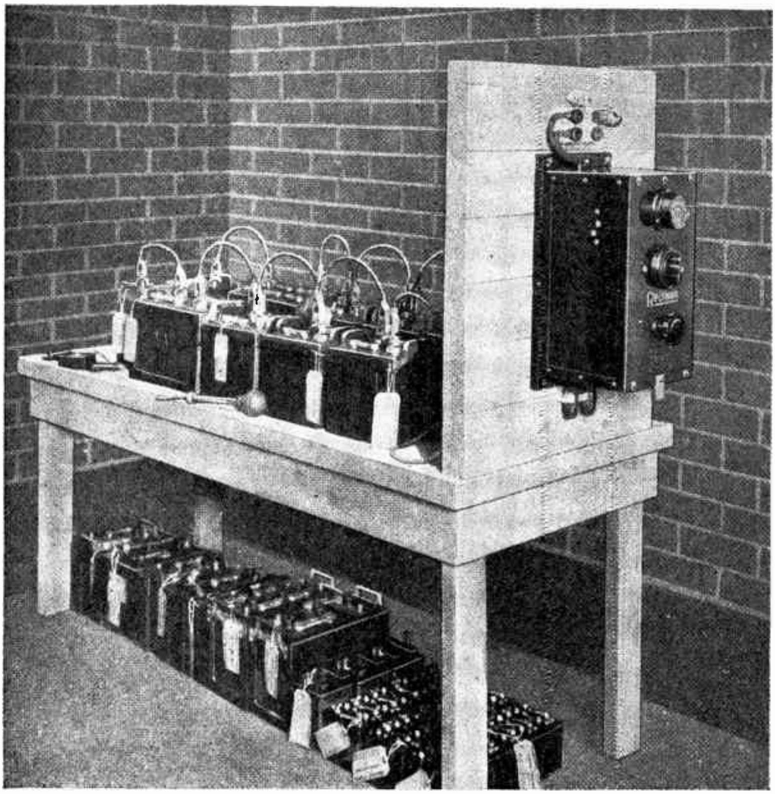


Fig. 43—Typical installation of 6-ampere, 75-volt Rectigon suitable for small battery service station

on the A.C. supply and of regulating the current. This tungar is particularly adapted to overnight charging without any attention. It delivers a steady flow of current which insures proper charging of the batteries.

Figures 40 and 41 show Westinghouse Electric Company 6-ampere 75-volt Rectigon Outfits. This charger is very suitable for battery service stations where a number of batteries are to be charged. All parts are mounted in a steel case and are readily accessible through a hinged door on the side to permit replacement of fuse or bulb. Leads from the alternating current and direct current are brought out at the top and bottom of the Rectigon and plainly marked. This outfit can be easily installed by placing it on a bench or mounted on the wall by means of a special mounting bracket, which is furnished with the outfit. There are only four wires to be connected, and the connections are clearly indicated.

Figure 42 shows a Westinghouse Twin Six Rectigon for large Service Stations. This 12-ampere 75-volt Rectigon is a simple and very efficient battery charging set for use by large Battery Service Stations which have a large volume of battery business. Such a unit is also to be recommended for use in small Service Stations where a higher charging rate is required than that obtained from the smaller 6-ampere 75-volt Rectigon outfit. Although this outfit is primarily designed to charge from 3 to 30 lead cells at a 12-ampere rate, nevertheless the construction permits of at least 3 possible combinations of connections for charging batteries.

Figure 43 shows a typical installation of a 6-ampere 75-volt Rectigon Outfit for a Battery Service Station.

TEST QUESTIONS

Number your Answer Sheet 27—2 and add your **Student Number.**

1. Describe the salt water method of determining the positive terminal of a circuit.
2. What should be used for testing the condition of a storage battery?
3. What should be the total resistance used when charging a 6-volt battery from the 110-volt D.C. lighting system at a 5 ampere rate?
4. What is a rectifier?
5. Name the three classes of rectifiers.
6. For what type of charging is the chemical rectifier best adapted?
7. Draw a circuit diagram illustrating a one-half wave mechanical rectifier.
8. Draw a diagram showing the connections of a half-wave electron tube rectifier.
9. What size and how many turns of wire are in the coil "B" of the transformer used in the construction of the 5-ampere charger described in this lesson?
10. What additional apparatus is added to the Tungar charger described on page 25 if it is desired to charge "B" batteries?

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BATTERY ELIMINATORS AND POWER AMPLIFIERS

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PERSEVERANCE

A Personal Message from J. E. Smith

Perseverance is gained largely through practice. It is true that persons differ in their natural attitude toward methodical habits, but relatively few of us are endowed with the readiness to stick to difficult, and sometimes tiresome, things without making any special effort at perseverance. Nearly all of us have to train ourselves to habits of work, and study, however pleasant much of it may be, is after all work. It requires perseverance.

There is no short cut to perseverance. It is simply a matter of practice, of habit. The oftener one goes ahead and finishes a job of any kind, the easier the next job will be.

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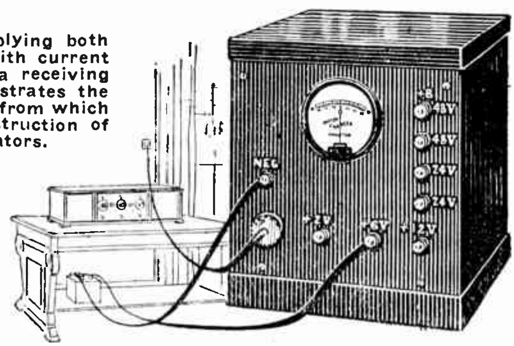
BATTERY ELIMINATORS AND POWER AMPLIFIERS

Power Units to supply "A" or filament lighting circuits of D. C. vacuum tubes used with some radio receivers may be divided into two classes:

In the *first* class, the early "A" unit comprised a step-down transformer, a storage battery and a charger that would supply a continuous trickle of electricity. See Fig. 1. This trickle charger would refurnish in 20 hours what the receiving set drew off in 4 hours of use at heavy current drain.

A rectifier unit supplying both A and B batteries with current in order to operate a receiving set. This really illustrates the stage of development from which we start in the construction of battery eliminators.



Then came the event of the automatic relay which worked from the switch on the receiver to connect the battery to the receiving set when reception was desired and disconnect the charger. This action was reversed to connect the charger to the battery when the receiver was turned off. The latter type did not use a trickle charger but a high-rate charger which tapered off the current as the battery became fully charged, and stopped charging when the battery was fully charged. The automatic relay consisted of a small magnet placed in the lead from the battery. Closing the receiver switch allowed current to energize this magnet, the magnet drawing down an arm which was really a switch in circuit leading to the charger and cutting it off. When the set was turned off, the magnet lost its energy and the arm flew back, reconnecting the charger to the battery to replace current drawn off while the receiving set was in use.

The basic elements used in the *second* class of A power units are: First, a transformer to step down the voltage, then a rectifier to change alternating current to direct current and, third, a filtering system to remove pulsations and make the

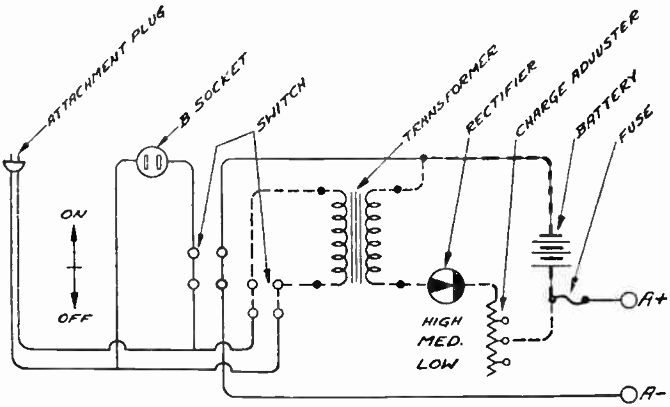


Fig. 1—Wiring diagram of Philco Socket Power "A" with manual control switch. This unit is a combination of a transformer, rectifier, storage battery and a trickle charger.

output a steady, unvarying flow of power. See Figs. 2 and 2A.

Power units of this class to supply A or filament lighting circuits vary chiefly in their rectifiers. Alternating house lighting current travels in one direction for an instant, and then reverses

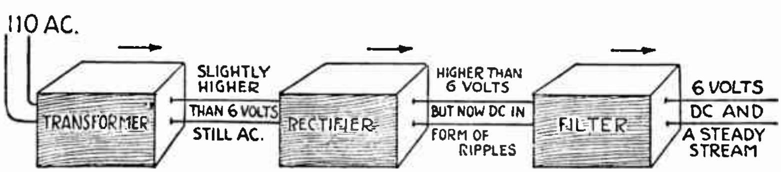


Fig. 2—Diagram showing how "A" Socket Power Unit transforms 110 volts A. C. to 6 volts D. C.

and goes the other way. This it does 60 times per second if the power company supplies 60-cycle electricity; 25 times per second if they supply 25 cycles. The rectifier must either block off the current going one way or must cause it to travel in the same direction without going the other way.

A rectifier which changes alternating current into pulsating current utilizing only one-half of each cycle is called a half-wave rectifier; one which causes both halves of the cycle to travel in the same direction during each half cycle of the alternating current supply is called a full-wave rectifier. It is well for students to remember these terms as you will see them very often in future text-books and service manuals. In *half-wave*

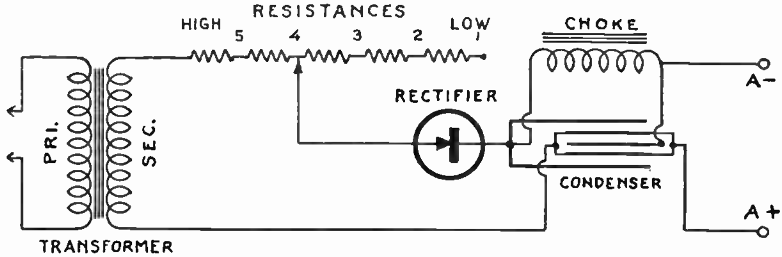


Fig. 2A—Wiring diagram of Balkite "A" Socket Power Unit. This unit does not use a storage battery and charger but a step-down transformer, rectifier and a high capacity electrolytic condenser with a choke coil and a resistance to regulate the output of the unit.

rectification only one part of the current wave is utilized, the rectifier acting as an electrical gate which allows the current to flow in one direction but stops the flow of current in the opposite direction. In *full-wave* rectification the action is more like that

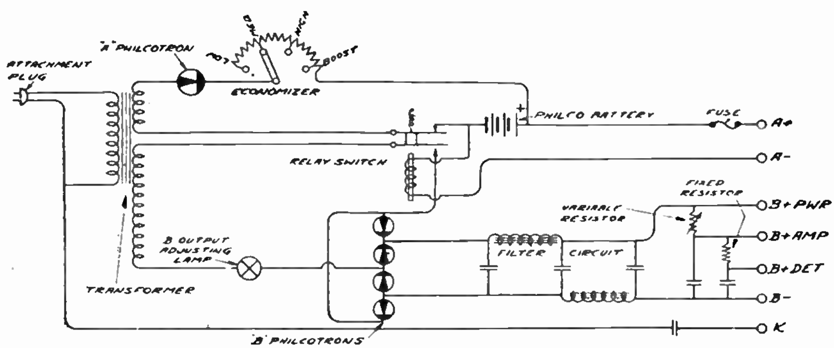


Fig. 2B—Wiring diagram of Philco AB Socket Power types AB-656 and AB-652.

of a specially designed turnstile which takes two lines of people going in opposite directions and turns them all into one line going in a single direction. The output from either type can be successfully filtered to make it suitable for filament supply. After rectification, the current is in a series of pulsations or surges which must be smoothed out. The smoothing out process consists of holding back part of each surge and releasing this part between the surge from which it was taken and that which follows. The more evenly a filter does this, the more successful

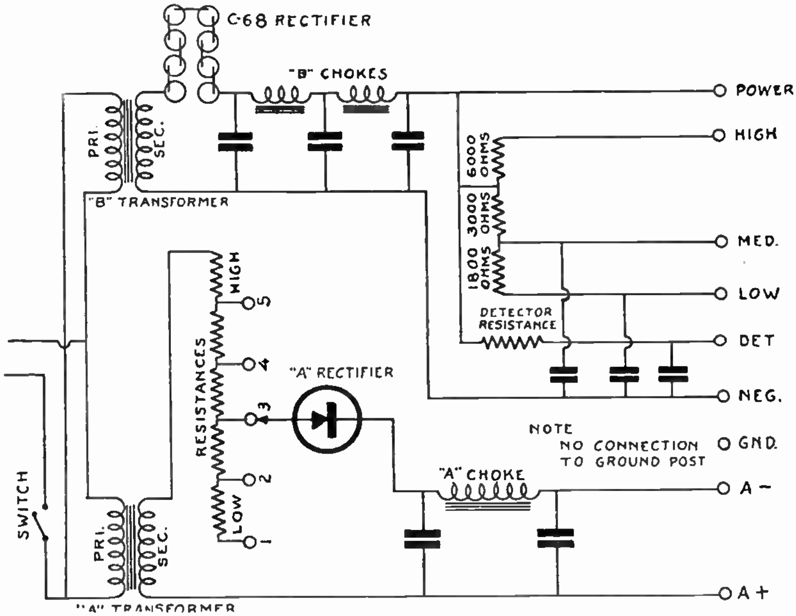


Fig. 2C—Wiring diagram of a Balkite AB Socket Power Unit 6-180 Form A.

it is considered to be. If the pulsations or surges are not smoothed out, there will be heard in the loud-speaker a steady, low musical note (hum) which will spoil reception if present.

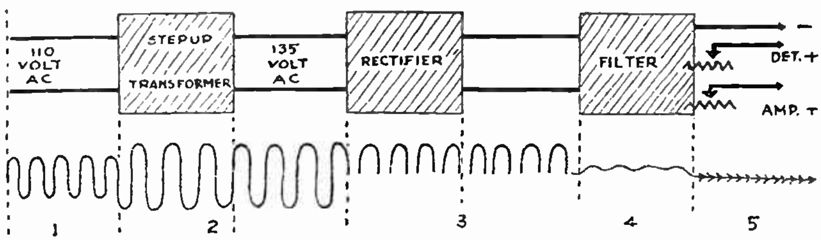
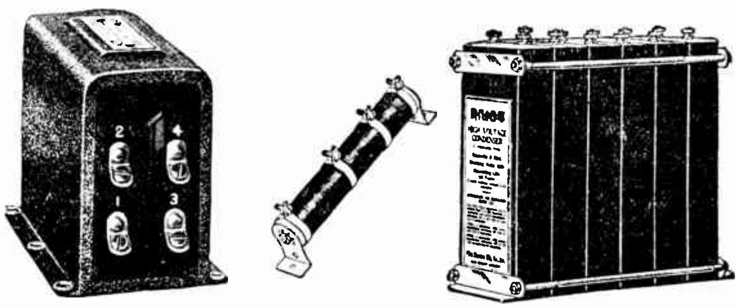


Fig. 3—The transformation of 110-volt A. C. into a variable direct current of 135 volts is shown graphically above. Section 1 shows the character of the incoming 110 volt alternating current; Section 2, the change in its character as it passes through the step-up transformer to 135 volts; Section 3, the rectification of one-half of the cycle as delivered by the tube. In the 4th Section, the process of filtering and smoothing the ripples is accomplished, and in the 5th can be seen the straight line of the direct current as delivered to the plates of the tubes in the receiver.

Filters to remove this hum usually contain a large coil of wire wound on an iron core, which is known as a choke, and condensers, the current coming into the filter as a series of sharp surges passes to the choke, the action of which is just what its name implies.

The condensers have the capacity of storing the electricity—not chemically as a battery—but keeping the electricity in the same form in which it flows along the wires, thus when an over-average pulsation of rectified current passes to the choke, part of it is crowded back and the condensers are provided at the proper place to take care of the excess for a moment and release it between surges. The result is a steady direct current output from the filter.



(A) (B) (C)

Fig. 4—Important units used in Battery Eliminators.
(A) Filter choke unit containing two iron core inductances for smoothing out D. C. pulsations. (B) Resistor unit strip for obtaining different voltage values. (C) Large condenser block used in filter section.

There are quite a number of different types of rectifying units used in A power units. There is the Tungar (or Rectagon) bulb, such as used quite often in battery chargers. This Tungar bulb contains a filament lighted by one winding of the transformer in the A power, and a plate to form the other element in the tube. When properly connected in an alternating current circuit, that half of the cycle which tends to flow from the plate to the filament can pass, but that which tries to go from the filament to the plate is blocked. This action is very similar to the action in a regular vacuum tube, but there is no grid in this tube, and it is a half-wave rectifier capable of handling 2½ amperes of current.

The *electrolytic rectifier* is also used in A power units. This type of rectifier contains an aluminum rod and a rod of another metal immersed in an electrolytic solution.

Another type of rectifier is the *dry disc* unit. It is named a dry rectifier as it does not use any liquid or give off light. It secures its rectifying action from the fact that if small discs of different metals (cupric sulphide as one active agent and magnesium as the other active agent) are placed against each other, and alternating in the metals used, current can pass through the pile of discs in one direction but not the other.

Still another method of obtaining D. C. power when only A. C. is available is to use the latter to operate heating coils which are in close proximity to a series of thermo-couples. It is well known that when the junction of two dissimilar metals are heated, a direct current will flow and while the potential of a single couple is quite low, the desired voltage may be obtained by using a battery of them connected in series.

A full-wave chemical rectifier changed to a "B" eliminator by the addition of a suitable filter is shown in Figure 5.

The Values to Use With Eliminator in Fig. 5

The following table tells you the values you will require for the inductance L, the condensers C^1, C^2 and C^3, and the resistance R, according to the number of tubes in your set:

Number of Tubes	Inductance of L	Allowable D.C. Resistance of L	C^1	C^2	C^3	R
3	20-40 henries	2000 ohms	2 mfd.	4 mfd.	2 mfd.	5000 to 10,000 ohms, variable
5	20-40 henries	1500 ohms	4 mfd.	4 mfd.	2 mfd.	ohms, variable
7, 8, or 9	20-40 henries	1000 ohms	6 mfd.	8 mfd.	2 mfd.	ohms, variable

THERMIONIC RECTIFIER TUBES

The two-element Tungar tube previously described depended upon the so-called "Edison" effect which is the emission of negative ions by a heated body, for its rectifying properties.

There are quite a number of commercial two-element thermionic rectifier tubes used in "B" supply units such as the UX-213, UX-218B, UX-280 and UX-281. The UX-216B and the UX-281 are half-wave rectifiers, and the UX-213 and UX-280 are full-wave rectifiers.

GASEOUS OR NON-THERMIONIC RECTIFIER TUBES

Gaseous Rectifiers are non-thermionic because they operate without a filament. Their structure is simple, consisting merely of two electrodes sealed in a glass tube containing a trace of a certain rare gas, neon, helium, etc.

The rectifying action of this tube depends upon a great difference in size between the electrodes. The polarity of the electrodes changes with each half cycle, so that if one has a much

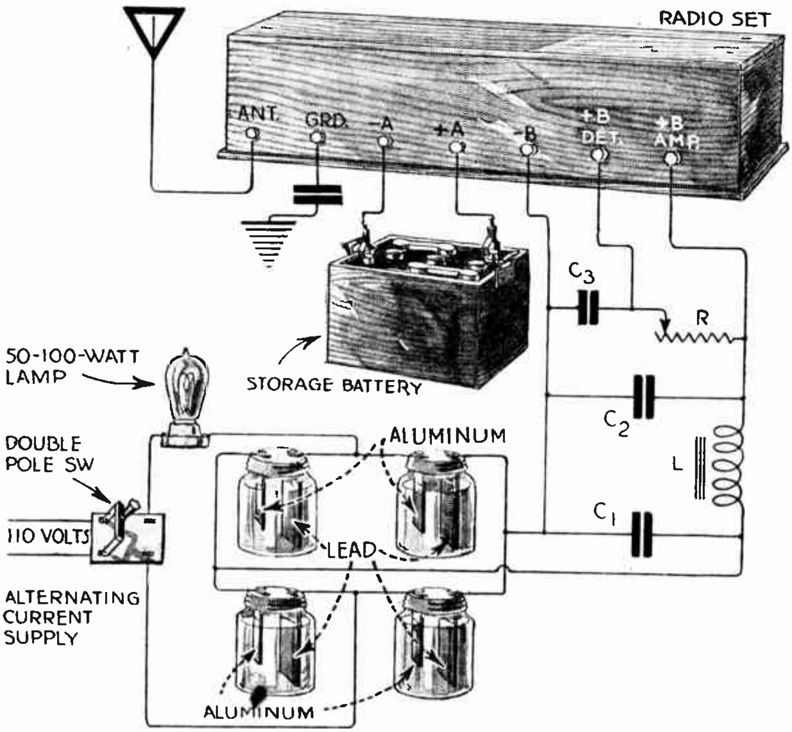


Fig. 5—This diagram shows how to wire the parts of the rectifier and connect it with your set. The values of the inductance, resistances and condensers you will need are given in the table on page 6.

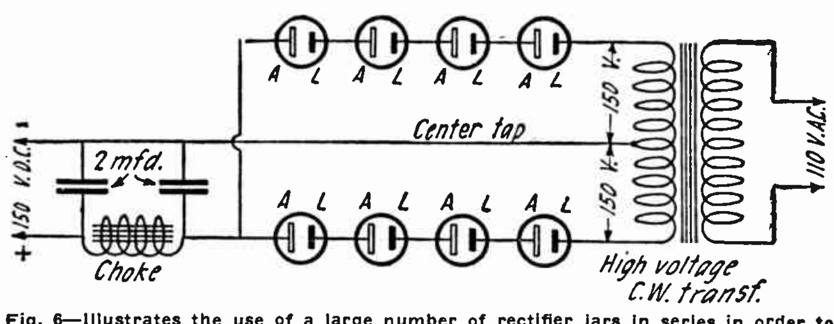


Fig. 6—Illustrates the use of a large number of rectifier jars in series in order to obtain higher voltages for the B battery supply.

greater area than the other, the larger will throw off many more electrons and establish a unidirectional current by ionizing the gas in the tube. Other factors are the pressure and purity of the gas, the quality of the material of which the electrodes are made, the frequency of the current, and the voltage with reference to the distance between the electrodes.

A helium tube following the general design features of the

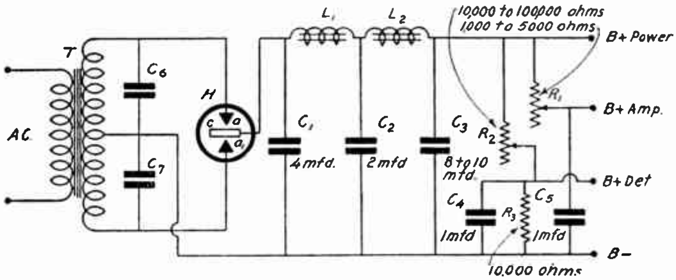
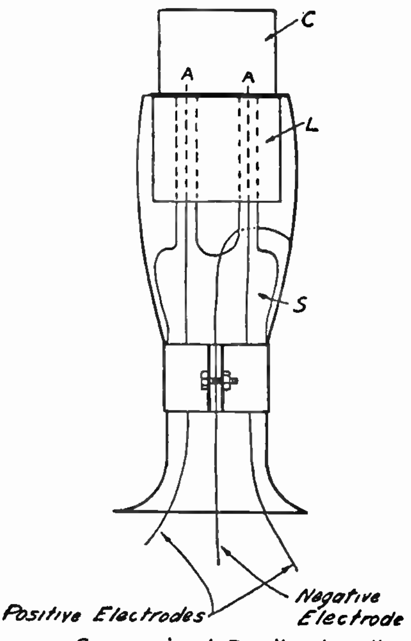


Fig. 6A—The Raytheon Full-wave Rectifier Circuit for "B" Power Supply.

Fig. 7.



Constructional Details of Helium Tube.

Fig. 8.

These two pictures illustrate the appearance and constructive features of the Raytheon tube. (Type B.)

style which approaches the ideal rectifier is on the market under the trade name "Raytheon."

This gaseous rectifier operates upon "the short path principle," whereby a rarified gas acts as an insulator between points which are in close proximity. This is an apparent contradiction of the observed phenomenon that the smaller the distance between two points the more rapidly a spark will jump between them due to the ionization of the gas. But if the distance is small enough and a suitable gas is used at sufficiently low pressure an electron may encounter no gas molecules in its path between the points and there will be no ionization by collision. Consequently the inert gas helium may be made to act as a perfect insulator at low pressures.

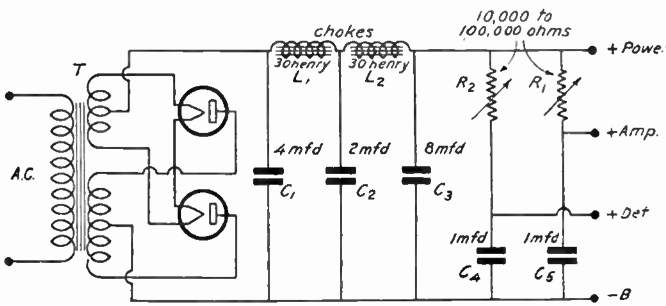


Fig. 9—"B" Power Supply using two half-wave filament type rectifying tubes for full-wave rectification.

Figure 7 indicates the appearance of the tube and Fig. 8 shows its construction. The two small positive electrodes AA are carried through two small glass tubes imbedded in a lava insulating block L so as to project very slightly into a relatively large cup C. The walls of this cup, being connected to the negative terminal through the base, constitutes the negative electrode. The diameters of the small wires and the diameters and position of the holes whereby they enter the cup are so proportioned as to give the necessary short path to the negative electrode. The cup C contains helium gas at such low pressure (high vacuum) as to prevent gaseous conduction. This construction makes possible extremely minute anode surface and consequently the "back" current is negligible, an important factor if the tube is to be used as an element in a "B" Eliminator.

Heretofore, the difficulty of insulating the electrode in the presence of a gaseous discharge gave a practical limitation to the reduction of its size. But in the tube the "short path principle" eliminates the difficulty.

Since the tube has two positive electrodes, full-wave rectication is performed in a single tube; because the minute anode surface rectification is unusually complete and since the tube has no filament, its life is usually long.

Figure 9 shows a typical installation, a two-tube rectifier in which the filter has been added. The rectifier tubes are lighted by A. C.

Commercial Non-Thermionic Rectifiers (Raytheon)

Type	Use	Max. A.C. Per Plate (volts)	Max Output (Milliamperes)
B	Full Wave	275	60
BH	Full Wave	350	125
BA	Full Wave	350	350

Commercial Thermionic Rectifiers

UX-213	Full Wave	220	65
UX-216B	Half Wave	550	65
UX-280	Full Wave	300	125
UX-281	Half Wave	750	110

How to Build a Universal "B" Battery Substitute Which is Highly Satisfactory in Operation and Low in Cost—The Parts Are Readily Obtainable.

Certain prevailing types of eliminators are suited for particular types of receivers, while they are entirely unsuitable for use on others. In order to make a choice between these various designs, the broadcast listener has had to try out one after another until he has obtained satisfaction. Even after a comparatively thorough test, he may find that the short life of the rectifier elements will cause an expense equal to that of maintaining "B" batteries.

It is the purpose here to describe the theory and construction of a universal B-battery substitute having excellent operating characteristics on all types of receivers, and an unusually long life. The cost of construction will not exceed twenty-five dollars, and, as all parts are readily available, the entire unit may be constructed at home. Several advanced features are present in the design described below.

Battery eliminators generally consist of three major elements: A **Transformer** to convert the **110**-volt A. C. supply to the required voltages; a **rectifier** which converts the A. C. into pulsating D. C.; and a **filter circuit** which smooths out the irregularities of the rectified voltage to a uniform D. C. The study and development underlying the design of eliminators has brought forth new facts which are extremely important in the attainment of high quality performance. Many weaknesses were present in the early designs, but the research Radio Engineers have succeeded in building up units of recognized quality and dependability.

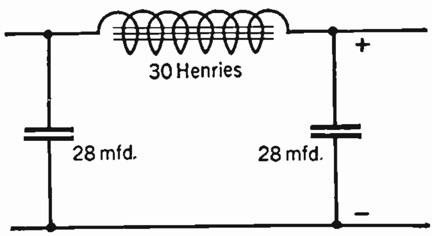


Fig. 10—Shows what is called a "brute force" or reservoir type of filter.

In the discussion given the student will find complete instructions and drawings for making a B battery substitute. The general design is similar to that developed by several manufacturers of B battery substitutes that are on the market. Complete dimensions, list of materials, size and turns of wire, etc., are given for those who want to make up a complete unit at home. This construction can be very easily accomplished, but for the convenience of those who prefer to use factory-made transformers and choke coils, units are described wherein use is made of these parts manufactured by the Acme Apparatus Company, General Radio Company, Dongan Electric Manufacturing Company and Jefferson Electric Manufacturing Company. On 60-cycle supply, any of these manufactured parts may be employed with excellent results, and the appearance of the unit using them will certainly surpass that of the home-made model. The photographs, Figs. 14 and 16, show the construction of models employing factory parts.

THE RAYTHEON TUBE

The very heart of the unit is the Raytheon rectifier tube, which has been developed for this purpose. In this tube, two anodes are provided, so that the tube rectifies both halves of the alternating current wave. This feature is of importance because it greatly simplifies the problem of filtering to obtain a pure D. C. supply. An additional feature made possible by the small anode area is that it permits but a minute fraction of the current to flow during the reversed voltage period of the current-flow cycle. Many rectifiers operating on the gaseous conduction principle give forth an extraordinarily high "back current," as it is called, which frequently rises to such a value as to become dangerous to the life of the tube and unnecessarily complicates the filter circuit problem. In the Raytheon tube it is extremely difficult to detect the back current by even the most sensitive measuring instruments.

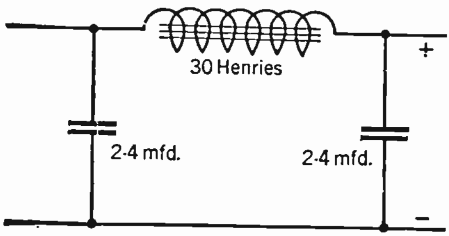


Fig. 11—A smoothing out type of filter.

The Raytheon rectifier has been designed to meet the requirements of most of the standard "B" battery substitutes. Its starting voltage is very low—approximately 155-160 volts—and its current carrying capacity is high. The Raytheon tube type B is rated at 60 milliamperes at 150 volts D. C. output. As there is no filament to burn out, the life of the rectifier is extremely long. Standard Raytheon tubes have been on test at maximum output for more than 4,000 hours, and have not yet shown signs of deterioration. It is doubtful if the maximum life of these tubes can be determined at intermittent operating periods such as they would receive in the ordinary operation of a current tap. If not abused by overload or continued short-circuit, they should last for years.

The operation of the Raytheon tube in a B-substitute is unusually quiet, the reason for this is that the gaseous discharge is entirely enclosed. There cannot be any sputtering of the discharge such as might occur if the elements were exposed to the glass tube or insulators. This conserves the helium gas with which the tube is filled, and greatly prolongs the tube life.

The operation of a properly designed current tap employing the Raytheon rectifier tube has unusually good characteristics. Some of these will be mentioned in connection with points previously explained. First of all, we have exceptionally good "regulation." The increased impedance of the Raytheon tube with load is less than that obtained from other types of rectifiers, causing an upward curve in the load characteristic, in distinction to the usual straight line falling curve of other rectifiers that give low voltage at full load current. The fact that the output voltage does not fall off as rapidly as usual obviates the necessity of providing an excessively high transformer secondary voltage. The lowered A. C. voltage is an important contribution to the safety of operation of the device.

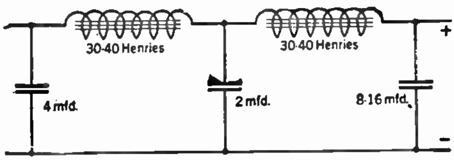


Fig. 12—Filter circuit common in new models.

List of Raw Materials Required

6 lbs. Silicon Steel	$ 1.20
28 ozs. No. 31 d. c. c. wire	2.19
12 ozs. No. 32 d. c. c. wire	.94
7 2-Mfd. Condensers	12.25
1 0.5 Mfd. Condenser	.90
2 0.1 Mfd. Condensers	1.40
1 Bradleyohm No. 10	2.00
1 Raytheon tube	6.00
1 Standard Socket	.25
1 10,000-ohm resistance	1.00
	$28.13

The prices quoted above are maximum retail prices. In some cases substantial reductions can be obtained from the costs given.

The current and power capacities of the Raytheon tubes are sufficient to supply the greater majority of radio receivers. The current output is rated at 60 milliamperes at 150 volts and it has been found from measurements of the plate current consumption of a large number of receivers that this value is more than sufficient for the demands of most receivers.

The filtering problem in plate current supply units is usually one of high cost and considerable difficulty. When the Raytheon tube is employed, the filtering requirements are much simpler, since it gives rectification of both halves of the A. C. wave. Here one tube does the work of two at a great saving in cost, and at a

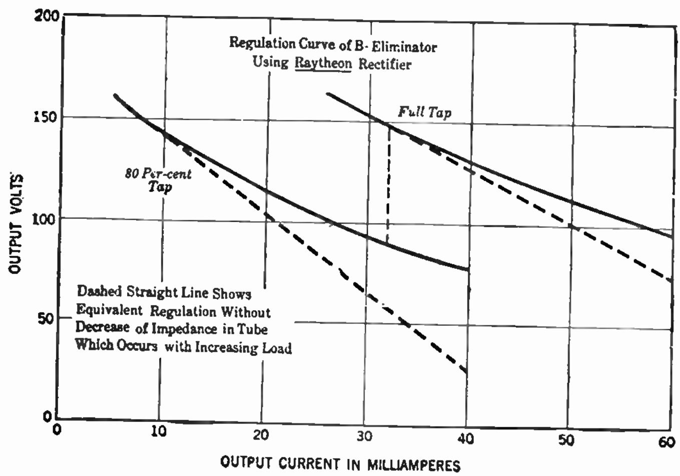


Fig. 13—Curves showing output current in milliamperes plotted against the voltage.

higher efficiency. As indicated previously, there is no back-current perceptible. Back-current is a bad feature from a filtering standpoint, as it complicates the filtering problem, and often heats up the choke coil windings to an injurious degree.

Another important feature of the Raytheon rectifier is that it requires no power for lighting a filament. This power very often demands a large transformer supply, the cost of which is an item of great importance. With the use of the Raytheon tube, a complete B-substitute can be made up in a space no larger than a heavy-duty B-battery.

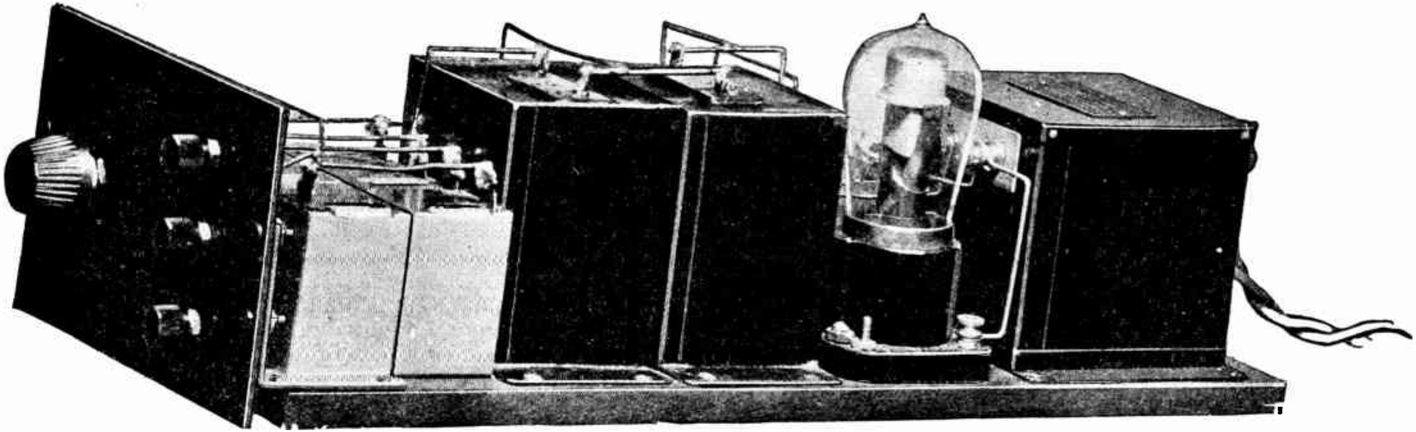


Fig. 14—A compact model of the battery eliminator described here. Note the large condensers which are employed in the filter circuit to insure a smooth D. C. output.
(Courtesy of Radio Broadcast.)

HOW TO BUILD THE APPARATUS

We will now proceed with the building of the eliminator. Figures 14 and 16 show the arrangements of the parts when the unit is assembled from factory models. The basis of these models is the circuit diagram, a schematic drawing of which is shown in Fig. 17. The values of capacity, inductance, and resistance shown in this diagram have been determined after considerable investigation, and should be adhered to as strictly as possible. These instructions also apply to the construction of the home-made transformer and chokes described below.

Dimensions for the transformer used in this eliminator are shown in Figure 18.

The transformer is made up of three coils of insulated copper wire wound over a core composed of a large number of strips of No. 29 gauge Apollo special electrical steel. These strips are carefully cut by hand from an old power transformer or from sheets of the proper material, and shaped into the forms shown in Fig. 18. Enough pieces are cut out to make up a complete core of the dimensions given in Fig. 18, when they are assembled and clamped together in a vise to determine if the required amount of steel has been prepared. All rough edges must be removed, and the dimensions uniform.

There are three windings on the transformer which are wound in place on the winding form illustrated in Fig. 19. The winding spool may be assembled on a long stove bolt with nut and clamped in a hand drill, carpenter's brace, or in the chuck of a lathe for convenience in winding the coils. Some means should be provided for counting the turns exactly as they are applied. If the ratio of turns of the hand drill is known for one turn of the handle, it is a very simple matter to use this in counting the turns as they are applied. Care should be used to obtain within one per cent of the specified number of turns on each winding. The primary winding is applied first over the entire length of the winding form, and consists of 1250 turns of No. 31 enameled copper wire, with a tap taken out and insulated at the 1000th turn. Two layers of Empire cloth are placed over the primary winding, then two separate secondary windings are wound, each of which consists of 2750 turns of No. 32 enameled copper wire. These two secondary windings are insulated from

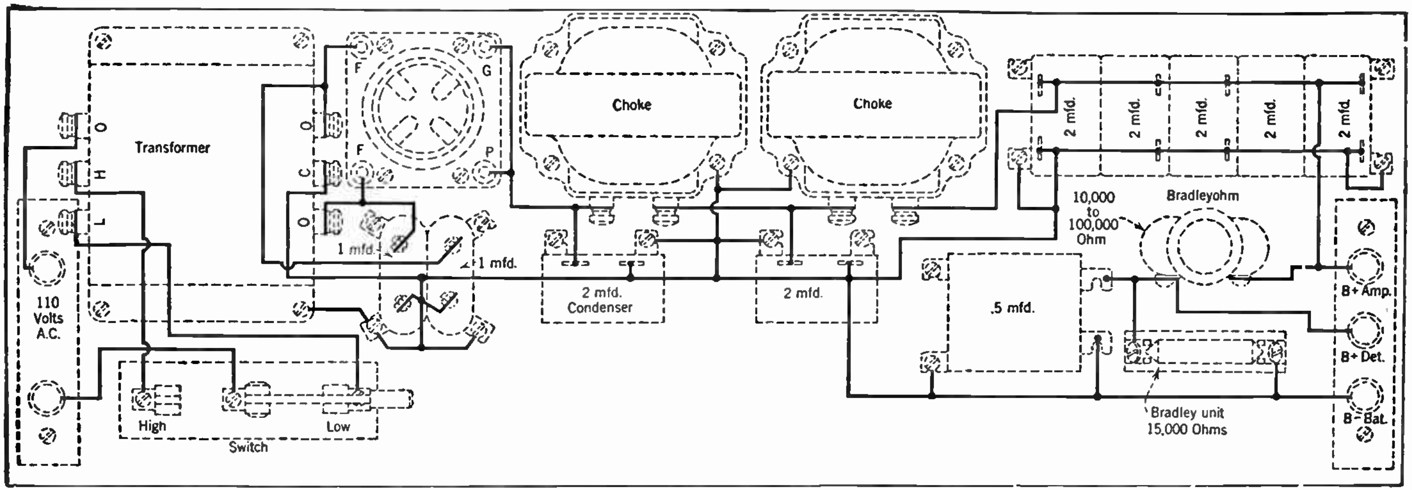


Fig. 15—A picture diagram and wiring layout of the eliminator whose circuit is embodied in the diagram Fig. 17.
(Courtesy of Radio Broadcast.)

each other at the middle of the winding form by means of a rectangular separator of .010-inch fiber. This separator is cut out after the primary insulation has been applied, and is put in place by means of a slot cut in one face of the separator. See Fig. 19.

While the first secondary is being wound, the remaining winding space is tightly filled up with a number of strips of cotton muslin or cotton tape, in order to prevent the wire from crowding the winding separator out of place. In all cases, insulated leads 8 inches long, of flexible stranded wire (six No. 30 D. C. C. wires twisted together are satisfactory) are soldered to the ends of the windings for terminals, before the ends are brought out from the winding. Each terminal is tied in place in order to prevent its being ripped from the coil by accident. If it is necessary, thin strips of paper may be laid over each layer of wire as it is completed, in order to insure smooth layers in the winding. When the coils are completed, the outside is wrapped with two layers of Empire cloth or heavy manila paper as a protection and insulator.

The steel laminations are now inserted one by one in the completed winding, as shown in Fig. 18 and the transformer is bolted together. If it is not convenient to drill holes in the laminations for the clamping bolts, the builder may cut out clamping plates from hard-wood or angle iron. In such case, the bolts will pass through the ends of the clamping plates at the ends of the core, instead of through the holes therein. Figure 22 shows the method of clamping adopted by the author in preference to drilling holes in the core. If the builder desires, he may put mounting brackets on the base of the transformer to aid in securing the instrument to the base board.

The Choke Coils

The choke coils, shown at L^1 and L^2, Fig. 17, are constructed in a manner similar to that employed in the making of the transformer. Each of these coils will have an inductance of approximately 20 henries if care is taken in constructing and assembling the cores. All rough edges should be removed and the cores assembled in an orderly manner. (See Figs. 20 and 21.)

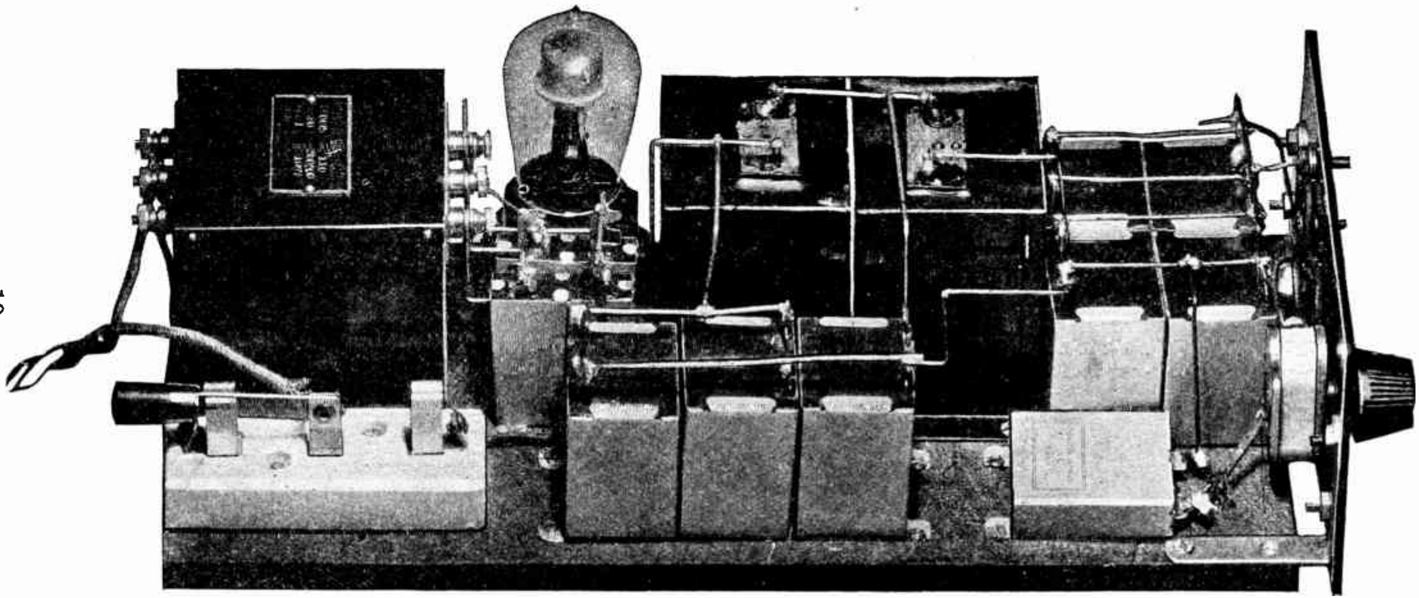


Fig. 16—A different view of the eliminator employing manufactured parts.
(Courtesy of Radio Broadcast.)

The winding on each choke coil consists of 5000 turns of No. 31 enameled copper wire, wound in smooth layers with the necessary interleaving papers. The outside of the completed coil is wrapped with one layer of heavy manila paper as a protection. The laminations shown in Fig. 20 are inserted in the completed windings, and the entire coil is assembled in accordance with the description of the power transformer above. A piece of .010 red fibre strip is inserted in the air gaps of the choke coil cores, to insure the magnetic stability necessary under the operating conditions. When this has been accomplished, the clamping plates are secured as described above.

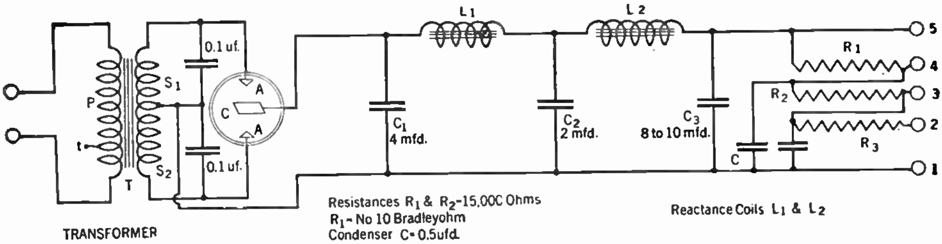


Fig. 17—The circuit diagram of "B" eliminator using Raytheon tube. The transformer at the left steps up the line voltage, passes it to the double-wave tube which rectifies both halves of the cycle. Thence it is passed to the filter where it is smoothed out into pure D. C. The resistances permit the tap-off of the desired voltages necessary to the operation of the receiver.

The filter condensers, shown in Figs. 14 and 16 were procured from Tobe Deutschmann, Canton, Massachusetts, and have passed the most severe operating conditions. They were subject to repeated charging and discharging at 700 volts D. C., and withstood the strain upon the dielectric successfully. None of the samples examined in this way were broken down. The equivalent series resistance was found to be low enough to give excellent results in connection with the "B" battery filter circuit. The particular arrangement of the filter circuit shown in Fig. 17 requires a total capacity of 14 mfd. and the distribution of this quantity is more important than the absolute value. If this circuit does not meet with the requirements of attached receiver and loud-speaker, a slight improvement will be effected by increasing the value of C^3 to 12 or 16 mfd. Increasing this capacity beyond 20 mfd. does not add greatly to the standard of quality already established and, for average conditions, this capacity need not exceed 8 mfd.

The arrangement of the detector voltage control shown in Fig. 17 is unique in some respects, and is an improvement over the usual series resistance method. A 0.5 mfd. condenser is used to by-pass any disturbance that might reach the detector through

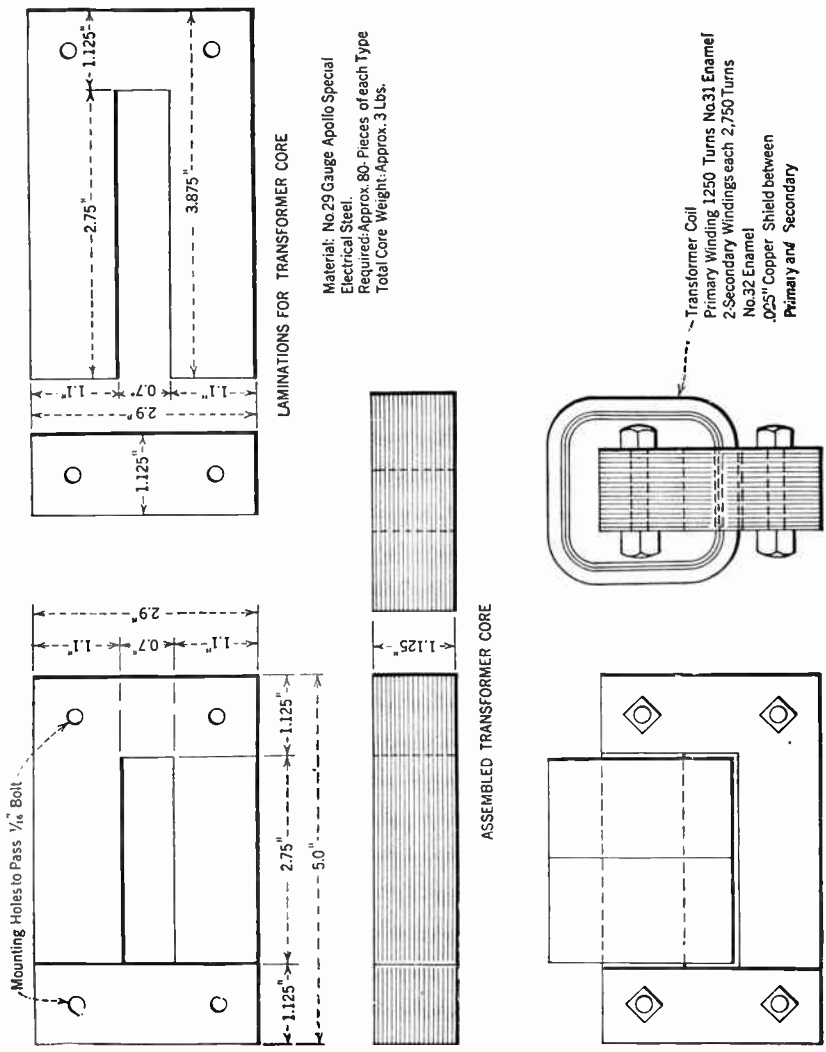


Fig. 18—This illustrates the important features in the design of the transformer and shows the dimensions, also specifies details in regard to the material to be used in its construction.

other paths. The amplifier voltage is controlled by means of the switch shown in Fig. 15. The blade of this single pole, double throw switch is connected to one side of the 110 volts A. C. line; one lug goes to the 1000th turn tap on the primary, the other lug goes to the full primary terminal at 1250 turns. When the switch is thrown to the 1000-turn tap, the output voltage will be from 30 to 50 volts higher than on the 1250 tap, depending upon the connected load.

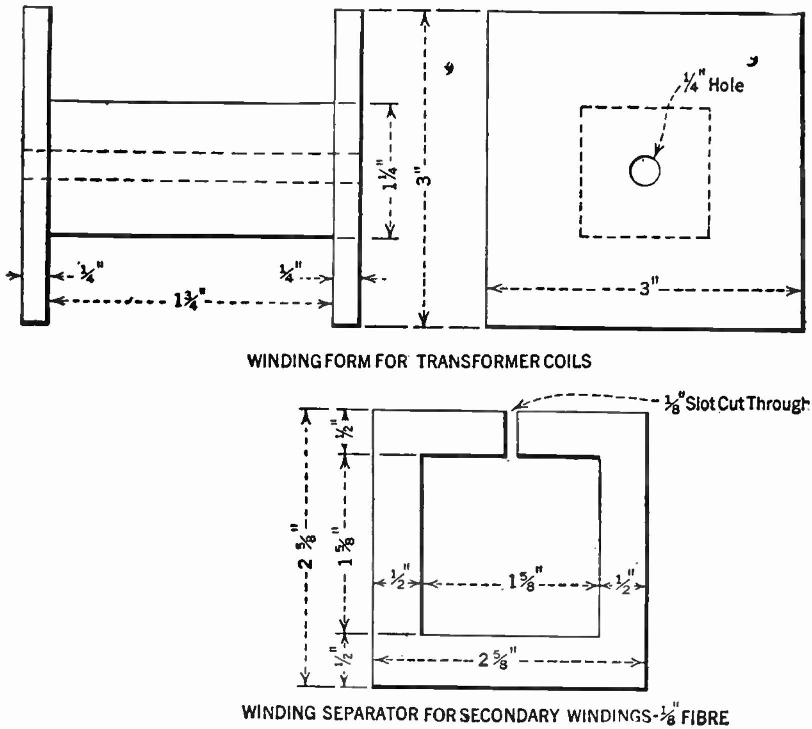


Fig. 19—Illustrates the construction of the winding forms for the transformer coils.

The Raytheon rectifier tube will ordinarily run at a temperature in the neighborhood of 200 degrees F. In case the cup becomes red hot, there is evidence that the circuit is being overloaded. Although no permanent damage will be done, it is not advisable to continue this load for more than a few minutes. Continued overloading will soon saturate the cores of the choke coils and render them useless as filter chokes.

In order to prevent the transmission of power line noises through the eliminator circuit, a copper shield has been placed between the primary and secondary windings, and thoroughly insulated therefrom. This consists of a strip of .005-inch copper carefully wrapped over the Empire cloth insulation, and extending to within 1/4 inch of the entire surface of the primary winding. A flexible lead is soldered to the shield, brought out from the winding, and later connected to the ground terminal of the eliminator. All cores of the instrument should be connected together and to the ground terminal. The home-made unit should be placed in an iron or steel case which completely encloses it.

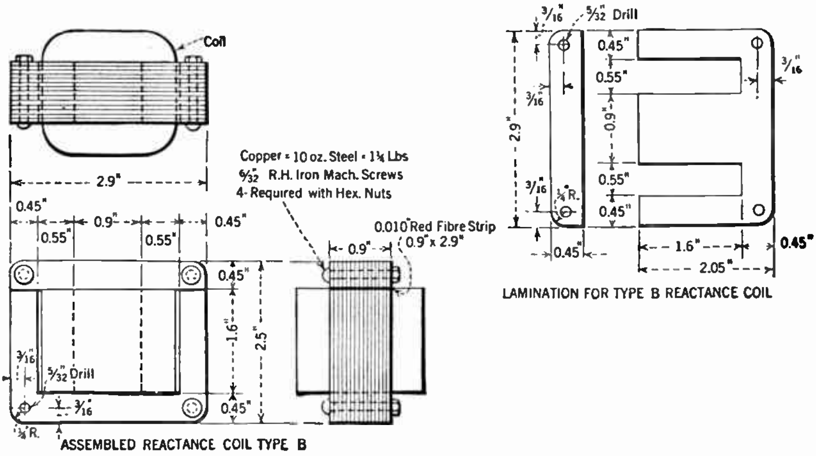


Fig. 20—This illustrates the constructive features for the choke coil.

In the case of the factory units, each part has been placed in an iron magnetic shield, and this is connected to ground to prevent induction of hum in the receiver. Another means for preventing the transmission of line noises through the eliminator is the use of the buffer condensers, shown shunted across the mid-tap and outer leads of the secondary of the transformer, Fig. 17. These each have a capacity of 0.1 mfd. and serve the purpose of balancing the admittance of each secondary to the neutral or ground side of the line. In this way an easy path to ground is provided for any disturbing unbalance that might arise in any part of the circuit. The inclusion of these condensers is an important feature, and one that will more than repay their cost.

SPECIFICATIONS FOR THE DESIGN OF "B" BATTERY SUBSTITUTE

I. Transformer

1. Power loss should not exceed 10 watts.
2. Should operate on 25 to 75 cycles A. C.
3. Secondary voltage should not exceed 300 volts for safety.
4. Should be shielded in magnetic shield.
5. Should have electrostatic shield between primary and secondary windings to prevent transmission of line noises to radio receiver. Secondary winding should be balanced for inductance and capacity.

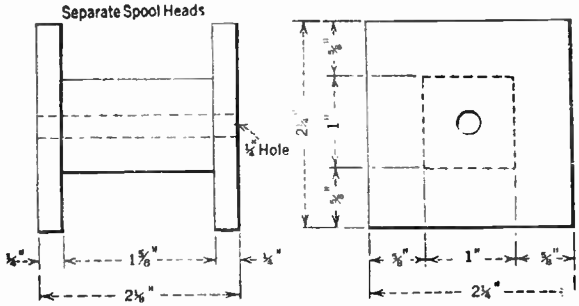


Fig. 21—Illustrates the construction of the winding forms for the choke coils.

II. Rectifiers

1. Should have life of at least 5000 hours.
2. Should deliver sufficient current at all times.
3. Should have low impedance, preferably rising characteristic. (See Fig. 13.)
4. Should rectify completely with no reverse current, and with quiet performance at all times.
5. Should rectify both waves of cycle.
6. Should have low starting voltage—i. e., not greater than 160 volts.

III. Filter Circuit

1. Should filter perfectly, leaving no hum in head-phone or loudspeaker.
2. D. C. resistance should not exceed 750 ohms.
3. Should consist of two or more sections.

IV. Miscellaneous

1. Should give complete control of amplifier and detector voltages.
2. Should be small and light in weight.
3. Should be capable of being installed in receivers without producing interference.
4. Cost of construction and maintenance should be low.

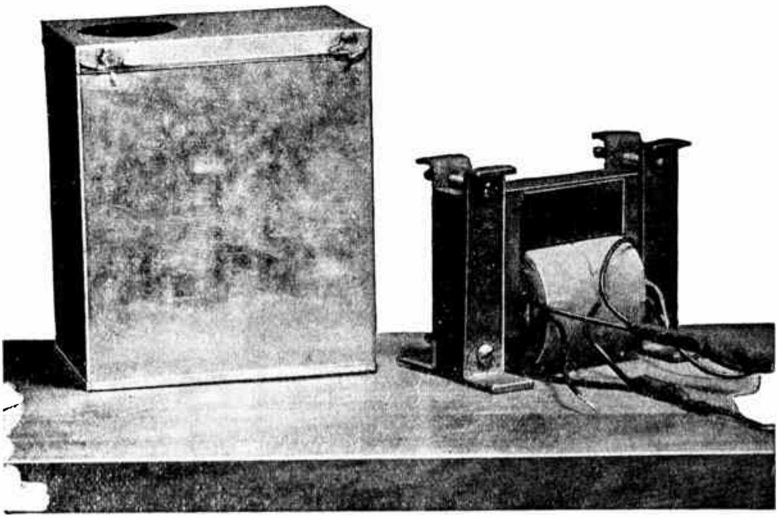


Fig. 22—This shows the made-up transformer with the metal can for shielding.

POWER AMPLIFIERS AND POWER UNITS

We have just given a detailed description of the construction and operation of a "B" battery eliminator and now we will present for the student's consideration some power amplifiers and power supply units.

The power amplifier consists of two main divisions: first, the power supply which furnishes high voltage plate current, as well as low voltage filament current; and second, the audio-frequency amplifier which steps up the incoming signal voltage to a point where it will operate the power tube.

In turn, each of the two main divisions may be further subdivided. By looking at a power amplifier as being made up of many simple parts, all problems are greatly simplified.

The power supply consists of portions furnishing the high voltages for the amplifier tube, plate circuits and of portions furnishing the filament current to amplifier tubes. The high voltage supply includes: first, a transformer for increasing the voltage received from the house lighting circuit; second, a rectifier which changes the alternating current into a pulsating direct current; third, a filter system which smooths out the

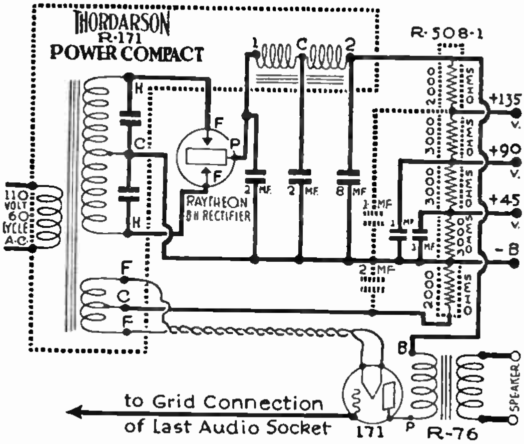


Fig. 23—Circuit of power amplifier using 171 tube and Raytheon rectifier.

variations or ripples in the direct current; and fourth, a voltage divider which divides the output between the various plate circuits and, in some cases, between the grid biasing circuits.

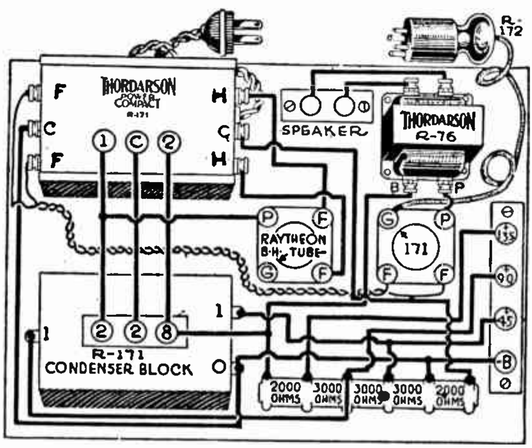


Fig. 23A—Showing apparatus mounted on baseboard.

NOTE: (Terminals marked H & H of power pack should be connected to filament terminals of the 171 tube socket and H & H terminals to the filament terminals of BH tube socket.)

Figure 23 shows a popular power amplifier and B supply unit using a Raytheon rectifying tube. Such an amplifier is very simple to assemble. This unit contains a power supply transformer, filter choke system, 171 tube filament supply, and two

0.1 mfd. buffer condensers placed across the high voltage winding, all assembled in one case as shown in Fig. 23A. It is designed for 110 volts 60 cycles alternating current.

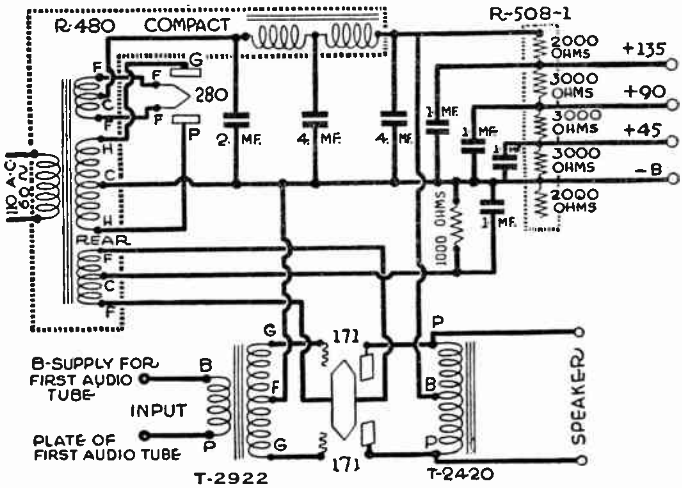


Fig. 24—Push-pull amplifier using 280 tube for rectifier.

Figure 24 shows a power amplifier using two 171 tubes as a push-pull amplifier, with a 280 full-wave rectifying tube. This

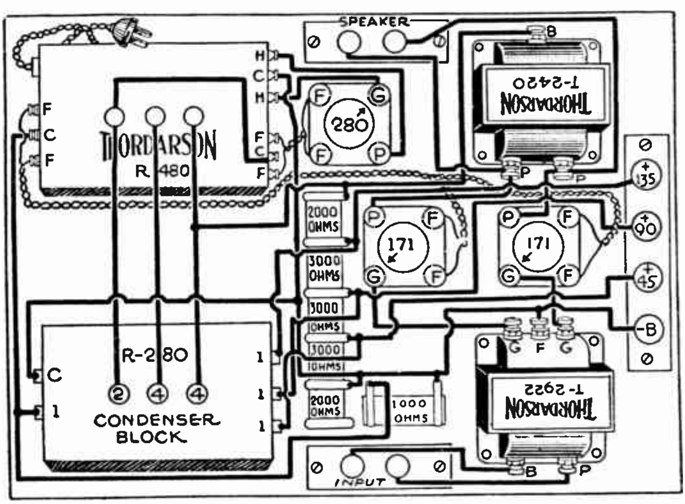


Fig. 24A—Push-pull amplifier and power unit apparatus mounted on baseboard.

unit supplies 5 volts center tapped for the filament of the 280 rectifier tube, 5 volts center tapped for the filaments of the 171 tubes, and high voltage center tapped, for the plates of the rectifier tube. The high voltage current, when rectified, and passed through the filter system, which consist of the two 30-henry chokes and the necessary filter condensers, is delivered to

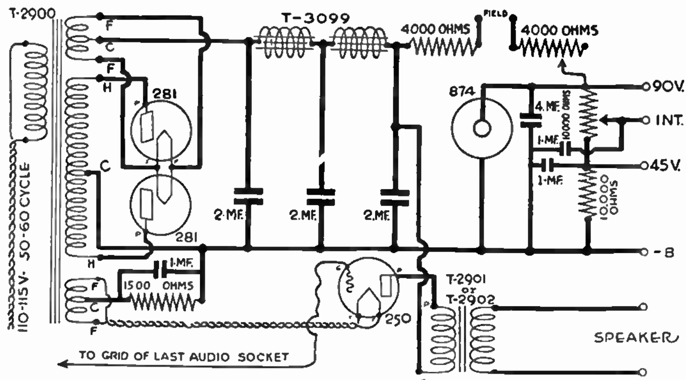


Fig. 25—Circuit of power amplifier using 250 tube, two 281 rectifying tubes for full-wave rectification and regulating tube 874.

the plates of the 171 tubes and the voltage divider as pure direct current.

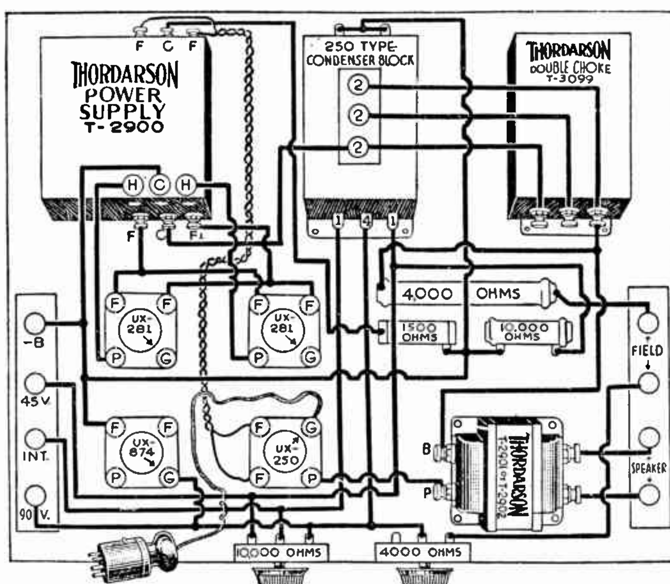


Fig. 25A—Arrangement of apparatus on baseboard for 250 amplifier and power unit.

Where a dynamic speaker is to be employed, the 171 push-pull arrangement is to be preferred since the undistorted power output of a single 171 is hardly adequate for the satisfactory operation of dynamic speakers.

The one stage power amplifier and B supply unit shown in Figure 25 incorporates the 250-type power amplifier tube and is designed for last stage audio amplification in receivers for home or demonstration use, and may be used with either dynamic or ordinary high impedance speakers.

In order to supply the field of the dynamic speaker, the voltage divider circuit is opened between the two 4,000 ohm resistance units. The field winding is placed in series with the output and by adjusting the 4,000 ohm variable unit, 100 volts is allowed to act upon this winding. From 40 to 60 milliamperes of current is put through the field. When high impedance speakers which employ no externally operated field circuits are used, the dynamic field binding posts should be connected together.

TEST QUESTIONS

Number your answers 28 and add your **Student Number.**

No. 1. Describe the thermo-couple rectifier for changing A. C. to D. C.

No. 2. Illustrate by a drawing the transformations (showing steps) to change 110 A. C. to steady D. C.

No. 3. Make a wiring diagram for a "B" battery eliminator for a five-tube set using four lead-aluminum rectifier jars with filter (mark values for filter parts).

No. 4. Name a few types of tubes which are well adapted for use in a rectifier.

No. 5. Give a wiring diagram for a "B" battery eliminator using two tubes with full-wave rectification.

No. 6. What is the output current and D. C. voltage of the Raytheon (B type) rectifier?

No. 7. Make a circuit diagram of "B" eliminator using Raytheon rectifier tube.

No. 8. Give the approximate length and dimensions of the cross-sectional area of the iron core, also size wire and number of turns in both primary and secondary windings for the rectifier transformer.

No. 9. How would you construct a 20-henries choke coil for the rectifier?

No. 10. What method is used in building the rectifier transformer to prevent noises from the power line?

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(2nd Edition)

RADIO INTERFERENCE AND ITS ELIMINATION

Originators of Radio Home Study Courses
···Established 1914···
Washington, D. C.

REST

A Personal Message from J. E. Smith

Students should not use their eyes too steadily. At intervals of half-hour or so, they should close their eyes for three minutes, or, if it is daylight, look out upon the green grass, or trees. Green is very restful to the eyes.

If they need glasses, as a large proportion of people do, they should certainly wear them.

It is a very simple thing to follow common sense practice in matters connected with one's work. Disregarding such practice always has a decidedly unfavorable effect on one's attainments.

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

RADIO INTERFERENCE AND ITS ELIMINATION

Radio interference consists of any kind of electrical impulse, other than the desired signal, which may be heard from the radio receiver when in operation.

Notwithstanding the excellence of our broadcasting stations and the general high quality of radio receiving sets, a percentage of broadcast listeners do not have normal reception on their sets because of local outside interference. This interference may take the form of harsh non-descript sounds, so-called "static," crashing, buzzing, clicking noises, etc., which either spoil the program or blot it out altogether.

Almost any piece of electrical apparatus is a potential source of disturbance to a sensitive radio receiving set. Wherever an electric spark is formed, waves of high-frequency electrical energy are sent out. They are identical, though untuned and uncontrolled, with those transmitted from the broadcasting station. Consequently, they are picked up by the radio installation and amplified in the same manner as radio speech or music.

There are two methods of suppressing the interference due to sparking electrical apparatus. One is to eliminate the spark by removing the apparatus or placing it in a condition so that the spark will not occur. The other is to use a filter device so as to confine the electrical waves set up by the apparatus to a very small area and thus prevent interference to the reception of radio programs.

Classification of Outside Interferences.

(A) Static. Static is a broad term used to cover noises in reception caused by electrical discharges in the atmosphere. There is always a certain amount of this present, and the more sensitive the receiver, the more readily it is detected.

(B) Code Signals. This is in the form of an intermittent buzzing or "peeping," resembling telegraphic code (dots and dashes), and is due to the operation of a powerful radio code transmitter, either commercial or amateur, in the immediate vicinity. Although this transmitter may be sharply tuned, if it is powerful and sufficiently close, it may cause interference through forced oscillation which cannot very well be prevented.

(C) Radiating Receivers. The familiar "squeal," varying in intensity and volume, which is sent out or broadcast when a regenerative or other oscillating receiver is tuned in, is gradually disappearing. This is one of the annoyances to which the broadcast listener is subject. This type of set is rapidly becoming obsolete and is being replaced by the stabilized type. Interference of this kind can only be eliminated at the source, by proper operation of the offending receiver.

(D) Electrical Apparatus and Wiring. Electrical machinery in operation and defective electric wiring is responsible for a great deal of noise in radio reception. This is particularly true in a city or town where there are always many electrical devices, appliances and machinery in more or less continuous operation. The nature of the noise in each case depends upon the type of machinery causing it and the defect of electrical wiring or electrical discharge responsible for the radiation of the disturbances. Among the more common sources of trouble of this nature, classified by the National Electric Light Association, are the following:

Power Circuits. (1) Lines; (2) Insulators; (3) Lightning Arresters on power lines; (4) Transformers; (5) Generators and Motors; (6) Induction Voltage Regulators.

Industrial Appliances. (1) Street Lighting Circuits; (2) Telephone and Telegraph Lines; (3) Street Car and Electric Railroads; (4) Mechanical Interrupters; (5) Motors.

Household Appliances. (1) Electric pads; (2) Violet-Ray Machines; (3) Flat-irons; (4) Door Bells, Light Switches, Various Small Motors, etc.

Miscellaneous. (1) X-Ray Machines; (2) Storage Battery Chargers; (3) Annunciator Systems; (4) Stock Tickers; (5) Ignition Systems; (6) Electric Elevators and Electric Furnaces; (7) Moving Picture Equipment; (8) High Voltage Test Equipment.

The above list covers in a general way most household and industrial noise makers.

Radio-Tricians in all parts of the country continually encounter cases of interference from local electrical apparatus, defective power transmission apparatus and lines, radiating radio receivers, and other sources.

Locating Radio Interference.

Before the Radio-Trician can determine how the interference in any particular locality may be suppressed, he must first locate the source of it. This can be found by using a sensitive loop-operated portable receiver.

Since the output of the receiver, as indicated audibly, may have the same apparent intensity over a considerable distance on either side of the disturbance, it is necessary to use visual means for indicating the source of the interference. The construction of such a visual indicator is relatively simple, this being nothing more than a simple type of vacuum tube voltmeter.

A transformer having a one-to-one ratio is connected at the output of the portable receiver. The secondary of this transformer is connected to a 201-A tube having some means of varying the grid bias. A D. C. milliammeter having a full scale deflection of not over 25 milliamperes is connected in the plate

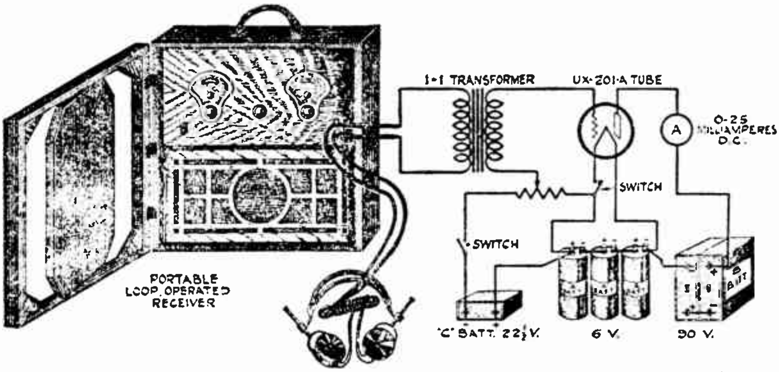

Fig. 1—Visual Indicator connected to a portable loop operated receiver. Used to locate Radio interference.

circuit of this tube. The grid bias of the 201-A tube is so adjusted that when a minimum of interference is being picked up, there is no deflection of the plate current milliammeter. The indicator should not be operated from the batteries which are supplying current to the receiver.

When this device is used, it will be found that the deflection of the meter increases rapidly as the source of the interference is approached and decreases with equal rapidity when the source of the interference is passed. For best results, it should be used in conjunction with a head-set in order that this visual and aural indications may be compared. Fig. 1 shows the proper manner of connecting this device.

When the interference has been located, it is sometimes difficult to determine just what piece of apparatus or circuit is causing the trouble. An analysis of the sounds produced by different types of apparatus will help solve this problem. A steady howl is usually caused by a radiating receiver. A rapid and steady clicking noise is often caused by a vibrating armature, battery charger or other electrical apparatus which has a vibrating reed for opening or closing circuits. (The electric bell is one example of this type of apparatus.) Intermittent rasping and crackling noises may be due to defective insulation or loose connections in power lines, or they may be static caused by natural means. A more or less steady crackling noise may be caused by an arc light or some medical apparatus. A rapid whirring noise, or a hum, may be caused by a generator or motor in the neighborhood.

Reducing Static Disturbances.

Many anti-static devices have been suggested from time to time for eliminating the intensity of the static crashes so that the signals can be distinguished above the static noise. Some are simple and others are rather complicated in theory. It is necessary by trial to find a particular arrangement that most perfectly meets the local conditions.

Any static eliminator which reduces the interference to a point where the crackling is not audible during the program, and can only be heard faintly during the intermissions, can be considered highly successful from the broadcast listener's point of view. With careful attention to the following principles, the Radio-Trician can generally install a small device which will greatly improve the clarity of the signals.

Both static and radio signals are the result of electrical disturbances, and both strike the aerial at the same time. It is therefore rather difficult to unscramble them so that the charges induced by the electromagnetic waves are retained, and the impulses, due to atmospheric electrical charges, are grounded and rejected. The separation is partly made possible by the fact that some radio signals are of much higher frequency (or shorter waves) than the static impulses. Hence the two can sometimes be separated by a tuning or filter system. By a suitable arrangement of choke coils, that will stop the radio waves, but allow low frequency and static to escape to the earth, it is possible to greatly reduce the crackling and other disagreeable noises.

Tuned circuits, tuned to a given frequency or wavelength, are not set into oscillation by other wavelengths or frequencies unless these waves are unusually strong. Most receivers will oscillate at their resonant frequency in the vicinity of a powerful broadcasting station, even when the station is operating on a widely different frequency or wavelength. The shock must be many times the ordinary signal strength to set up such a condition and the atmospheric charges are heavy enough to do this very thing. In other words, we now have no means of separating the desired signal from the undesired static, since both disturbances cause the set to oscillate at the same frequency. The tuning unit is ineffective in such a case and must be given outside aid.

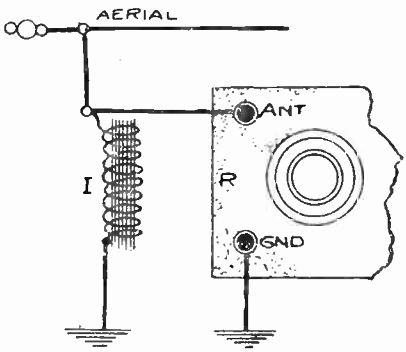

Fig. 2—Ground choke.

Simple Static Reducers.

It is generally considered that the elimination of static means a reduction of signal strength, and this is true of most static eliminators so far devised. Weakening of the signal is not so important as the relative weakening of the static, or the signal static ratio, as it is sometimes called. If a certain system weakens the static at a more rapid rate than it weakens the signal, then a point is eventually reached where the static will disappear entirely with some of the signal still in evidence. It is only when the strength of the static greatly exceeds the signal that it becomes highly objectionable. A simple, and often very effective static eliminator is the choke coil shown by Fig. 2. This is suitable only with inductively coupled receivers having a primary aerial circuit electrically separated from the secondary circuit.

The choke must have a sufficiently high inductive value to hold back the longest radio waves that are expected to be received. The long wave static passes freely through the choke without the high-frequency radio waves following. There are all sorts of values used for the choke coil, ranging from the 400 turn honeycomb coil to the secondary winding of an audio transformer. Good results can be obtained by using the primary coil of the audio transformer, leaving the secondary coil open. However, this may not suit in every case. In any event, the inductance of the choke coil must be very much higher than that employed for tuning in broadcast wavelengths.

An alternative arrangement can be had by placing the choke coil in series with the ground wire of the receiver. In some cases, and with certain types of receivers, it may work better than the arrangement shown in Fig. 2.

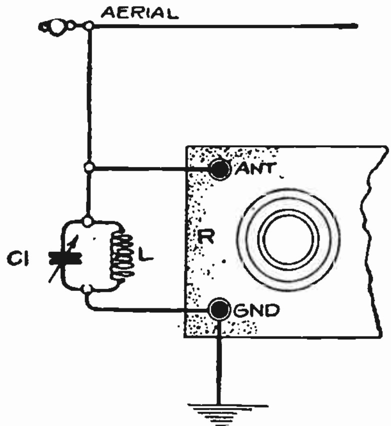

Fig. 3—Wave trap in parallel with antenna and ground terminals of receiver.

Tuned Traps (Selective).

Very often the wave-trap idea works out successfully, and it has a further advantage in that it can also be used to increase the selectivity of the receiver. In Figure 3, we have a combination of a variable condenser, C1, and a honeycomb coil, L, connected across the aerial and ground post of the receiver, R. This arrangement is adaptable only to receiving sets using an inductively coupled aerial circuit.

By varying the capacity of the variable condenser, C1, the frequency or wavelength of the trap is varied so that all the radio-frequency signals are shunted into the receiver, while the undesired waves of different frequencies pass through to ground without entering the receiver. Under some conditions, this is highly effective. It is difficult to prescribe any definite size for the condenser and coil due to the great variations in conditions, but a 23 plate .0005 mfd. variable condenser with a 50-turn coil, L, on a 3½″ diameter tube, should be about right. A vernier arrangement should be used, as the trap tunes very sharply. Fig. 4 shows the trap placed in series with the set. The condenser and coil can be mounted in a separate cabinet, making a convenient unit for tuning the set.

Aerial Specifications.

To minimize the reception of static, the aerial conditions must be carefully controlled, even when static drains are employed. For summer reception, a low aerial not more than 25 or

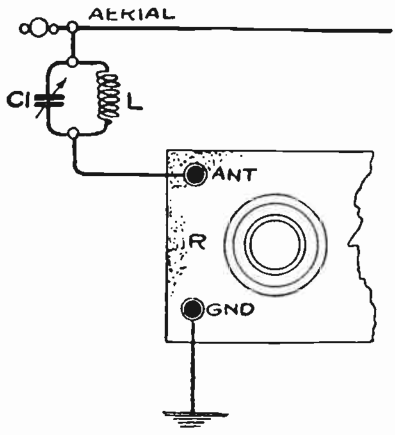

Fig. 4—Wave trap in series with aerial and ground.

30 feet above the ground should be used, since atmospheric potentials increase rapidly as the altitude. A single wire, not more than 50 ft. long, is the best, and while this may reduce the signal strength slightly, it decreases the static rapidly, thus giving a better signal static ratio than a longer aerial.

Inductive Type Reducers.

A type of tuned absorption reducer is frequently very successful in eliminating static, and it is easily adjusted to local conditions. This is a modified form of the type of trap already described. In addition to reducing static, this arrangement makes the receiver more selective. Figure 5 is a common form of coupler having an aperiodic primary, P, the secondary being tuned as usual by the variable condenser, C1. This is a common unit which can be used to good advantage in some radio receiving sets.

Very loose coupling between the primary and secondary of the radio-frequency coils will, to a certain extent, eliminate noises and give selectivity, but it will reduce the signal strength slightly. The ratio of signal strength to static will be greatly improved. Shielding a radio receiver will also eliminate static to a certain extent.

Interference from Devices Outside the House.

Power lines and lightning arresters used on same only cause interference when they are not in proper condition. It is only possible to eliminate the interference from such devices

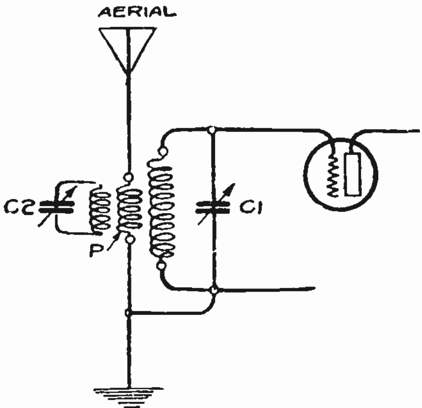

Fig. 5—Wave trap inductively coupled to a receiver.

merely by putting them in perfect order. It is also possible to eliminate, in part, the interference caused by arc light circuits, telephone and telegraph lines, electric street railways, farm lighting plants, etc. This is usually rather difficult and each individual case requires careful study by an expert or someone who has had previous experiences with that form of interference.

Some of these forms will be considered and whenever possible, a general solution will be given.

Power Circuits.

Lines. The electrical power system contains two varieties of transmission lines for connecting the customer with the generating apparatus.

Transmission lines comprise relatively large voltage circuits of long length and considerable energy which are susceptible to transient disturbances. The great length and large amount of energy carried by these lines makes any radio-frequency regeneration caused by them very serious. In general, it is only possible for the power lines themselves to cause interference when there is some defect, as an over voltage causing a discharge to take place at the surface of conductors, or by the line operating through a partial ground. Neither of these is a usual working condition.

In low voltage power lines, the factor of safety used in insulator installation is high. Practically the only possible source of interference is "arcing," due to defective insulation on the conductors themselves. In most cases, the interference is due to arcs, to trees through which the wires are run, to partial

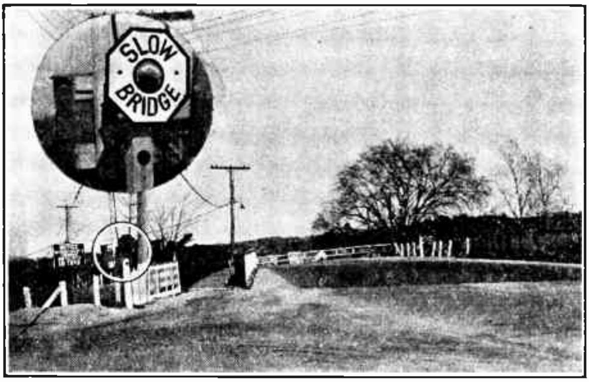

Fig. 6—Blinker causing interference.

contact with some other conductor running to ground, or to partial contact with a sheath or casing when the wires are run underground in conduit.

Insulators. In the case of transmission lines, defective insulators are quite often a source of interference. The arc or spark formed is due to either leakage along the core, a cracked porcelain, a low resistance path of ice or sleet, or a conductive coating on the surface. The high voltage arc generates a highly damped disturbance which travels for a considerable distance along the transmission line and sometimes it radiates to an appreciable extent.

A defective insulator which is simply leaking energy down the core and not spilling over, will tune to a very short wave-length and, generally, will not travel over more than one span, while if there is an external discharge, the whole line is excited, resulting in a long wavelength fundamental.

Lightning **Arresters** (Used on Power **Lines**).

The oxide film arrester consists of a number of plates operated and insulated from each other by a porcelain ring. The surface of these plates is covered with an insulating varnish and the space between filled with lead peroxide. When a lightning surge occurs on the power line, the varnish coating is punctured and the current drains to the ground through the resistance lead peroxide. The heat generated, however, changes the lead peroxide to red lead or litharge, a very high resistance conductor, so that the current flow is stopped. Accordingly, the breaking down of one of these arresters will cause disturbance, for a short period, but normally no trouble will occur.

Transformers. Faulty transformers are sometimes to blame for grounded conditions. In case of defective insulation of winding or bad connections, very severe interference is generated, but as a rule, transformers are kept in good condition by the Power Companies.

Generators and Motors. The normal arcing of generators and motors will produce considerable interference with radio receivers located nearby, especially where there is close coupling to power leads leading direct from the generator. Usually the output from an A. C. generator is fed directly to step-up transformers which insulate the line from the radio-frequency disturbance. If bad arcing exists and the generator is directly connected to the line, the interference may travel over the entire line, or to the first transformer.

Induction Voltage Regulators. Induction voltage regulators are used where it is desired to have a constant voltage on a line which would otherwise have poor voltage regulation.

In order to make their operation automatic, it is necessary to use additional apparatus, consisting of a transformer, relay switch, line drop compensator, etc. All of the above mentioned parts are possible sources of radio disturbance due to poor contact or grounded windings and leads, resulting in the formation of an arc.

If the interference caused by the regulator can be detected, it is possible to by-pass the interfering energy to the ground by connecting two condensers, of approximately 1 mfd. each, in series with the outgoing feeders and then grounding the common connection of the condensers. If one side of the feeder is grounded, only one condenser is necessary.

STREET LIGHTING

Troubles on street lighting circuits are usually obvious as to their source, since they are experienced only during the hours the circuit is energized. The complaints assigned to this cause are in most cases due to slight grounds on the circuit such as tree grounds, touching of guy wires, the lead-in rubbing on a cross-arm or brace, grounds in the lamp itself, etc. Other sources of trouble may be a loose contact in the lamp, the bayonet holding a film cut-out, etc. The remedy in practically all cases is careful maintenance.

Improvement in the design of street lighting fixtures has cut them down as the sources of noise. If the series arc circuit

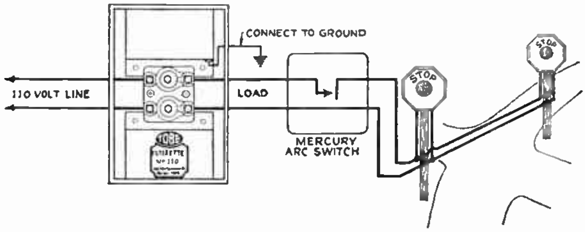

Fig. 7—Method of attaching filter to stop blinker interference.

is fed by mercury arc rectifiers or brush arc generators, serious radio disturbances may be produced along the circuit. When an abnormal vacuum is obtained in the tube, the mercury arc rectifier will generate high-frequency current. Condensers cannot be used, as they interfere with the normal operation of the rectifier, but choke coils of special design will eliminate the disturbance, as will replacement of the tube. Trouble from the brush arc generator, which is inherently a high-frequency source because of poor commutation, may also be eliminated by the use of chokes. If trouble is experienced on these types of equipment, the matter should be taken up with the power company.

Telephone and Telegraph Lines.

The wires used in telephone and telegraph communication carry such small amounts of energy that the condition of the lines themselves should never become sources of trouble.

Some of the equipment used in telegraph communication and for signalling purposes on telephone lines are productive of high-frequency waves. They radiate over their connecting lines, and where these are open wires, many homes may be affected. Ringing machines, lighting devices, automatic telegraph and tickers have been found to be sources of such disturbances. Because small currents are handled at low voltages, the elimination of radio noises traceable to this type of apparatus is comparatively easy. Proper chokes and filters have been developed and are now available to all communication utilities, although these have not been installed in every case.

ELECTRIC STREET RAILWAYS

Interference from this source presents a problem for which no really satisfactory solution has yet been found. Some suggestions are offered which will be found helpful.

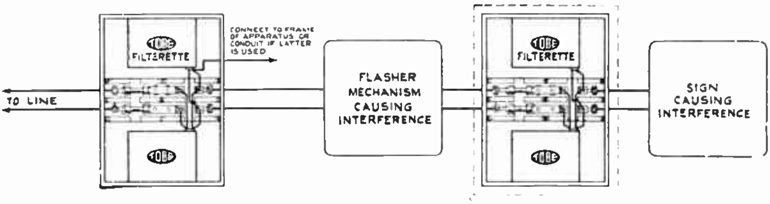

Fig. 8—Filters connected between line and flasher mechanism and also between sign and flasher mechanism to eliminate interference.

If the antenna is installed at the front of the building, facing the car lines, it should be shifted to the rear as far as possible. If conditions permit, it should be run at right angles to the line of interference. One or two feet variation in the plane will make a difference. We suggest when installing the aerial that one end of the horizontal portion be permanently fixed; the other end temporarily attached to a pole which may be carried backward and forward on the roof. In this way you are able to locate the position of minimum interference.

After noting the relative intensity of the interference at each setting, a permanent pole is fixed at the proper point. Remember that lighting and power circuits nearer the residence than the trolley feeders are involved in transferring the disturbance to the antenna, and distortion of direction is more or less bound to occur.

Sparks at the trolley wheel that cause clicking interference is another source of trouble. If the positive lead of the station generator goes direct to the trolley wire, interference will probably result. If this lead goes to the series field winding first, the free end of the series field going to the line, the choking effect of the coil tends to suppress any commutator interference.

Greater efforts are being made in every city to keep the rail bonding in good shape. More careful attention to car motors and equipment will tend to alleviate the situation.

Mechanical Interruptors.

Current interrupting devices are usually a source of radio disturbance. Many of these devices employ a high-voltage

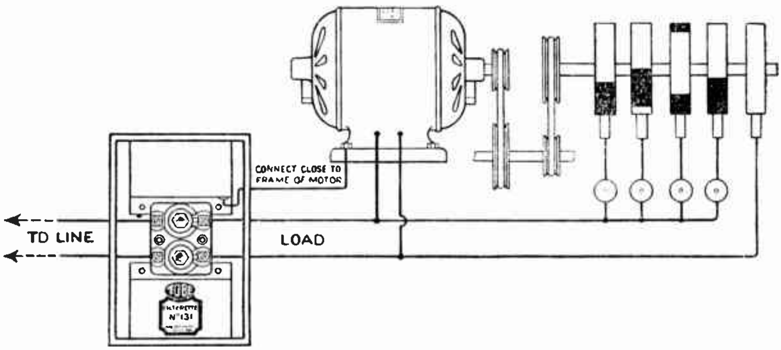

Fig. 9—Modern type of electric sign flasher, a common source of industrial interference, silenced with a filter designed for that purpose.

mechanical rectifying device which have in the past often been bad offenders against the radio public. The smaller vibrating or mechanical rectifiers used for battery charging are inherently a source of disturbance due to the vibrator contact or interruptor, which even with the best possible adjustment, will spark to a certain degree. A one-half mfd. condenser placed across the contact will usually lessen the disturbance; suitable chokes will eliminate it entirely.

Sign-flashing devices and light equipment are in the same class. The use of a condenser in the supply lead directly at the flasher mechanism will prevent the radio disturbance from spreading back over the supply wires if the latter is not too closely coupled with the wires extending from the flasher mechanism to the sign itself. This will not entirely prevent the disturbance from being received by nearby radio sets. The radiation from the vertical sign lead is appreciable unless they are inclosed in grounded piping.

Since the spark is generated by the make and break of each of the several contacts, riding on the rotating drum, a condenser should be placed across the common lead and each contact arm. A series choke should also be placed in each supply lead in order to entirely eliminate the disturbance.

Motors.

Commutators are always a possible source of trouble if allowed to accumulate dirt and their maintenance generally neglected. Apartment house elevator motors are often the cause of complaints, because of their proximity to receiving sets. An ordinary motor, well maintained, is seldom the source

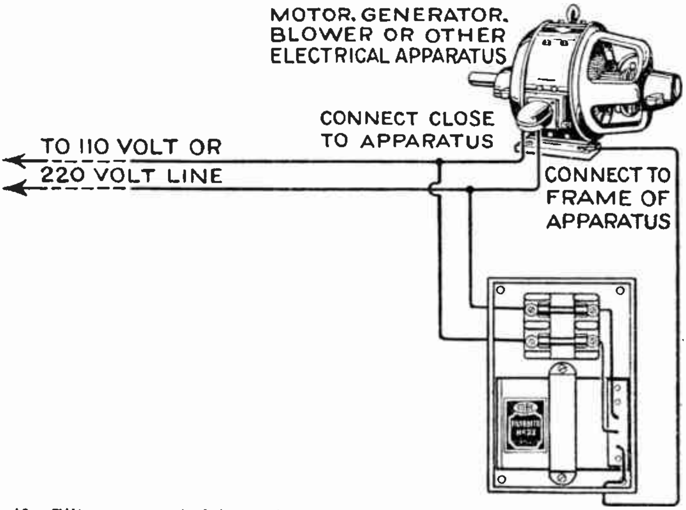

Fig. 10—Filter connected to motor, generator 110 or 220 volt AC or DC line.

of appreciable disturbance, except in the case of certain series motors and repulsion-induction motors, such as used in electric refrigerators and oil burners. These will be taken up under Household Appliances.

With the knowledge that practically all radio disturbances are caused by sparks, brush discharge, arcs and like phenomena, an endeavor should first be made to eliminate the cause. If this proves impracticable, recourse must be had to shields, chokes and condensers. The idea of the shield is self-explanatory, but complete shielding is expensive and should be adopted only as a last resort. Even with complete shielding, filter units are necessary in all leads entering the screened area. On the other hand, condensers are comparatively simple and inexpensive and they are usually the first remedial measure attempted. Care must always be taken to see that they are of the proper voltage rating. Usually two 1-mfd. condensers in series across the line with the midpoint grounded, offer the best solution. The ground leads should be as short and well grounded as possible, and attached to the frame of the apparatus causing trouble. For protection against short-circuiting the line if the condensers puncture, two fuses should be used. They are not necessary, however, if condensers of sufficiently high rating are used. In cases of severe disturbance, it is well to use choke coils in addition to condensers.

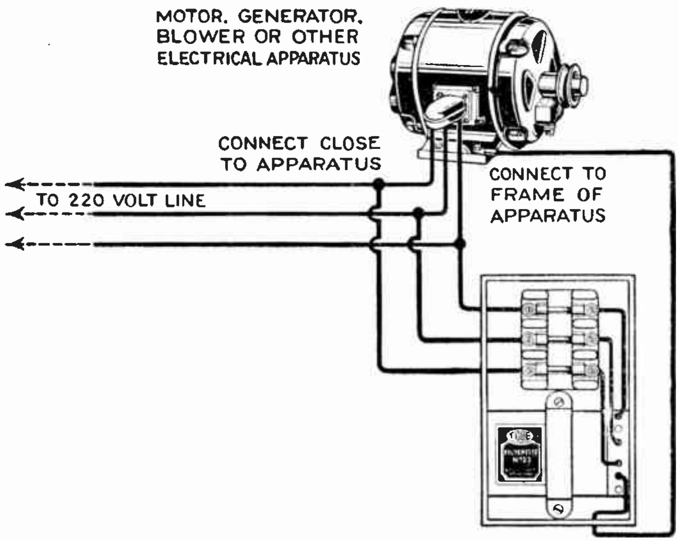

Fig. 11—Filter connected to motor, generator, where a three-wire system is used.

These chokes should, of course, be placed in series with each line of the supply circuit as close to the source of disturbance as possible, but beyond the condenser connections. A 2-millihenry choke is generally sufficient, though ones of larger inductance are occasionally necessary.

A 200-turn coil wound on a 3-inch non-metallic spool will give roughly 2 millihenries.

There are now on the market commercial filters of various kinds approved by the Fire Insurance Underwriters—their use is recommended both from an efficiency and safety standpoint.

Most of the public utility companies now employ trained radio men, whose duty it is to locate and remedy any interference caused by their apparatus. As this class of interference is beyond the control of the average Radio-Trician, it is well to take up in detail how to reduce the interference caused by our own household appliances.

INTERFERENCE FROM HOUSEHOLD APPLIANCES

In the succeeding pages, the interference caused by the use of household electrical appliances will be discussed and methods suggested for its elimination.

Let us consider for a moment the number of electrical appliances now in use in many homes which create interference with radio reception. In the basement, there may be an oil burning furnace with its electric motor and thermostatic control, an

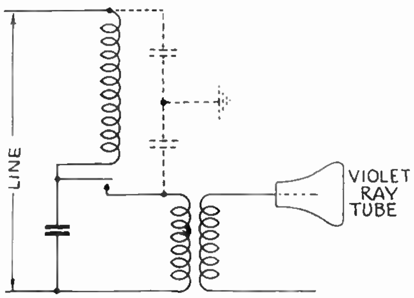

Fig. 12—Showing connections for condensers.

electric washing machine and ironing machine, and the motor and automatic starter for an electric refrigerator. In the kitchen, there may be an electric range, perculator, waffle iron and in some cases, an electric dish washer. In the living room, an electric heater, fan, and the Radio itself, perhaps an electric victrola. In the bedroom, there may be an electric curling iron, heating pad, electric hair drier, vibrator and massage machine, and the violet-ray machine. In the bathroom, various forms of electric water heaters. In another room, an electric sewing machine, vacuum cleaner, and various other household appliances. In the boys' room, an electric train and other small toys containing electric motors. The average home today also contains an increased number of electric lights, bridge lamps, table lamps, and numerous outlets, switches and other forms of sockets and conveniences. Of course, if every home contained all of these items, the interference created would be enough to render radio reception impossible. Since only some of these appliances create continuous interference and others create it when they are turned on or off, the situation at present is bearable.

We know that whenever we turn an electric light on or off or make or break any other electric circuit, we create a certain amount of interference, because when a spark occurs it is picked up by the set and can be heard in the loud-speaker.

Some forms of household appliances use a vibrating or thermostatic contact. Whenever the circuit is made or broken by such a contact, a high-frequency current is generated and a crash is heard in the loud-speaker. If the circuit is made or broken only once, only one crash will be heard. If the circuit is made and broken several hundred times per minute, a crash will be heard at each make and break of the circuit. These crashes can

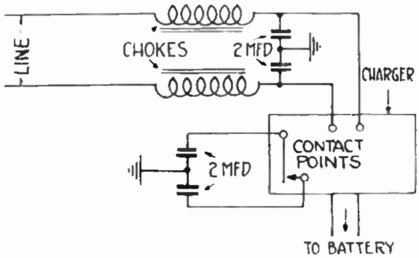

Fig. 13—Filter for charger.

be heard in the speaker regardless of whether or not there is any direct connection between the receiving set and the appliance.

Some means must be devised to prevent the high-frequency disturbance from traveling along the wiring system and being radiated, or the disturbance following the lines from the house to the power lines and being radiated over a wider area by the power mains. The real remedy lies in preventing this radiation by the main power lines as well as the household wiring. This can be done in most cases by means of a smaller filter and anti-sparking arrangement which is described later.

In the near future whenever a customer purchases an electrical appliance he will demand that the appliance must not create any disturbance which will interfere with either his own Radio reception, or that of his neighbor. The sooner we come to this condition, the better off we will all be. We will have the engineering forces of all the manufacturers competing with each other, and each will see that the article he manufactures will be equipped so as to prevent any disturbance which might affect Radio reception.

In the outline given herewith, the appliances have been divided into three types according to the following classification: a vibrating contact, electric motor, or a circuit made and broken only infrequently.

(A) Interference arising from appliances using vibrating contacts.

- (a) Door-bells.
- (b) Violet-ray outfits.
- (c) Annunciator systems.
- (d) Contacts on electric refrigerators.
- (e) Contacts on oil burning furnaces.
- (f) Heater pads.
- (g) Vibrating storage battery chargers.
- (h) Thermostatic contacts of various classes.

(B) Appliances using motors.

- (a) Electric sewing machines.
- (b) Electric vacuum cleaners.
- (c) Electric refrigerators.
- (d) Electric dish-washing machines.
- (e) Electric oil burning furnaces.
- (f) Electric washing and ironing machines.
- (g) Electric fans.
- (h) Electric hair driers.
- (i) Electric vibrator or massaging machines.
- (j) Electric toys.

(C) Miscellaneous sources of interference.

- (a) Electric irons.
- (b) Electric ranges.
- (c) Electric percolators.
- (d) Electric toasters.
- (e) Electric waffle irons.
- (f) Electric heaters.
- (g) Electric curling irons.
- (h) Electric water heaters.
- (i) Electric pads.
- (j) Electric switches, sockets and wherever current is turned on or off.

In order to determine whether or not the interference is coming from the electric light line, entirely disconnect the aerial and ground wires from the receiver. If the interference ceases, it is proof that it was picked up by the aerial or ground systems and not caused by the electric light line or any appliance connected to it. If the interference does not stop, it shows that the interference is caused by some appliance connected to the electric light line. All appliances in the house using electricity should then be disconnected. If the interference continues it shows that it is caused by some appliance not used in the house. By connecting one appliance at a time to the line and listening to see whether or not the interference is present will show definitely if the interference is caused by appliances used in the house.

Interference Arising From Appliances Using Vibrating Contacts.

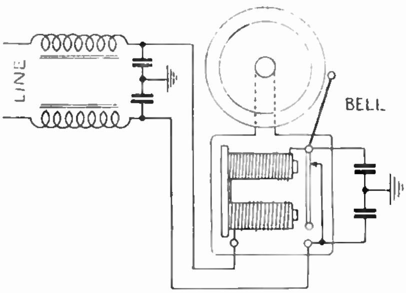

Fig. 14—Showing filter connected to an electric bell.

Experiments have been performed to determine the feasibility of eliminating all classes of interference caused by household electrical appliances. In most cases, it was possible to either eliminate the interference entirely or reduce it so that it was not noticeable. Various forms of filter arrangements were used, these being the most practical way of reducing or eliminating this form of interference. Such filters will be taken up later on.

The violet-ray presented the most difficult problem on account of the fact that we not only had a vibrating contact, but also a high-frequency current with which to deal. By shunting two condensers of 2 mfd. each, in series, across the vibrating contact and the induction coil (see Fig. 12 dotted lines), and grounding the center point of the condensers, a large portion of the interference was eliminated. All other filter arrangements reduced the interference to a certain extent, but as they reduced the strength of the violet-ray they could not be used.

All experiments were performed using a Super-heterodyne receiver operated by means of a "B" eliminator and deriving its power from the A. C. (alternating current) mains. The appliance, under consideration in each case, was plugged in at the same outlet. The high-frequency surges had as direct a connection as possible with the receiver, and could react directly on it, without having to travel through other parts of the wiring system.

A vibrating contact storage battery charger was found to create almost as much interference as the violet-ray. The charger was placed directly underneath the receiving set, and the interference was enough to overcome the signals from a local high powered Broadcasting Station. Nevertheless, it was found that

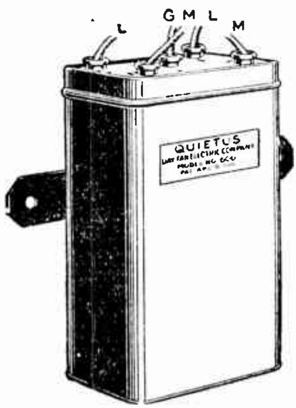

Fig. 15.

the interference could be entirely eliminated by using an arrangement shown in the diagram, Fig. 13.

The successful elimination of the interference caused by the charger led to other experiments on various classes of household appliances. In each case, it was found that by inserting a choke coil in each side of the line, and between the choke coils and the appliances two condensers connected in series, with the center point grounded, and the outside terminals connected to each side of the line, the interference could be entirely eliminated, or reduced to a point where it would not interfere with reception and could only be heard by listening very closely.

In some cases, it was found that it was necessary to shunt either one or two condensers, in series, across the vibrating contacts. When two condensers were used, the center point was grounded. This reduced sparking at the points and also provided a low reactance path to ground for all high-frequency current. By this means, the interference from a large bell or buzzer operated directly from the A. C. mains, and placed very near the receiving set, was entirely eliminated. See Fig. 14.

In a few cases, it was found that the frequency of the interference was changed and could be heard at another setting of the dial. However, either an increase or decrease in the size of the chokes would entirely remove the interference from the broadcast band, so that it could not be heard at any dial setting.

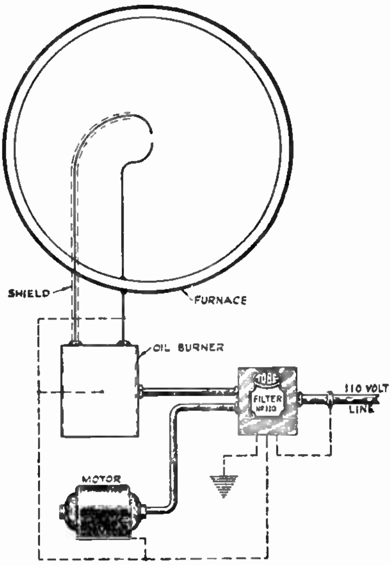

Fig. 15A—Filter used for suppressing Radio interference from oil burner having grounded ignition system.

APPLIANCES USING MOTORS

The interference arising from the use of an electric motor, can be classified either as a steady hum, or a sputtering, crackling noise, similar to static. It has been found that the sputtering or crackling noise is frequently due to sparking at the commutator. Fortunately, this form of interference can be easily eliminated, since it is due only to the rough surface of the commutator.

A small piece of fine sandpaper, about 00 grade, held against the commutator while the motor is running, will clean the commutator and decrease the amount of sparking. With the decrease in sparking, the interference will be eliminated. This is an easy method of eliminating this class of interference. About all that is necessary is to frequently examine the motor, see when excessive sparking is occurring and sand the commutator as above. When the owners of these motors realize that in order to prevent this form of interference, they must keep their equipment in good condition and go over it frequently. If one is not familiar with the apparatus, an expert from the Power and Light Company or from any Electrical Company, can perform the operation in a few minutes and at a very small cost.

The second form of interference, arising from the use of electric motors, the humming noise, cannot be prevented quite so easily. It can be effectively eliminated without a great deal

Fig. 16.

of expense. Several manufacturers have recently put out filter systems designed for this purpose and two such are illustrated in Fig. 15 and Fig. 16.

The filter shown in Fig. 15 is connected between the appliance and the line supplying it—that is, the terminals marked "M" should be connected to the line leading to the motor, and the terminals marked "L" to the supply line. The terminal marked "G" should be connected to the ground. This filter is not designed to be used with or connected to the receiving set, but only near an electric motor.

The Tobe filter shown in Fig. 16 is connected between the line and the appliance. The two left-hand posts marked "line" are connected directly to the electric light line supplying the appliance, and the two right-hand leads are connected to the appliance or motor. The center post is connected to the frame of the motor and the motor frame grounded.

This filter is suitable for use with all types of fractional horsepower motors consuming 8 amperes or less at 120 or 200 volts. As most motors used in household appliances are not larger than ¼ horsepower, this filter is very well suited for eliminating this class of interference.

Figure 17 illustrates a typical filter circuit used with electric motors. The two inductances shown are small iron core chokes of approximately 200 milli-henries each. The condensers, C1 and C2, should be at least 1 mfd. capacity or better yet, 2 mfd.

The function of the chokes is to prevent the disturbances created by the electric motor from entering the house wiring system and power lines and being radiated over a wide area.

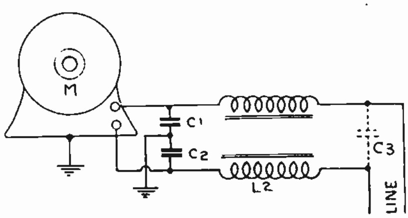

Fig. 17—Schematic diagram of Motor Filter System.

They prevent a high reactance to the flow of high-frequency current and effectively prevent it. By shunting the two condensers, C1 and C2, across the line, and connecting the center point to the ground, a low reactance path is provided for this high-frequency current to flow to the ground. The condenser shown as C3 in the diagram is not absolutely necessary and in most instances, it is not used. However, it is shown here as it sometimes helps in eliminating this type of interference.

For those who wish to "build their own," a description is given herewith. Each choke consists of a total of 176 turns of No. 16 DCC copper wire on a porcelain tube 1 inch in diameter, and approximately 6 inches long. They are layer wound with 88 turns to the layer—two layers being used, and one thickness of Empire cloth inserted between each layer of wire. The whole is given a good coat of insulating varnish when complete, with one layer of Empire cloth on the outside.

A small piece of ordinary stove pipe iron, about 18 gauge, is cut to form the core. It should be rolled and inserted in the porcelain tube in such a way as not to make a complete circle; that is, a small arc of at least ⅛ inch is left out. The iron should be approximately 5x3 inches to be used with the porcelain tube having an internal diameter of 1 inch. The condensers used should be preferably mica condenser of 2 mfd. each. However, a paper dielectric may be used, if the condensers are constructed so as to withstand the voltage. A very suitable condenser for this purpose is the WS-3735 condenser manufactured by the Wireless Specialty Company, or the Dublier No. 902-2 mfd. condenser.

The ordinary 1 mfd. condenser used in the receiving set is not suitable for this purpose, as it will not stand the voltage to which it will be subjected. Precaution must be taken in order to prevent these condensers from breaking down, and causing a short on the line. It is best to use a condenser having a much higher voltage rating than the voltage to which it will be subjected.

TABLE I.

Current Carrying Capacity of Copper Wire Used for Choke Coils.

American (B & S) Wire Gauge	Amperes Allowed by Underwriters Rubber Covered	Other Insulation
18	3	5
16	6	10
14	15	20
12	20	25
10	25	30
8	35	50
6	50	70
4	70	90
3	80	100

Whenever there is a permanent installation of a motor, such as in the electric refrigerator, the oil burning furnace, the washing machine, or elsewhere, one of these filters can be installed between the motor and the line. All that is necessary to do is to cut the leads running to the motor and insert the filter with the connections as shown in Fig. 17. The ground connection is attached to the water pipe system and the condenser side of the filter always goes next to the motor.

MISCELLANEOUS SOURCES OF INTERFERENCE

Under this heading, you will note that most of the household heating appliances are listed. Very little interference arises from this source, except when the circuit is made or broken. In some instances, a thermostatic attachment is used (see Fig. 18), whereby the circuit is made or broken automatically, of course, interference arises here because as previously stated, whenever an electric spark occurs. or a circuit is made or broken. a disturbance will be created which will be manifested by a crackling sound in the head-set or loud-speaker. It is possible to reduce this class of interference to a minimum, and several experiments have been performed in order to determine just how it could be eliminated.

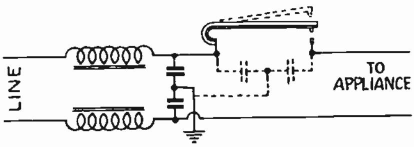

Fig. 18—Filter connections for Thermostatic contact.

However, there are practical limits to installing some form of filter arrangement at every electric switch or plug. A diagram though is given herewith in order to show just how this can be accomplished. See Fig. 19.

The fundamental idea in reducing interference is to prevent the high-frequency disturbances from entering the power lines and being radiated by them. A great deal can be accomplished by inserting a filter on all of the permanent installations. A filter inserted near the meter will prevent disturbances from coming in on the line.

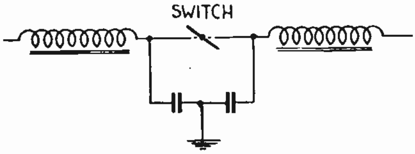

Fig. 19—Filter connections for a switch.

Such a filter is illustrated in Figs. 20 and 21. The chokes should consist of a total of 264 turns of No. 10 DCC wire on a tubing 2 inches inside diameter. The tubing should be bakelite or some non-combustible material. The wire should be wound in three layers of 88 turns each with two layers of Empire cloth between each layer of wire. After the winding is finished, the whole should be given a coat of insulating varnish. The winding form or tubing should be approximately 9 inches long and small feet are attached to each end for support. The core can be formed by rolling a piece of ordinary black sheet iron approximately 6x8 inches. It will then just fit on the inside of the form without the edges coming in contact and making a cylinder; that is, an air gap of 1/4 inch should be allowed between the edges as shown in the diagram. The condensers should have mica insulation, and they should have a rating of at least 1 mfd. capacity, and perhaps 2 mfd. would be better.

Condensers having a rating of at least 1,000 volts should be used to prevent any short occurring in the line. The whole should be mounted in a steel cabinet such as specified by the Underwriters for switches, fuses, etc.

This filter will prevent to a certain extent any disturbances or interference arising from appliances used in the house from entering the power lines and being radiated over a wide area. It will also prevent to a certain extent, any disturbances arising

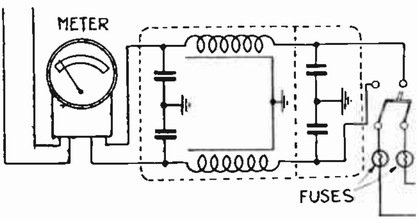

Fig. 20—Showing how filter circuit is connected to meter.

in the power lines from entering the house and being radiated by the house wiring system.

Before installing any of the filters described herein, it is advisable to consult the local power company for aid in making the installation.

FARM LIGHTING PLANTS

Interference from this source is confined to rural districts. The characteristic click, click, corresponding to the ignition spark, reveals the source at once. Trouble rarely originates from the commutator. This continuous clicking is very loud on nearby radio receivers, and because of the large number of plants in operation in communities not served by electric power companies, the total interference is very annoying.

Complete elimination of the disturbance created is relatively a simple matter. Nearly all these plants being bolted down to a wooden platform, are insulated from the ground. Two 2-mfd.

condensers in series, midpoint connected to the engine frame, and bridged across the outgoing D. C. feeder, will clear up the clicking. Ground connection of the series wire should not be

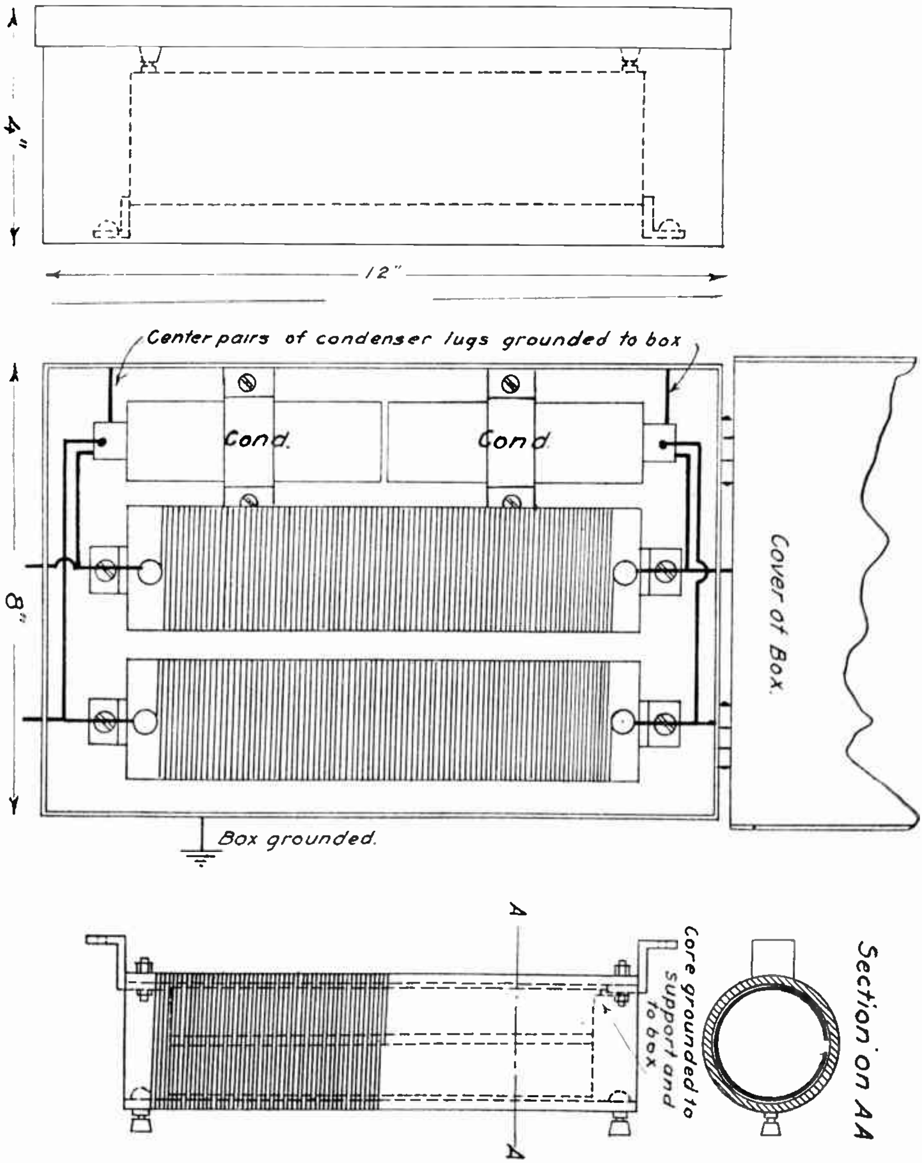

Fig. 21

made to a water pipe or earth rod in this case. Even 1-mfd. condensers will be found suitable for small plants.

If the engine bed is of concrete or the plant is grounded in some other way, complete elimination is not obtained by the above method, although the reduction (about 80%) is material. The remaining interference is not likely to be serious. Where it is desired to clear this out choke coils should prove effective.

It is not uncommon to find the exhaust pipes of such plants

TABLE II.
Commercial Filtering Devices
(TOBE FILTERETTES)

MODEL	Applications for Filterette	Capacity
Junior	Small motors, as on: barbers' clippers, cash registers, hair dryers, electric fans, vacuum cleaners, and similar devices.	110 Volts D.C. or A.C. 500 Watts
No. 10	D.C. motors, generators, chargers, house lighting plants, etc.	110 Volts D.C. 5000 Watts
No. 11	Motors, generators, chargers, transformers, house lighting plants, etc.	110 Volts D.C. or A.C. 5000 Watts
No. 20	D.C. Motors, generators, chargers, house lighting plants, etc.	220 Volts D.C. 10,000 Watts
No. 22	Motors, generators, chargers, transformers, house lighting plants, etc.	220 Volts A.C. or D.C. 10,000 Watts
No. 23	Same as No. 22, but where three wires are required instead of two.	3 phase 220 Volts A.C. Single phase 110-220 Volts A.C. 3 wire 110-220 Volts D.C. 15,000 Watts
No. 55	Motors, and any other apparatus operating on 440 or 550 volts A.C.	440-550 Volts A.C. 25,000 Watts
No. 56	Same as No. 55, but where three wires are required instead of two.	3 phase 440-550 Volts A.C. 30,000 Watts
No. 60	Motors, generators, chargers, house lighting plants, etc.	600 Volts D.C. 25,000 Watts
No. 110	Refrigerators, oil burners, chargers, dental motors, electric heating pads, small electric signs or blinkers, and any type of apparatus within maximum potential named. Also properly shielded violet-ray or diathermy apparatus.	110 Volts A.C. or D.C. 500 Watts Maximum current 5 Amperes
No. 221	Same as No. 110.	220 Volts A.C. or D.C. 1000 Watts—5 Amperes

TOBE FILTERETTES FOR MOTOR DRIVEN SIGN FLASHERS
(Maximum potential 110 volts A.C. or D.C.

No.	Maximum Cur.	Maximum Load	Outside dimensions
131		1,000 watts	13″x9⅜″x3⅛″
132	20 amperes	2,000 watts	13″x9⅜″x4⅛″
133	30 amperes	3,000 watts	19″x12⅜″x4⅛″
134	40 amperes	4,000 watts	19″x12⅜″x4⅛″
135	50 amperes	5,000 watts	19″x12⅜″x4⅛″

carried to a muffler drum in the ground. Such a connection to earth offsets the effect of the condensers and more satisfactory results will be obtained if this pipe is cut and a section of asbestos or other suitable piping is inserted.

In all cases attachment of the condensers is made at the switchboard, under the same terminals to which the two lighting mains are connected.

TEST QUESTIONS

Number your Answer Sheet 29—1 and add your **Student Number.**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What are the two methods for suppressing Radio interference due to sparking electrical apparatus?
2. What apparatus is necessary to locate any interference caused by electrical apparatus?
3. Draw a diagram showing how to install a simple anti-static device in a receiving aerial.
4. What effect will reducing the size of the aerial have on the strength of the in-coming signals?
5. Draw a diagram of a wave trap that can be used with a receiving set.
6. What is the advantage of using a wave trap?
7. Do motors having their commutators and brushes in good condition cause interference with Radio reception?
8. How would you clean the commutator of a motor to prevent sparking?
9. Draw a diagram showing how to connect a filter to a motor.
10. Give the dimensions for building a choke coil suitable for an electric motor.

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SOME GOOD STUDY HABITS

A Personal Message from J. E. Smith

Criticism. This is a valuable study habit, provided it is not carried too far. The ability to criticise the ideas or opinions of another; the power to pass accurate judgment on a piece of work is largely a matter of experience, and experience is habit. Students too often make the mistake of swallowing all that they hear and read, without first passing judgment on its worth.

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CHANGING SOUND TO AUDIO-FREQUENCY CURRENT

The entire purpose of a radio broadcasting system consisting of a studio, a radiotelephone transmitter, the ether, a radio receiving installation, and a loudspeaker, is to reproduce in the home of the radio listener speech and music originating in the studio of a distant broadcasting station. Before considering in detail the design and operation of the vast array of apparatus incorporated in the modern broadcasting station, it is, therefore, desirable that we consider in some detail the exact nature of this phenomena which we call sound, and the limitations and possibilities of that human sense which we call the sense of hearing.

FREQUENCY SENSITIVITY OF THE HUMAN EAR

The sensation of sound is produced by wave-motion ordinarily traveling in air. Since sound is a wave-motion, we can discuss the frequency, wavelength of these waves, and the velocity with which they will travel through various media. Not all wave-motions which might be produced in air or similar media are capable of producing the sensation of sound. The human ear is capable of responding to only a limited range of these wavelengths or frequencies. About the lowest frequency which any individual can detect as a musical tone is 16 cycles per second. The highest is around 30,000 cycles per second. However, these are extreme limits. The range of the average human ear is much less than this. Anyone who can detect as sound the frequencies lying between 20 and 20,000 cycles per second may consider that his ears are very good indeed.

POWER REQUIRED TO PRODUCE THE SENSATION OF SOUND

The amount of power required to produce the sensation of sound in the average human ear is very, very small. This amount depends upon the particular frequency of the sound wave striking the human ear. The ear is most sensitive to frequencies lying between 2,000 and 4,000 cycles per second, and only .000,000,000,000,000,4 of a watt is ordinarily necessary to produce the sensation of sound if the frequencies involved lie between these limits. A sound wave striking the ear drum applies a pressure to the drum. Pressure is force per unit of area and pressure on the ear drum is ordinarily measured in terms of dynes per square centimeter. A dyne is a unit of force which is approximately 2 millionths as large as the force exerted by gravity upon a mass of 1 pound.

The sensitivity of the ear varies greatly with the frequency of the sound striking it. Fig. 1 shows this variation of sensitivity for frequencies lying between 20 and 20,000 cycles per second. The curve is labeled "Threshold of Audibility." For

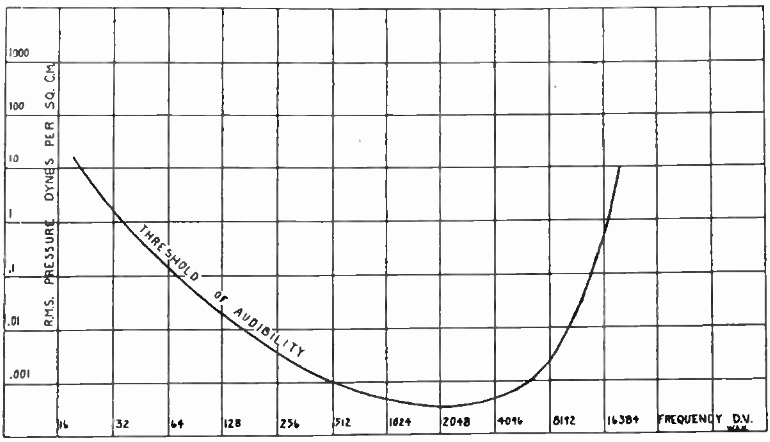

Fig. 1—Sensitivity of the average human ear.

a given frequency, pressures represented by points lying above the curve will produce the sensation of sound unless these pressures are so great as to produce the sensation of pain.

Note that the space between two lines does not always represent the same number of units of pressure. Thus, the next to the top line is labeled 1000 dynes per square centimeter, while the second line from the top is labeled 100 dynes per square centimeter. This space then corresponds to a change of 900 dynes per square centimeter in pressure. The next lower line, however, is labeled 10 dynes per square centimeter and the space between it and the 100 line, therefore, corresponds to 90 dynes per square centimeter. In describing certain phenomena, this type of graph is very useful. It is called a logarithmic graph. Referring to the graph, you will note that while at 512 cycles per second, it requires only .001 dyne per square centimeter of sound pressure to cause the sensation of sound in the average human ear; it requires over 1 dyne, that is, over 1000 times as much pressure at a frequency of 32 cycles per second.

SOURCES OF SOUND

We have seen that the range of frequencies which will produce the sense of sound in the human ear varies greatly with individuals but for the average human ear this range may be considered as lying between 20 and 20,000 cycles per second. We have also seen that the amount of power required to produce the sensation of sound is very, very small, and that the minimum

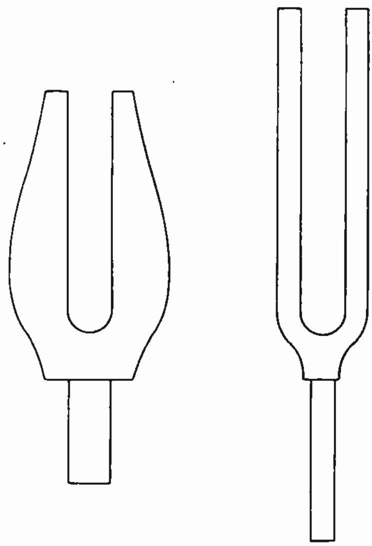

Fig. 2—Cross section drawing of two tuning forks.

amount of power required varies greatly depending upon the frequency of the sound wave striking the ear. With this very brief discussion of sound waves, let us consider just how sound is produced.

Sound waves are produced by vibrating bodies. The rate at which a body vibrates determines the frequency of the wave produced. The types of bodies which may vibrate and produce sound waves are many and include stretched strings, columns of air, stretched diaphragms, rods, plates, vocal chords in the human throat, and many others. The vibration of bodies such as these produce waves in the air which may produce the sensation of sound in a human ear providing the frequencies produced lie within the range of audibility. If the vibrating source is in water or associated with some other medium, then the sound waves may be carried by it. As we shall see shortly, the frequencies produced and their amplitudes are of great importance in determining the character of the sound.

CHARACTERISTICS OF SOUND WAVES

If the vibrating source produces only a single frequency, then the sound is said to be a **pure tone.** Practically pure tones can be produced by tuning forks. Fig. 2 is a drawing showing the outline of two tuning forks. Fig. 3 shows sets of tuning forks for producing various frequencies with a high degree of accuracy. The set of forks to the right will produce a frequency considerably higher than the set of forks on the left. The longer

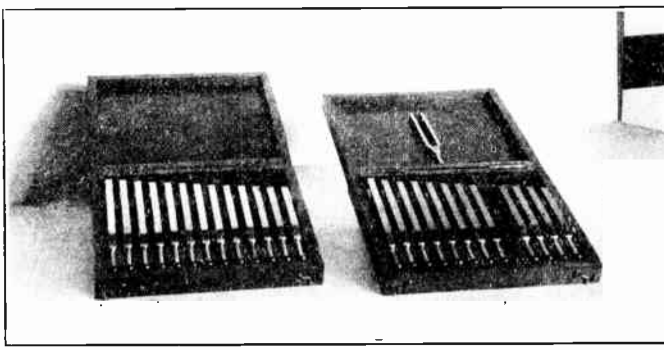

Fig. 3—Sets of tuning forks.

forks are approximately 8 inches long. The tuning fork is set in vibration by striking it with a small padded mallet or by bowing with a violin bow. If the fork is struck softly, the **amplitude** of the vibrations of the fork will be small, and the sound produced will be soft. If, on the other hand, the fork is struck more forcibly, the **amplitude** will be greater and the sound produced is said to be **loud. Loudness** then will vary with the **amplitude** of vibration of the source; the greater the amplitude the louder will be the sound.

Let us assume that we have available a group of ten tuning forks such as is shown in Fig. 4. The frequencies produced by these ten tuning forks are as follows: 128, 256, 384, 512, 640, 768, 896, 1024, 1152, 1280. From the lessons you have already studied, you will readily see that the frequencies produced by striking these ten forks consists of a fundamental and its harmonics. The 128-cycle note is the fundamental, the 256-cycle note, the second harmonic, the 384-cycle note, the third harmonic, etc.

A pure tone as produced by a single tuning fork, such as the one producing a frequency of 128 cycles per second, is not particularly pleasing to the ear. If, however, we strike the ten forks simultaneously or one after the other, we will find that the tone produced is decidedly pleasing to the ear.

The 128-cycle fork by itself will not produce a particularly pleasing tone. However, as the harmonics or **overtones** produced by the other forks are successively added, the tone grows richer until when all ten forks are operating simultaneously, a very pleasing musical tone is produced.* If one were to listen to the sound

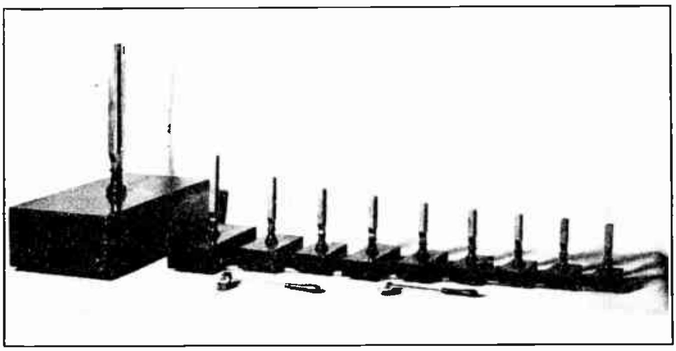

Fig. 4—Set of tuning forks for demonstrating the quality of composite tones.

from these ten tuning forks without seeing them struck, he would hardly be conscious of the fact that it is originating from ten separate sources, but he would rather be inclined to think that the sound came from one source. As a matter of fact, sounds composed of a fundamental and a series of harmonics are very frequently produced by a single source. They are often referred to as **composite tones.**

If a violin string is bowed, or the key to an organ is pressed down, then a composite musical tone is produced. The tone in each case will consist of a fundamental and a series of harmonics such as was produced by the tuning fork. The violin string produces in addition to a fundamental frequency a large number of harmonics. A certain amount of sound energy will be produced in the fundamental, different amounts will be produced in the

*Figs. 2, 3 and 4 are taken from "The Science of Musical Sounds" by Dayton C. Miller, published by Case School of Applied Science, Cleveland, Ohio. This book is highly recommended to those students who are interested in obtaining a comprehensive non-mathematical book on the general science of sound. It should be in the library of every broadcasting station engineer.

various harmonics. The same holds true for the column of air in the organ pipe.

The lower chart in Fig. 5 shows the distribution of energy in the fundamental and harmonics produced by bowing a violin

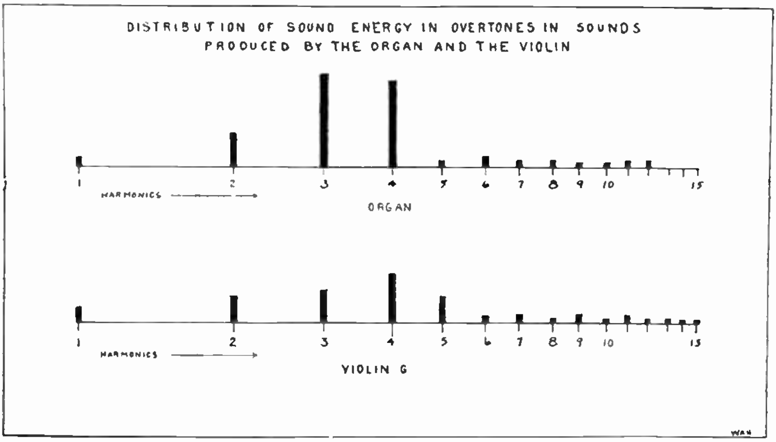

Fig. 5—Distribution of sound energy in overtones produced by the organ and the violin.

string. The upper chart of the figure shows the distribution of energy in fundamental and harmonics as produced by a particular organ pipe.

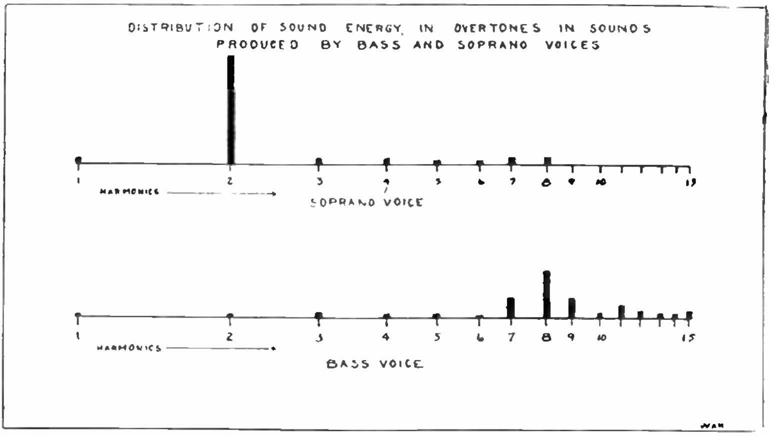

Fig. 6—Distribution of sound energy in overtones produced by bass and soprano voices.

Let us assume that the fundamental frequency produced by both the violin string and the organ pipe is 256 cycles per second. The second harmonic will then have a frequency of 512 cycles per second and the third harmonic a frequency of 768 cycles, etc. Referring to Fig. 5, you will note that there is approximately twice as much energy in the second harmonic produced by the violin as in the fundamental and something more than twice as much in the third harmonic. Referring now to the upper chart in Fig. 5, you will note that there is at least three times as much energy in the second harmonic produced by

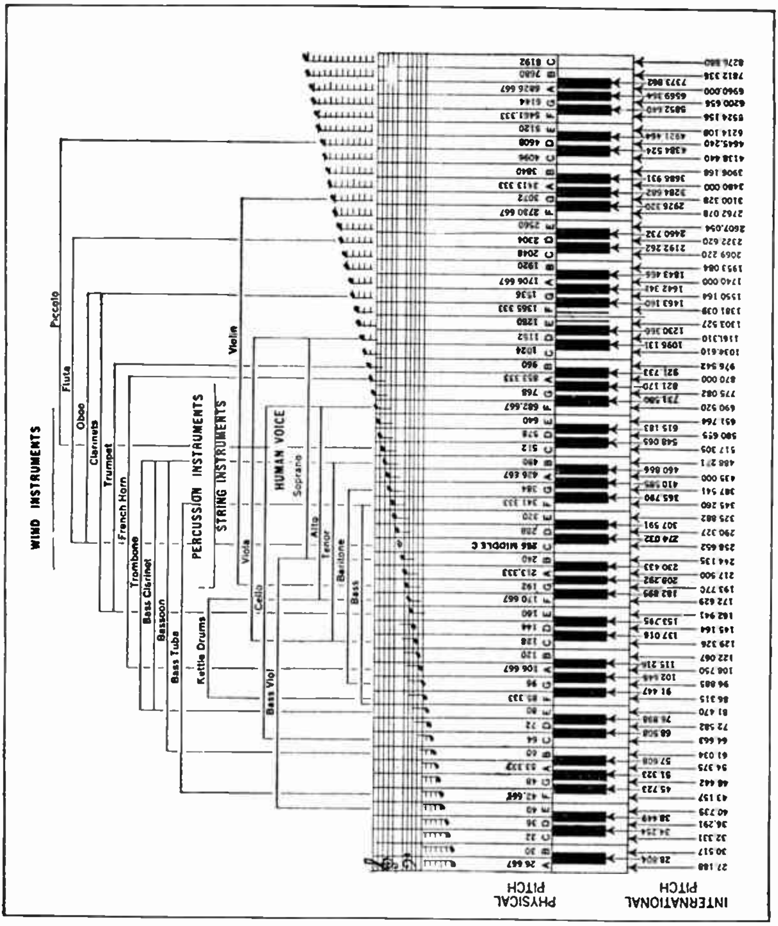

Fig. 7—The relation between musical scale and the piano keyboard.

the organ as in the fundamental and approximately ten times as much in the third harmonic as in the fundamental. In other words, although the frequencies produced in fundamental and harmonics by the violin string and the organ may be the same, the relative amounts of energy may be quite different. You are well aware of the fact that if a frequency of 256 cycles (middle C) is produced by a violin and then the same frequency is produced by an organ, you will in general have no difficulty in telling which note is produced by the organ and which by the violin. The two tones possess different characteristics. It is the varying amount of energy in the harmonics of the two notes which determines the difference and enables us to distinguish between the musical instruments. In other words, it is the relative amounts of energy in the fundamental and harmonics of a musical note which determine its **quality** or **timbre.**

There is one other characteristic of musical tones with which you should be familiar. The **pitch** of a musical tone depends upon the frequency of the fundamental. We may, therefore, use alternately the terms **pitch** and **frequency,** but when we do, it must be remembered that we are referring to the frequency of the fundamental even though, as is shown in Fig. 5, the amount of energy in the fundamental is relatively small in comparison to that in the harmonics.

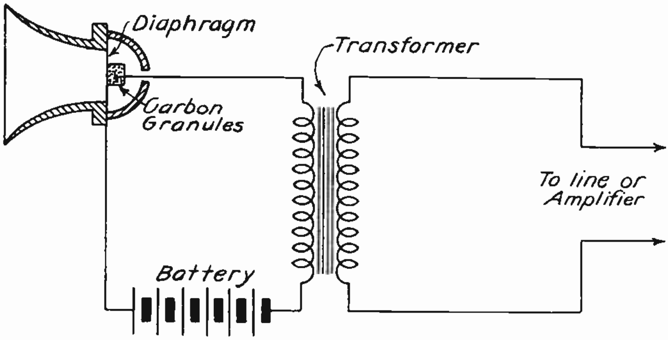

Fig. 8—Simple microphone circuit.

The range of fundamental frequencies produced by musical instruments varies greatly. Most fundamental frequencies produced by a violin lie approximately between 193 and 3900 cycles, by a harp between 32 and 3100 cycles, by a piano, between 27 and 4138 cycles, etc. Fig. 7 is a splendid graphic picture of the frequencies produced by various musical instruments shown together with the musical scale and with a picture of the piano keyboard. This figure contains much valuable information and is worthy of considerable study. It should be remembered that the range of frequencies for various instruments and for the human voice as shown in Fig. 7 cover only the fundamentals produced, as we have seen in addition to a fundamental, each of these instruments will produce a large number of harmonics, each containing different amounts of energy. Since the harmonics are always frequencies higher than the fundamental, you can readily see that the frequencies produced by musical instruments extend much higher than 4000 cycles. Many of the frequencies produced in music extend as high as 15,000 or 16,000 cycles. It is important that this fact be borne in mind. As we have seen, it is the relative amounts of energy in the harmonics and fundamentals which enable us to determine the **quality** or **timbre** of a musical note, and enable us to differentiate between sounds as produced by various musical instruments. Unless a radio broadcasting station provides for the transmission not only of the fundamental frequencies found in music, but also of the harmonics of these frequencies, then the quality of the program will be lost.

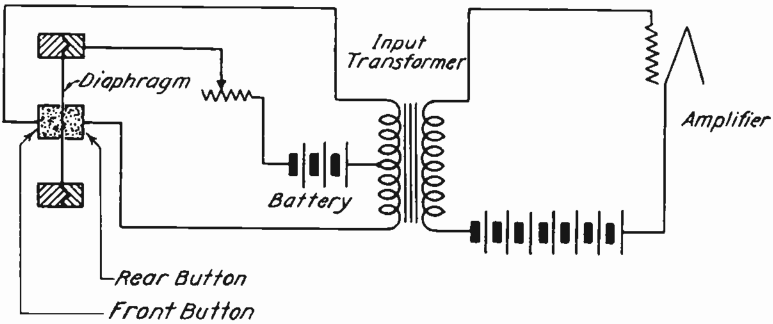

Fig. 9—Double button microphone circuit.

THE CONVERSION OF SOUND TO ELECTRIC ENERGY

Radio broadcasting makes use of electromagnetic waves. Electromagnetic waves are produced by high frequency alternating electric current which have been modulated at audio frequency. It is, therefore, essential that a broadcasting system contain apparatus which will convert sound energy as produced in a broadcasting studio to electric energy, and that the electric frequencies correspond to the sound frequencies it is desired to broadcast.

The device which performs this function in a broadcasting station is called a **microphone** or a **transmitter.** The sole function of the microphone is to convert sound energy to electric energy.

Fig. 8 is a schematic circuit drawing designed to show the method of operation of an ordinary single button microphone such as is used in the ordinary wire telephone system. Fig. 9 shows the connections for a two-button microphone such as is used in the great majority of radio broadcasting stations. Both the one and two-button microphones make use of carbon buttons. These are shown graphically in the figures. The buttons in both types are filled with small particles of carbon. The principle of operation depends upon the fact that if the carbon granules in the button are compressed, the resistance offered to an electric current is decreased. If, on the other hand, this pressure is removed, the resistance is increased.

Fig. 10 shows a cutaway picture of a two-button microphone such as is used in most broadcasting stations. The two carbon buttons can be clearly seen in the center of the picture.

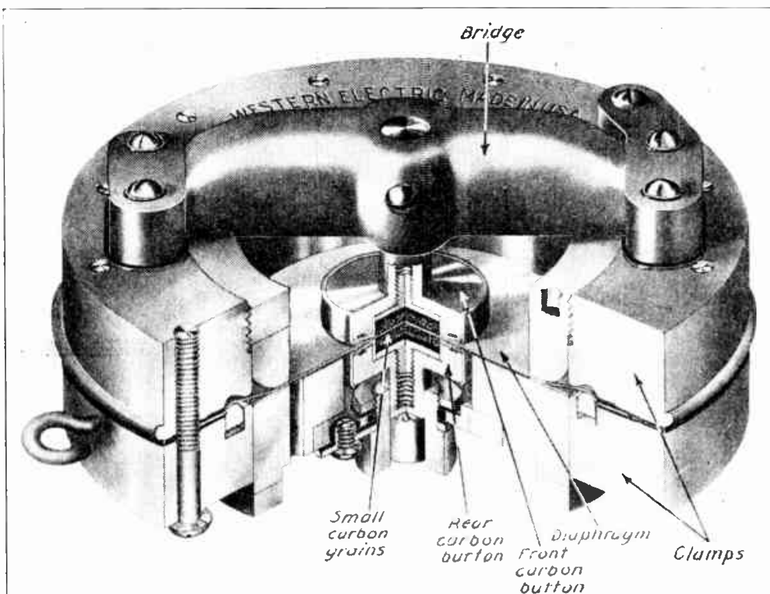

Fig. 10—Cutaway view of a double button microphone.

Referring to Fig. 8, let us assume that no sound is striking the microphone diaphragm. A steady current will then flow through the microphone from the battery and through the primary of the transformer. This is as shown in the left-hand portion of curve (b), Fig. 11.

Let us now assume that a pure tone from a tuning fork is produced in front of the carbon microphone. A sound wave such as would be represented by a sine wave will then strike the diaphragm of the microphone. This will cause pressure to be exerted on the diaphragm first in one direction and then in the other as is shown by curve (a) Fig. 11. This pressure upon the diaphragm first in one direction and then in the other as shown will cause the resistance offered by the carbon button to the passage of electric current to first decrease and then increase. The electric current which will flow through the circuit will then be as shown in curve (b) Fig. 11. This current will consist of an alternating component superimposed upon a direct component.

The effect of the alternating component flowing through the primary of the transformer will be to produce an alternating voltage in the secondary of the transformer as is shown by curve

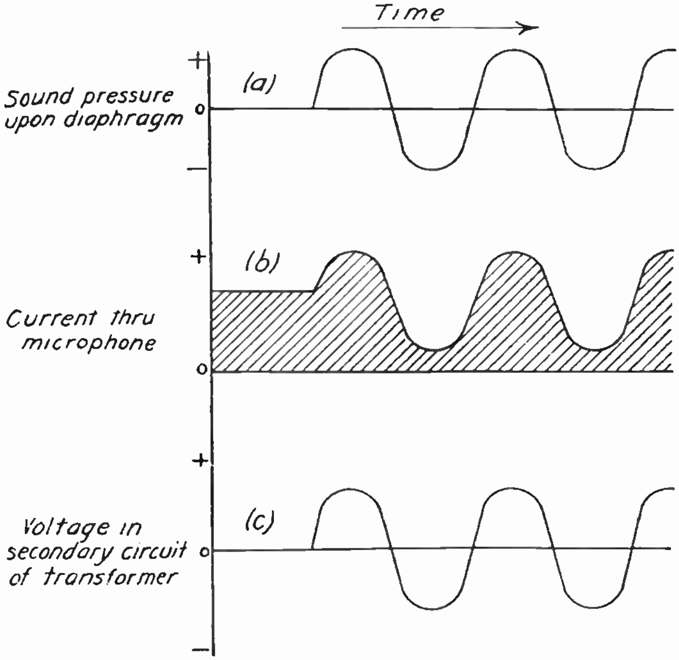

Fig. 11—Curves illustrating the conversion of sound to electric power using a single button carbon microphone.

(c) Fig. 11. The electric voltage generated in the secondary may be used to cause currents to flow over a wire line and to actuate a telephone receiver at the other end, or the voltage may be applied to a vacuum tube amplifier and its effect amplified.

If instead of a sound wave possessing the characteristics of a pure tone striking the diaphragm of the transmitter, we have complex sound waves such as would be produced by speech and music, then the alternating currents and voltages resulting will, if the system is operating properly, truthfully represent the complex waves which strike the microphone diaphragm. If, on the other hand, the system is not operating properly, then the electric currents and voltages produced by the sound wave will not truthfully correspond in wave form to the sound wave striking the diaphragm and distortion will result.

The theory of operation of the two-button microphone shown in Fig. 9 is identical with that of the single button microphone shown in Fig. 8, with the exception that now as the diaphragm vibrates back and forth, due to the effect of the sound wave striking it, it increases the resistance of the carbon button on one side and at the same time correspondingly decreases the resistance of the carbon button on the other, etc. The effect of this is shown graphically in Fig. 12, curve (b). The upper portion of curve (b) shows graphically the variation in current through the circuit connected to the rear button while the lower half of the curve shows the variation in current through the front button. During the part of the cycle when the resistance of the rear button is **decreasing** and the current through it **increasing**, the resistance of the front button is **increasing** and the current through it **decreasing**. The direction of winding of the transformer is such that the effects of the two buttons add and a voltage such as is shown in curve (c), Fig. 12, will be produced in the secondary circuit of the transformer.

While the operation of the single button carbon microphone such as is used in the ordinary telephone system depends upon the same principle as does the operation of the two-button microphone such as is used in broadcasting stations, the details of construction and the characteristics of the two types are entirely different. For instance, the amount of electric energy produced by the single button microphone is far greater than that produced by the two button. On the other hand, the distortion introduced by the single-button microphone is far greater than that introduced by the two-button microphone. Consequently, the single-button microphone as described can only be used satisfactorily for the transmission of speech, but it produces sufficient energy to permit the transmission of this speech by wire over considerable distance. On the other hand, the two-button microphone, because of its better frequency characteristics, will satisfactorily reproduce both speech and music, but because the amount of energy obtained from it is so much less than that from the single-button microphone, amplifiers must always be associated with it. Figure 13 shows a two-button microphone connected to the input of a two-stage amplifier. The voltage for the operation of the microphone is obtained from the filament battery. There are many other points which might be mentioned with respect to the characteristics of these two microphones. Inasmuch as we are now concerned primarily with the theory of operation of microphones and not with the details of their construction and practical operation, we will leave this subject for further consideration in later lessons designed to teach you the details of operation of modern broadcasting installations.

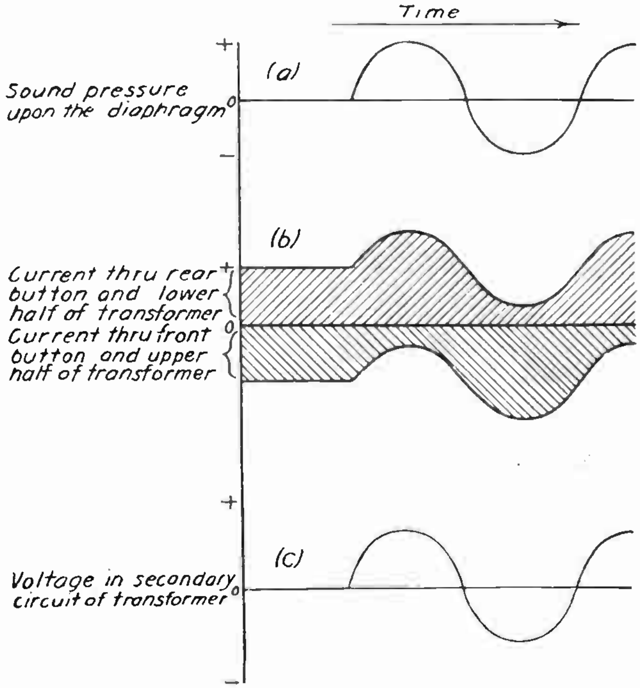

Fig. 12—Curves illustrating the conversion of sound power to electric power using a double button carbon microphone.

Carbon microphones are not the only devices which can be used to convert sound to electric energy. Another device which is enjoying increasing use in broadcasting station installations is the condenser transmitter. The condenser transmitter consists of a small block of metal called a back plate such as is shown in Fig. 14 in front of which is stretched very tightly a thin metal diaphragm. The front surface of the back plate must be as nearly plane as possible and the diaphragm must be stretched very tightly, as the diaphragm must be placed very close to the back plate although it must not touch it. This space between diaphragm and back plate is usually about .001 inch.

As can be seen from Fig. 14, one side of the 130-volt battery is connected to the diaphragm, while the other side is connected through an iron choke coil to the back plate. An electric potential of 130 volts will then exist between the back plate and the diaphragm. The back plate and diaphragm of the transmitter constitute two plates of a small condenser. A charge will, therefore, exist. Sound waves striking the diaphragm will cause it to move back and forth thereby varying the distance between the diaphragm and the back plate. This variation in distance between diaphragm and back plate results in a change in the capacitance of the condenser. As the diaphragm moves closer to the back plate, the capacitance increases, while during that half of the cycle when it moves away from the back plate, the capacitance decreases.

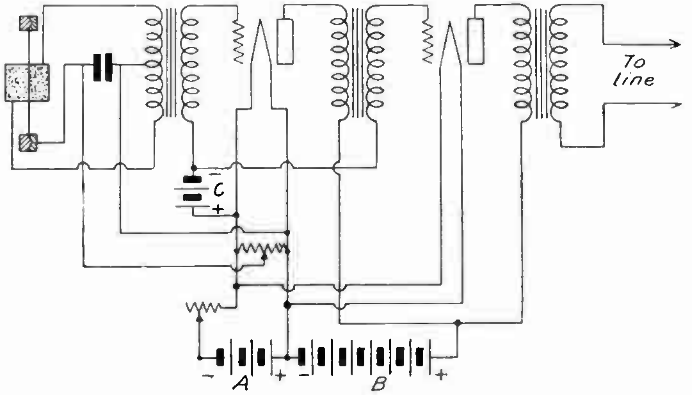

Fig. 13—Two button microphone connected to the input of a two stage amplifier.

The effect of the large iron choke coil is to oppose any change in current. The voltage across the condenser, the charge on the plates of a condenser, and capacitance of the condenser are always related by the formula—**charge = capacitance** times **voltage**. Algebraically, this equation is given as follows:

$$Q = c \times V \quad (1)$$

A change in the amount of charge upon the condenser plates can only result by a flow of current through the choke coil. The inductance of this coil is, however, so great that practically no current will flow through it at audio frequency. As the capacitance of the condenser increases due to motion of the diaphragm, towards the back plate, the voltage across the condenser must decrease since the charge remains constant. As the capacitance of the condenser decreases, due to motion of the diaphragm away from the back plate, the voltage across it must increase. In other words, the product obtained by multiplying capacitance by voltage must always be constant. If one increases, the other must decrease, etc.

As can be seen from Fig. 14, the condenser microphone, choke coil, and battery are so connected that the alternating voltage produced by the motion of the diaphragm is applied to the grid of the first tube of an audio-frequency amplifier. These voltages are then amplified and may be used to modulate a radiotelephone transmitter.

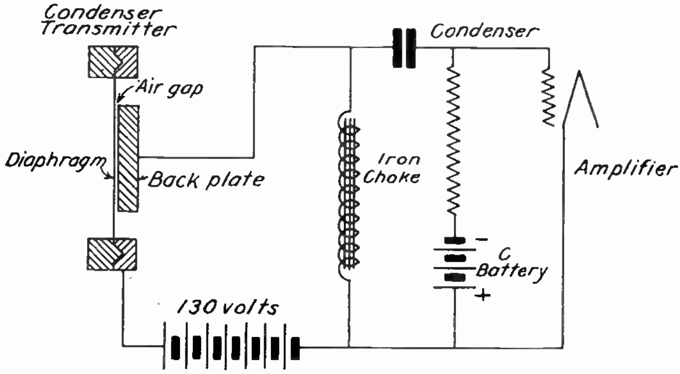

Fig. 14—Schematic circuit showing the use of a condenser transmitter.

The amount of electric energy produced from transmitters of this type is even less than that produced by the two-button carbon microphone. However, the frequency characteristics of a conversion system such as this are superior even to those of the two-button microphone and consequently, the condenser transmitter is particularly applicable to handling speech and music. It is, however, necessary to use more stages of amplification than with the ordinary two-button type.

There is one other device which should be discussed at this time although it is not used to convert sound waves directly to electric current. This is what is known as the magnetic pick-up. This device is used to convert energy mechanically from a phonograph record to electric energy which can then be amplified and used either to operate a loudspeaker or to modulate the output of a radiotelephone broadcasting set. Briefly described, the theory of operation of the magnetic pick-up is somewhat as follows: As the needle of the device traverses the channels cut upon the phonograph record, the motions imparted to it cause a small armature to move in a magnetic field. The motions of this armature in turn cause variations in the number of magnetic lines which link with a coil of wire. These in turn set up voltages in a coil of wire which correspond to the sound wave as recorded upon the record. The electric energy produced may then be amplified and used to operate a reproducer or to modulate a radiotelephone transmitter as the case may be.

As has been stated above, the electric energy obtained from either the two-button carbon microphone as used in broadcasting stations or from the condenser transmitter is so small that it must be amplified. Accordingly, these conversion devices are connected to the input terminals of multi-stage vacuum tube amplifiers known as **input** amplifiers.

Fig. 13 is a schematic circuit diagram showing how a two-button carbon microphone might be connected to the input terminals of a two stage vacuum tube amplifier. This is not meant to be a working diagram but only to illustrate the theory of operation of the microphone and amplifier. A practical amplifier would have to have associated with it a device for controlling the **amplification** or **gain** of the device. Detailed information concerning input amplifiers, mixing systems, volume indicators, signalling systems, and monitoring systems will be given in a later lesson devoted to the operation of practical broadcast equipment.

THE TRANSMISSION UNIT AND ITS USE

In the first part of this lesson we have studied in some detail the nature of sound, particularly such sounds as are produced by the human voice and by musical instruments. We have considered the range of frequencies to which the human ear is ordinarily sensitive. We have also considered and discussed the small amounts of power which are involved in sound waves. We have found that **amplitude** determines **loudness, frequency** determines **pitch** and that the relative amounts of energy in fundamental and harmonics determine **quality** or **timbre.** Sound waves as ordinarily received by the human ear travel through air with a velocity of 1080 feet per second at ordinary room temperature. In radio broadcasting stations, it is essential that the energy contained in sound waves be converted to electric energy so that it may be used to modulate the output of the high frequency transmitting device. We have now reached a stage in our discussion where we must digress from the consideration of fundamental principles and discuss methods of measuring the electric power resulting from the operation of the microphone and the apparatus associated with it.

You are undoubtedly quite familiar with the general terms used in the measurement of electric power, potential and current in electric power systems such as are used for house lighting. Electric pressure is measured in volts. Electric current is measured in amperes. Power is measured in watts. Energy delivered to a house is measured in watt-hours. These are all comparatively familiar terms and it might seem that in referring to the power produced by a microphone, the power delivered to a telephone line by an amplifier, etc., that we might speak in terms of watts or some sub-multiple such as the microwatt (millionth

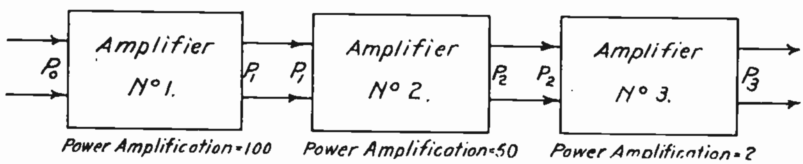

Fig. 15—Block diagram showing three amplifiers connected in series.

watt). For instance, we might say that a carbon microphone produces 10 microwatts of electric power, an amplifier delivers .5 watt to a line, or a loudspeaker requires 25 watts to produce satisfactory volume in a given room. Although this might seem a logical course of procedure, as a matter of fact, an entirely different set of nomenclature and an entirely different way of expressing the characteristics of amplifying apparatus, etc., has been developed. There are, as you will find after having had some experince with this new system, certain very decided advantages which it holds as compared with the system used in connection with power apparatus. The new system which we are about to describe in some detail is known as the Transmission Unit System, commonly known as the TU. Recently the term "Decibel" or "DB" was adopted by nearly all countries for use instead of TU. Wherever TU occurs in place of DB in older writings they are interchangeable as the values are the same.

TRANSMISSION UNIT OR DECIBEL

Let us assume that we connect a microphone to the input of the three amplifiers shown in Fig. 15 and that a given amount of sound power is then delivered to the microphone. Let us assume that this power (P_o) is 1 microwatt, (.000,001 watt). Let us further assume that the power output of the first amplifier (P_1) is 100 microwatts, of the second amplifier (P_2) 5000 microwatts and of the third amplifier (P_3) 10,000 microwatts.

The power amplification factor for the first amplifier can be obtained by dividing the power output (P_1) by the power input (P_o), or

$$\text{Factor for amplifier No. 1 } (F_1) = \frac{P_1}{P_o} = \frac{100}{1} = 100 \qquad (1)$$

$$\text{Factor for amplifier No. 2 } (F_2) = \frac{P_2}{P_1} = \frac{5000}{100} = 50 \qquad (2)$$

and

$$\text{Factor for amplifier No. 3 } (F_3) = \frac{P_3}{P_2} = \frac{10,000}{5,000} = 2 \qquad (3)$$

Suppose now we wish to obtain the power amplification factor for the entire combination. This is given as follows:

$$\text{Factor for all three } (F_{1+2+3}) = \frac{P_3}{P_o} = \frac{10,000}{1} = 10,000 \qquad (4)$$

This may be obtained from the individual amplification factors by multiplying them together.

$$(F_{1+2+3}) = 100 \times 50 \times 2 = 10,000 \qquad (5)$$

We must now turn our attention to certain algebraic expressions which are called **logarithms**. If a number is multiplied by itself, we say that the number has been squared. Thus 4 is the square of 2 since $2 \times 2 = 4$. This is sometimes written 2^2 which is read "2 to the second power." If we multiply the number by itself again, we have $2 \times 2 \times 2 = 8$. This may be written 2^3, that is "2 to the third power." Likewise, $2 \times 2 \times 2 \times 2 = 2^4 = 16$ and $2 \times 2 \times 2 \times 2 \times 2 = 2^5 = 32$, and so on.

Now let us consider the number 10.

$10^1 = 10$ (10 to the first power is 10).
$10^2 = 10 \times 10 = 100$ (10 to the second power is 100).
$10^3 = 10 \times 10 \times 10 = 1000$ (10 to the third power is 1000).
$10^4 = 10 \times 10 \times 10 \times 10 = 10,000$ (ten to the fourth power is 10,000), etc.

Now the logarithm of a number is the power to which 10 must be raised to obtain the number. Thus, the logarithm of 10 is 1 since $10^1 = 10$; the logarithm of 100 is 2 since $10^2 = 100$, and the logarithm of 1000 is 3 since 10^3 is 1000, etc., etc. Now, if the logarithm of 10 is 1 and the logarithm of 100 is 2, then the

TABLE NO. 1

LOGARITHM TABLE

Numbers 1 to 100

No. Logarithm	No. Logarithm	No. Logarithm	No. Logarithm	No. Logarithm
1—0.000	21—1.322	41—1.612	61—1.785	81—1.908
2—0.301	22—1.342	42—1.623	62—1.792	82—1.913
3—0.477	23—1.362	43—1.633	63—1.799	83—1.919
4—0.602	24—1.380	44—1.643	64—1.806	84—1.924
5—0.698	25—1.398	45—1.653	65—1.813	85—1.929
6—0.778	26—1.415	46—1.663	66—1.819	86—1.934
7—0.845	27—1.431	47—1.672	67—1.826	87—1.939
8—0.903	28—1.447	48—1.681	68—1.832	88—1.944
9—0.954	29—1.462	49—1.690	69—1.839	89—1.949
10—1.000	30—1.477	50—1.698	70—1.845	90—1.954
11—1.041	31—1.491	51—1.707	71—1.851	91—1.959
12—1.079	32—1.505	52—1.716	72—1.857	92—1.964
13—1.114	33—1.518	53—1.724	73—1.863	93—1.968
14—1.146	34—1.531	54—1.732	74—1.869	94—1.973
15—1.176	35—1.544	55—1.740	75—1.875	95—1.978
16—1.204	36—1.556	56—1.748	76—1.881	96—1.982
17—1.230	37—1.568	57—1.758	77—1.886	97—1.987
18—1.255	38—1.579	58—1.763	78—1.892	98—1.991
19—1.278	39—1.591	59—1.770	79—1.898	99—1.996
20—1.301	40—1.602	60—1.778	80—1.903	100—2.000

logarithm of a number between 10 and 100 must be some number between 1 and 2. For instance, it can be proven that the logarithm of 20 is 1.301; this is written—

$$\log 20 = 1.301 \tag{6}$$

Similarly, it can be proven that—

$$\begin{aligned} \log 40 &= 1.602 \\ \log 60 &= 1.778 \\ \log 80 &= 1.903 \end{aligned} \tag{7}$$

and so on. Note that we have not derived the above equations. While it is, of course, possible to derive the expressions for the logarithms of numbers, the mathematical processes are so long that tables known as **logarithm tables** have been published. These can be used to obtain the logarithms of numbers to a high degree of accuracy. Some of these carry the decimal as far as seven places.

Table 1 gives the logarithms for all numbers from 1 to 100, to the third decimal place. Note that the logarithm for any number between 1 and 10 lies between 0 and 1, while the logarithm for any number between 10 and 100 lies between 1 and 2. Note also that while the logarithm of 2 is 0.301, the logarithm of 20 is 1.301. Similarly, the logarithm for 200 would be 2.301 and for 2000 it would be 3.301, etc. Thus, if we know the log for any figure between 10 and 100, we can easily calculate the logarithms of any number obtained by adding zeros to this number. Thus, the logarithm of 45 is 1.653.

$$\begin{aligned} \log 450 &= 2.653 \\ \log 4500 &= 3.653 \\ \log 45{,}000 &= 4.653 \\ &\text{etc.} \end{aligned} \tag{8}$$

In a logarithm, the figure to the left of the decimal point is called the **characteristic** while the figures to the right make up the **mantissa.** Thus 4 is the **characteristic** of the log of 45,000 while 653 is the **mantissa.** Logarithm tables usually give only the mantissa.

Logarithms are very useful in solving certain kinds of mathematical problems. If you are interested in them you would find it well worth while to obtain a copy of a book on algebra and to read the chapters on logarithms. We are concerned with logarithms in this lesson because the **gain** and **loss** characteristics of amplifiers, lines and apparatus used to transmit speech and music are measured in terms of units which can be calculated **only** by the aid of logarithms.

The **Decibel** method of expressing the characteristics of speech and music transmission apparatus is based upon the logarithms of power ratios. (By power in this case, we usually mean electric power.) The gain in Decibels or **DB,** as they are called, introduced by an amplifier, is **obtained by taking the logarithm of the ratio of the POWER OUTPUT of the amplifier to the POWER INPUT and multiplying this logarithm by 10.** The mathematical expression for this is:

$$\text{DB gain} = 10 \log \frac{\text{P (output)}}{\text{P (input)}} \tag{9}$$

The ratio of power output to power input for amplifier No. 1 as shown in Fig. 15 is 100, the logarithm of 100 is 2, and

$10 \times 2 = 20$. The gain in DB introduced by this amplifier is 20 DB. Mathematically, this may be written:

$$\text{DB gain for amplifier No. 1} = 10 \log \frac{P_1}{P_0} = 10 \log \frac{100}{1} = 20 \tag{10}$$

Similarly—

$$\begin{aligned}\text{DB gain for amplifier No. 2} &= 10 \log \frac{P_2}{P_1} = 10 \log \frac{5000}{100} \\ &= 10 \log 50 \\ &= 10 \times 1.698 \\ &= 16.98\end{aligned} \tag{11}$$

(The logarithm of 50 can be obtained from Table 1 or from Fig. 16.)

Now 16.98 is approximately 17, so we would probably say that the gain introduced by this second amplifier is 17 DB. Also

$$\begin{aligned}\text{DB gain for amplifier No. 3} &= 10 \log \frac{P_3}{P_2} = 10 \log \frac{10{,}000}{5{,}000} \\ &= 10 \log 2 \\ &= 10 \times .301 \\ &= 3.01\end{aligned} \tag{12}$$

or since 3.01 is approximately 3, we would say the gain introduced by the amplifier No. 3 is approximately 3 DB.

Let us now consider the three amplifiers together. The total power amplification as a whole is $\frac{P_3}{P_0} = \frac{10{,}000}{1}$ or 10,000. To obtain this factor from the power amplification factors for the three individual amplifiers, we must **multiply** them together.

$$\begin{aligned}&\text{Factor for No. 1} = 100 \\ &\text{Factor for No. 2} = 50 \\ &\text{Factor for No. 3} = 2 \\ &\text{Factor for three amplifiers in series} = 100 \times 50 \times 2 = 10{,}000\end{aligned} \tag{13}$$

Now the DB gain for the combination of the three amplifiers is computed as follows:

$$\text{DB gain} = 10 \log \frac{10{,}000}{1} = 10 \log 10{,}000 = 10 \times 4 = 40 \tag{14}$$

Since the logarithm of 10,000 is 4 as we have seen. Now note how we obtain the gain in DB for the three amplifiers used together making use of the DB gain for each individual amplifier.

Gain introduced by Amplifier No. 1 = 20 DB
Gain introduced by Amplifier No. 2 = 17 DB (15)

Gain introduced by Amplifier No. 3 = 3 DB
Gain introduced by combination of three amplifiers = 40 DB

You can, therefore, see that by the use of logarithms we have substituted **addition** for **multiplication.** To obtain the power amplification factor for a series of amplifiers, the factors for the individual amplifiers must be **multiplied** together. To obtain the DB gain for a series of amplifiers, the DB gains for the individual amplifiers must be **added** together. I think you can now begin to see some of the advantages of the DB system of expressing gain and loss.

The three amplifiers such as are shown in Fig. 15 are presumably so located that the power output of amplifier No. 1 is equal to the power input of amplifier No. 2 and the power output of Number 2 is equal to the input of Number 3. This would not be the case in the event the amplifiers were separated by appreciable distances. For instance, amplifier No. 1 might be at a baseball park from which it is desired to broadcast a description of a World Series game. No. 2 might be in a studio control room three or four miles away, while No. 3 might be at the radio transmitter fifteen or more miles from the studio. With such an arrangement, power losses would take place in the lines connecting these three points.

Fig. 17 illustrates graphically the situation which might exist. Figures given on the diagram show average power levels at particular points throughout the system. Thus the average input power to amplifier No. 1 is 1 microwatt, its output 100 microwatts. The attenuation of Line No. 1 connecting the output of amplifier No. 1 with the input of amplifier No. 2 is such that the input power to amplifier No. 2 is only 20 microwatts. The power amplification factor for amplifier No. 1 is therefore $\frac{100}{1} = 100$. This factor is obtained by dividing the power **output** by the power **input.**

The **attenuation** factor for Line No. 1 is obtained by dividing the power **input** to the line by the power **output** from the line. The power **input** to Line No. 1 is the power delivered to it by

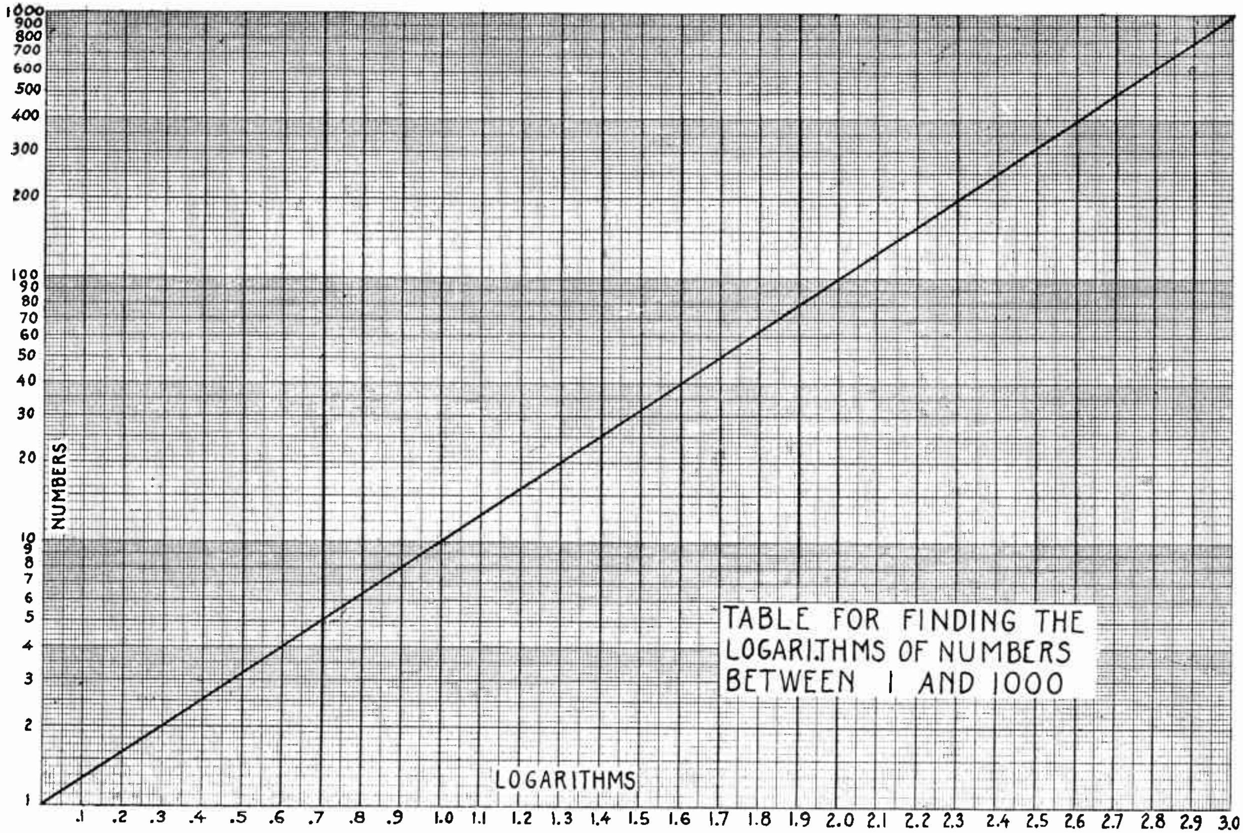

Fig. 16—Graph for producing the logarithms of numbers between 1 and 1000.

amplifier No. 1 which is 100 microwatts. The power output from Line No. 1 is the power the line delivers to amplifier No. 2 which is 20 microwatts. The attenuation factor for Line No. 1 is therefore $\frac{100}{20} = 5$.

The **loss** in DB introduced by a line or any piece of apparatus which introduces attenuation is calculated in exactly the same way as **gain** except that the logarithm of the ratio of the power **input** to the power **output** is used instead of the ratio of the power **output** to the power **input**. Thus, the loss introduced by Line No. 1, Fig. 17, is obtained by taking the logarithm of $\frac{100}{20}$ and multiplying it by 10

$$\begin{aligned}\text{Loss in DB (Line No. 1)} &= 10 \log \frac{100}{20} \\ &= 10 \log 5 \\ &= 10 \times .698 \\ &= 6.98 \\ &= 7 \text{ approximately}\end{aligned} \tag{16}$$

In exactly the same way, the loss introduced by Line No. 2 may be calculated.

Suppose now that we desire to find the total **gain** or **loss** due to the combination of lines and amplifiers between microphone and the output of amplifier No. 3. We first add the **gains** in DB, then separately add the **losses** in DB. If the sum of the **gains** exceeds the sum of the losses, then we obtain the total amplification by subtracting the losses from the gains.

Loss Line No. 1 = 7 DB
Loss Line No. 2 = 20 DB
Total Loss = 27

Gain Amplifier No. 1 = 20 DB
Gain Amplifier No. 2 = 17 DB
Gain Amplifier No. 3 = 3 DB

Total Gain = 40 DB
Less 27 DB

Total gain in system = 13

The graph shown in Fig. 18 provides a very convenient method for obtaining gain or loss in DB from power ratios or for obtaining the power ratios from gain or loss in DB. It can be proven that if the input impedance of an amplifier is equal to the impedance of the load across the output, the gain in DB introduced is given by

$$\text{Gain in DB} = 20 \log \frac{\text{I out}}{\text{I in}} \tag{17}$$

in which I out is the alternating current delivered to the load and I in is the alternating input current. Also, it can be proven that under the same condition

$$\text{Gain in DB} = 20 \log \frac{\text{E out}}{\text{E in}} \tag{18}$$

in which E out is the alternating voltage across the output and E in is the alternating voltage across the input. Curve 1, Figure 18, is for use with power ratios while Curve 2 is for use with current or voltage ratios.

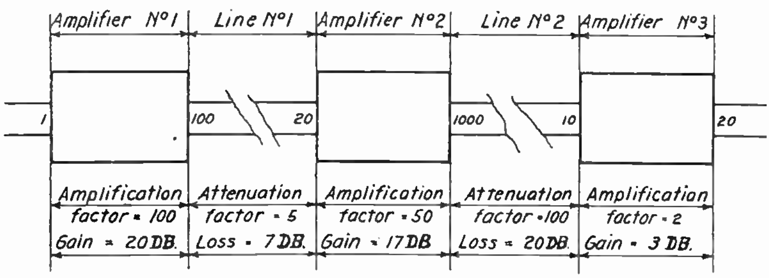

Fig. 17—Graphic representation of Decibel system including amplifiers introducing gain and lines introducing losses.

REFERENCE VOLUME

We have discussed the Transmission unit or Decibel System as applied to the measurement of gain and loss. In other words, we have used this system to describe the characteristics of amplifiers, apparatus and lines. In our discussions, we have assumed that the energy amplified has been uniform in character such as might be the case if the electric voltage applied were a combination of pure sine waves all of constant amplitude. We may also use the Decibel System as a means of expressing **power level.** If the energy under discussion consists of pure sine waves of constant amplitude, then the amount of power involved is a very definite and constant quantity. If on the other hand we are concerned with the electrical energy produced by a broadcast program consisting of speech and music, then the amount of power involved varies over a very wide range. The amount of power may be very small during a soft passage in the musical scale but may be many times this during some of the louder passages. In specifying the amount of power involved in a broadcast program, we usually mean an approximate average value, the measurement of which will be described later when we discuss volume indicators.

Let us select a specific amount of power for reference purposes. This power we will call **reference** volume. Ordinarily, 1 milliwatt (.001 watt) is referred to as reference volume. All other powers can be referred to as so many DB above or below **reference volume.** Thus, a power of 10 milliwatts (.01 watt) may be referred to as a volume 10 DB above reference volume. This can be determined from the curve shown in Fig. 18 or from the formula—

$$\begin{aligned}\text{Volume} &= 10 \log \frac{10 \text{ milliwatts}}{1 \text{ milliwatt}} \\ &= 10 \log 10 \\ &= 10 \times 1 \\ &= 10 \text{ DB above reference volume}\end{aligned} \tag{19}$$

In a like manner, the volume represented by .1 milliwatt (.0001 watt) would be calculated from the formula—

$$\begin{aligned}\text{Volume} &= 10 \log \frac{1 \text{ milliwatt}}{.1 \text{ milliwatt}} \\ &= 10 \times \log 10 \\ &= 10 \times 1 \\ &= 10 \text{ DB below reference volume}\end{aligned} \tag{20}$$

You will note that we refer to powers greater than reference volume as so many DB **above** reference volume and powers less than reference volume as so many DB **below** reference volume. In our computations for power above reference volume, we take the ratio of the power in question to the power corresponding to reference volume (1 milliwatt), while in computations where power is less than reference volume, we take the ratio of the power corresponding to reference volume to the power in question as shown by equations 20 and 21, respectively. 10 DB above reference volume is often written + 10 DB, 10 DB below reference volume is often written — 10 DB.

On the basis of the information given in the paragraph above, let us compute the **power levels** existing at various points

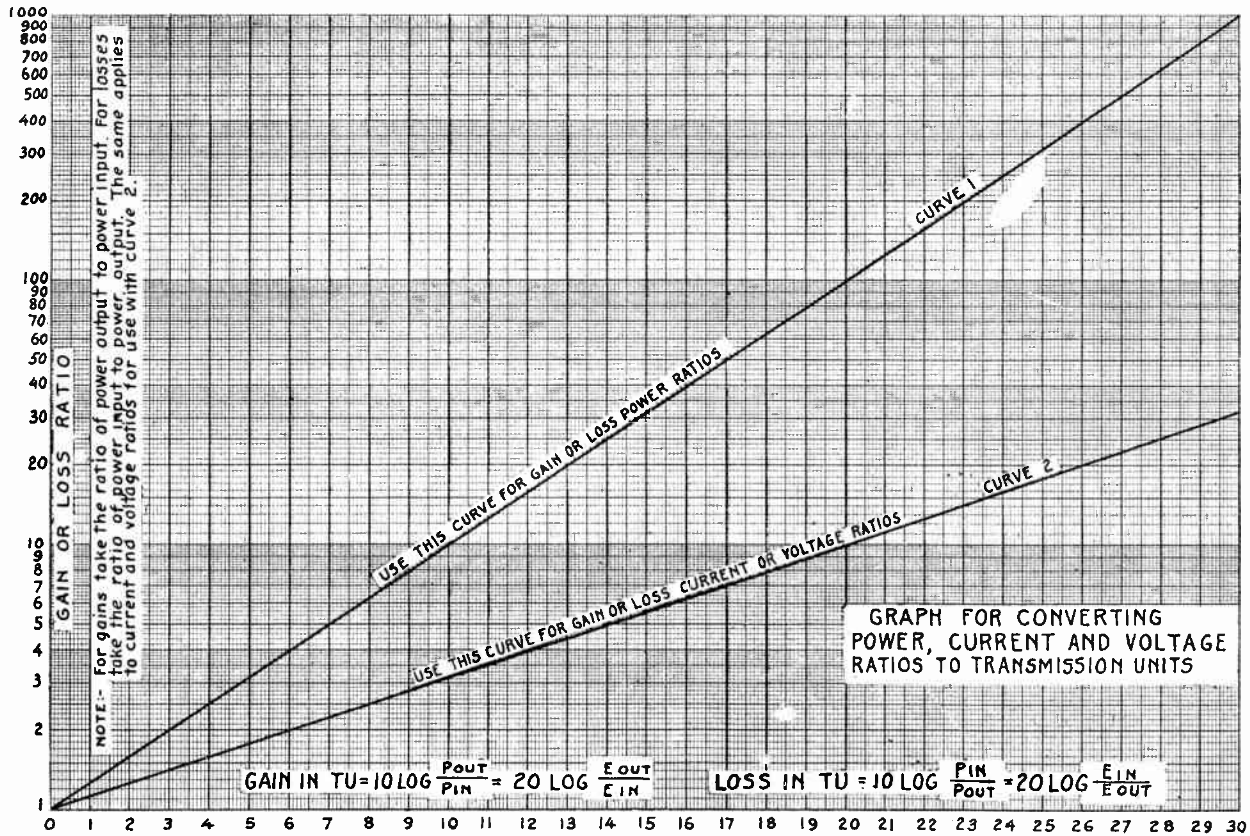

Fig. 18—Graph for converting power, current and voltage ratios to transmission units. TU or DB.

in our amplifier system as shown in Fig. 17. The results are shown in a following table.

1 microwatt	=	30 DB below reference volume (—30 DB)
100 microwatts	=	10 DB below reference volume (—10 DB)
20 microwatts	=	17 DB below reference volume (—17 DB)
1000 microwatts	=	0 DB or reference volume

The following table shows the volume level for a number of powers using .001 watt as reference volume. (Note: 1 milliwatt = .001 watt, 1 microwatt = .000,001 watt.)

Power in microwatts	Power in milliwatts	Level
1	.001	—30 DB
10	.01	—20 DB
100	.1	—10 DB
1,000	1	0
10,000	10	+10 DB
100,000	100	+20 DB
1,000,000 (1 watt)	1000	+30 DB

USEFUL CONSTANTS APPLICABLE TO SPEECH INPUT EQUIPMENT

We are now prepared to understand and make use of certain constants with respect to speech and music and apparatus designed to handle them. The information contained in the following paragraphs has been gleaned from several sources but mostly from articles published by members of the Bell Telephone organization. The engineers of this organization, because of their extensive studies with respect to the transmission of speech and music, have probably contributed more to the knowledge of mankind on this subject than any other group.

The range of audibility may be said to extend from about 20 to 20,000 cycles. This range, as has been pointed out, varies with individuals.

If a transmission system is to handle only those frequencies necessary for the transmission of intelligible speech, then only the band of frequencies lying between 200 and 2000 cycles need be accommodated. The "naturalness" of the voice will, however, to a certain extent be lost if this band only is accommodated.

The fundamental frequencies produced by the human voice and by musical instruments lie approximately between 30 and 4,000 cycles. However, some of the harmonics generated lie above 10,000 cycles per second. The faithful reproduction of speech and music requires provision for a band of frequencies lying between 30 and 10,000 cycles. However, fairly satisfactory fidelity will result if the band lying between 50 and 5,000 cycles is satisfactorily accommodated. Most broadcast installations and the lines connecting them are engineered to accommodate the band lying between 50 and 5,000 cycles.

The average human ear is most sensitive to sounds having a frequency lying between 2,000 and 4,000 cycles per second. For this frequency, the approximate minimum sound power which will produce the sensation of sound is .0,000,000,000,004 milliwatt per square centimeter. This is a power level approximately 124 DB below reference volume (assuming reference volume to be one milliwatt).

The ratio of the amount of sound power produced by an orchestra playing very loudly to the sound power produced while playing some of the softer portions of a selection is very great. The loud portions possess 30,000 times the power possessed by the soft portions. That is to say, the difference in level is approximately 45 DB. The average electric power output from a two-button carbon microphone such as is used for broadcasting is about 10 milliwatts (10 DB above reference volume) for a speaker close to the microphone and about .001 milliwatt (30 DB below reference volume) if the speaker is five feet away. The output from a condenser transmitter under similar circumstances will be considerably less.

TEST QUESTIONS

Number your answers 30—2 and add your **Student Number.**

1. State at what frequencies the human ear is most sensitive.
2. How are sound waves produced?
3. What is the function of a microphone in a Broadcasting Station?
4. Draw a circuit diagram showing the connections for a single button microphone.
5. What is the advantage and disadvantage of a single button microphone?
6. Name several devices which can be used to convert sound waves to electric current.
7. Draw a circuit diagram showing a double button microphone and 2-stage amplifier.
8. Upon what does the loudness, pitch and quality or timbre of musical sounds depend?
9. Explain the action of a magnetic pick-up.
10. What unit is used for expressing transmission loss or gain (amplification)?

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History, Development and Its Application to Modern Life

From the very first day, June 2, 1896, that Marconi made known his early discoveries of sending messages through space without wires, to the present day, there has been a feeling of awe and mystery in Radio communications. It is beyond the untrained mind to understand how such wonders as messages traveling through ether are performed. But the student who has studied the elements of Radio is as well aware how this transmission takes place as the ordinary person when he sees the transfer of disturbance in water due to dropping a stone into it.

The properties and characteristics of the electromagnetic (wireless) waves are as realistic to you as the water waves are to everybody. Radio Telegraphy is no longer a mystery to you and the art of sending speech by Radio will be made as simple and easy as addition and multiplication were during your early school days.

It was only a few years after Radio Telegraphy was put into practical use that the scientists in all countries began a study of Radio speech transmission. The most notable among these were Marconi, Fessenden, De Forest, Heising, Wm. C. White, E. H. Colpitts, Bancroft Gerhardi, Doctor Jewett, H. D. Arnold and Meissner. However, the strength of vibrations required to reproduce the sound of the human voice was so infinitely more complex than making the dots and dashes that the task demanded a longer time in development for practical operation.

It has been the ambition and dream of many a scientist to be able to pick up an ordinary telephone transmitter, talk into it and propagate the spoken words through the ether a distance of a thousand miles or more. How to do this was another story.

Dr. Lee De Forest was probably the first to present a workable Radio telephone equipment, which was tested out about the year 1912. This was made possible through the use of his new invention, the three-element vacuum tube, which has helped so much in the recent progress of speech amplification.

The possibilities of Radio Speech communication were realized by the American Telephone experts, but the successful solution of the problem would require a powerful organization of skilled workers with modern radio equipment and a strong financial backing.

The Bell Telephone organization, headed by John J. Carty, turned its attention to the problem of long distance speech transmission by Radio. The glory of spanning the Atlantic Ocean was sought by the American engineers. Mr. Carty and his staff started the work in a very quiet but effective manner. A small experimental tower was built at Montauk Point, Long Island, and another was borrowed at Wilmington, Delaware.

The tests were successful and the stations could talk freely with each other. Soon they expanded the distance to over 1,000 miles from Montauk Point to St. Simons Island, Georgia. "Do it first and then talk about it" was the maxim of Theodore Vail, president of the Bell organization.

It was on the 29th of September, 1915, that Carty conducted the demonstrations that thrilled the world and showed that Radio Telephony was an accomplished fact. Sitting in his New York office, Theodore Vail spoke into his desk telephone. The wires carried his words to the big Navy Radio Station at Arlington, Virginia, where they were delivered to the sending apparatus of the new Radio Station.

Leaping into space, they traveled in every direction through ether. The antenna wires of the Radio Station at Mare Island, California, caught part of the waves and these were amplified. John J. Carty could then hear his associates talk across the continent without wires. Still more wonderful distances were to be covered. Early next morning other messages were sent from the Arlington towers which were heard by Lloyd Espenschied, one of Carty's engineers, who was stationed in the Radio Room at Pearl Harbor near Honolulu, Hawaii. The distance covered being about 5,000 miles.

By the latter part of October all was in readiness for a transatlantic test, and on the 20th of October American engineers with American apparatus installed at the great French station at Eiffel Tower, Paris, heard the words spoken at Arlington, Virginia. The Atlantic was bridged and the glory came to the American engineer. Because of war conditions (The World

War—Germany, France, Italy, England and the United States) extended tests could not be carried on regularly.

In order to show the effective service which might be rendered by long wire and distance Radio Telephony in time of need, the Navy Department at Washington, D. C., in May, 1916, was placed in communication with every navy yard and port in the United States.

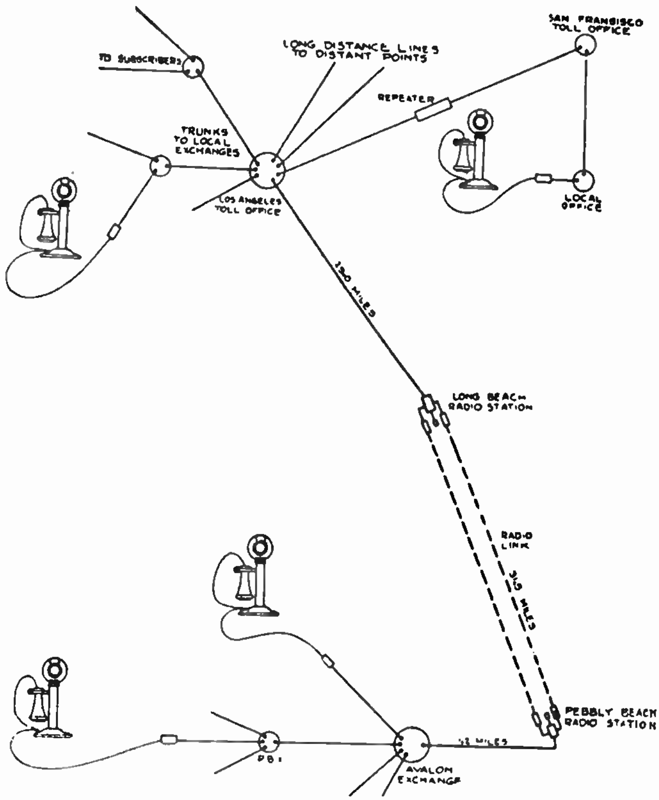


Fig. 1. Pictorial Diagram of Avalon-Los Angeles Circuit.

The Secretary of Navy can now instantly talk with those in charge of the posts throughout the country as well as our battleship commanders at sea. The development of the Radio phone since 1915 has been enormous, and it seems almost as simple as our regular wire telephone. The transmission of speech and music has passed the experimental stage and the results of this apparatus can be relied upon to render effective service at all times. Let us think for a moment where the Radio has made it possible for communication: First, ship to ship;

second, ship to shore; third, ship to submarine; fourth, between submarines; fifth, between shore and aeroplanes; sixth, between mainland and a small island; seventh, in thickly wooded sections; eighth, in certain types of region where telephone lines cannot be built or maintained; and ninth, between trains and fixed stations.

Moving vehicles, as repair wagons and taxicabs have been equipped with radio receivers in order to receive instruction regarding the next place for service. Special types of transmitters and receivers have been designed for each class of service stated above.

For example, a very light and compact form of transmitter and receiver was designed for use on aeroplanes during the World War. Many submarine sets are also in constant use. High power Radiophone sets have recently been installed on many of our battleships. The Catalina Long Beach Radio-Telephone Link is one of the early adaptations of Land Line service and Radio combined. By means of a 30-mile radio link between the coast of Southern California and Catalina Island it is possible for any telephone subscriber anywhere on the Bell system to call any subscriber on the island.

Figure 1 is a pictorial diagram of this system, and both stations may send and receive at the same time without interference, one using a 470-meter wave, while the other uses a 400-meter wave.

Figure 2 shows the sending and receiving circuit for each station and illustrates how the radio energy is transferred to the telephone lines. A loop antenna, 6 feet square with five turns, is used for receiving. This is a practical application of communication from a telephone subscriber to a second subscriber where a part of the span is accomplished by Radio.

It might as well be a passenger on the ocean, a person in a dirigible balloon or a person on a fast moving express train. The results are equally well secured. The use of the Radio Telephone transmitter for broadcasting valuable information, for the farmer, is proving very helpful. This service is maintained through the Government Post Office Department.

The largest and most popular use of Radio Telephony is for the sending out of news, speeches, sermons, musical concerts, weather reports, stock quotations, baseball results, etc. This is being done by many stations and there is hardly a time or place when one cannot pick up his radio receiver and tune into this interesting form of amusement.

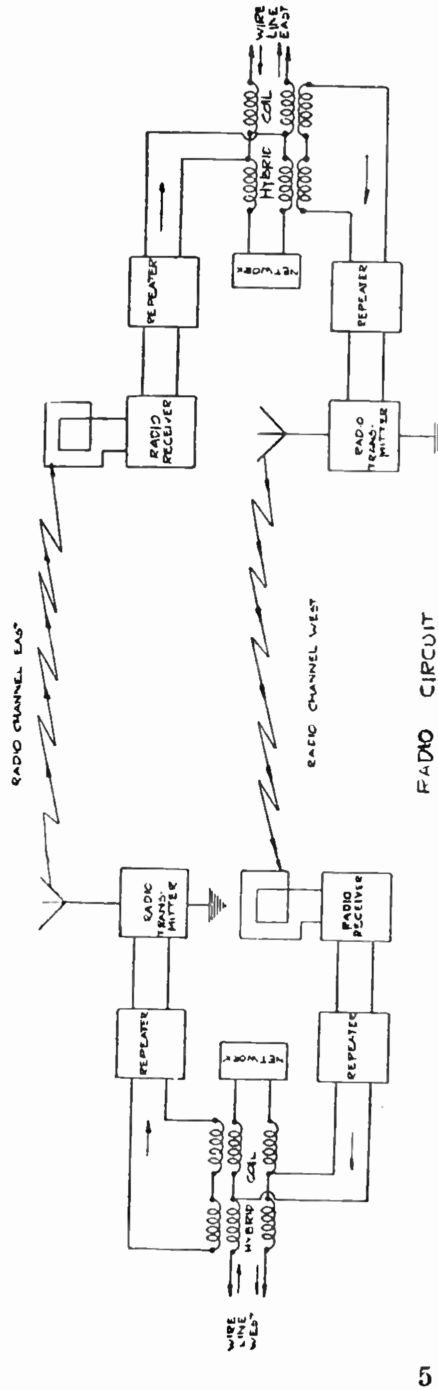


Fig. 2 Receiving and Transmitting Circuits.

Elements of a Telephone System.—The essentials of a telephone system are very similar to those of a simple telegraph system. An electric current is used to reproduce the human voice or any sound wave instead of the dot-and-dash signals used in telegraphy. To do this requires that the electric current be varied in a manner which imitates the sound waves and is able to reproduce them. The essential parts of a telephone system are: (a) A battery or other source of direct current; (b) a device, called the microphone transmitter by means of which sound waves cause corresponding variation of an electric current; (c) a device, called the telephone receiver, for changing the electric current variation back into corresponding sound waves; and (d) a conducting line connecting the two points in communication. These are shown in Fig. 3.

Modulating Device. — The device by means of which sound vibrations cause corresponding variation of an electric current is usually the carbon microphone transmitter. The action of this transmitter is based on the fact that the resistance of carbon varies with a variation of the pressure exerted upon it. The sound waves are made to cause a variation in pressure upon the carbon and hence cause a variation in resistance of the carbon. Figures 4, 5 and 6 illustrate the details of this action. A variable resistance causes a variable current and hence the current variation corresponds to the sound waves upon the transmitter diaphragm.

Telephone Receiver.—The device by means of which variation in the electric current reproduces the corresponding sound waves is the telephone receiver. Although made in several forms. the essential parts of all forms are very similar.

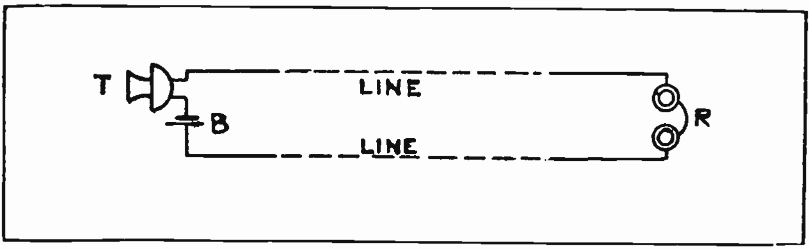


Fig. 3—Essentials of a Telephone System

Conducting Line Used in Telephony.—The circuit of a telephone line consists of a wholly metallic circuit made of wire of good conductivity. A ground return is not usually used, for it has been found that the very small stray currents existing in the earth affect the telephone receiver and thus make the line "noisy." The two wires of this circuit are always transposed, that is, they are made to cross each other at intervals as shown in Fig. 7A. This is done for the purpose of neutralizing any electromagnetic field, from adjoining telephone wires or other source, in the transposed wire. The wire used locally at telephone stations, the wire making a circuit in cables, and the wire used throughout the telephone system of a field army is a twisted pair. This is shown in Fig. 7B and gives the best kind of transposition. In many telephone lines coils of wire wound on iron cores are inserted in the line. These are called "loading coils" and introduce lumped inductance in the line. The use of loading coils properly placed on a line improves the transmission of the telephone current.

It is of vital importance that the modern radio engineer of the present time have an accurate and fundamental knowl-

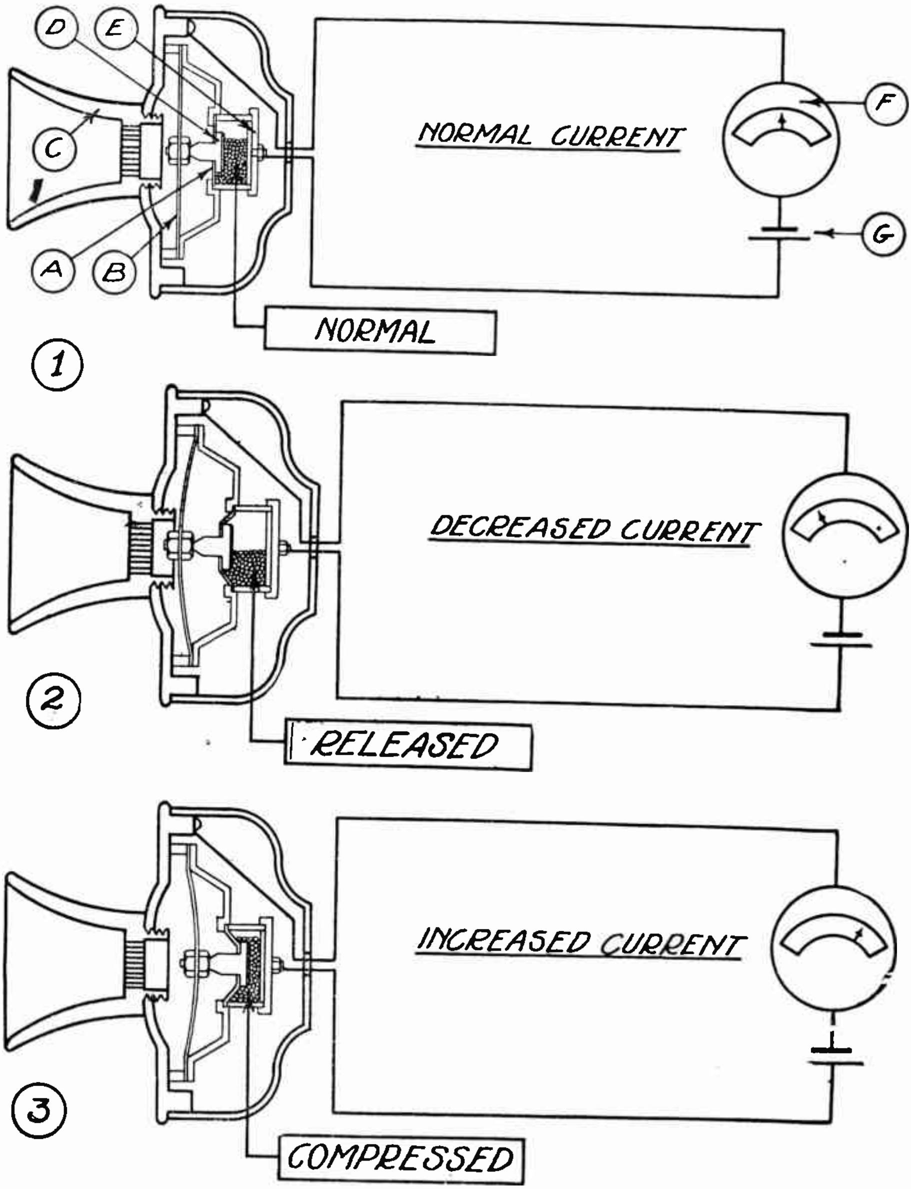
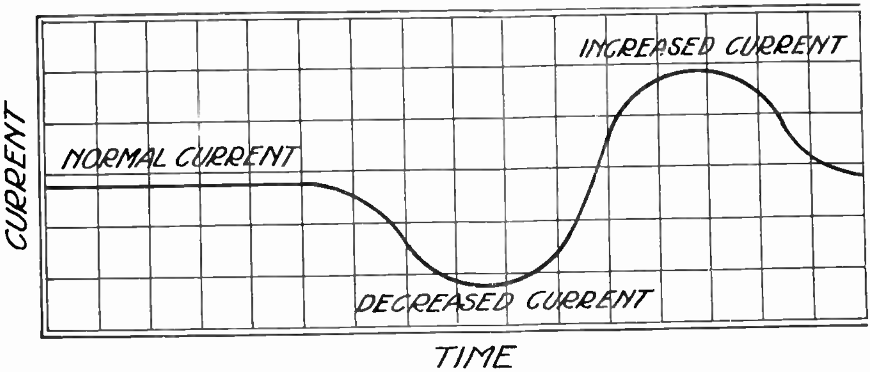


Fig. 4.—Illustrating How the Current Flowing Through a Microphone Varies With the Sound Waves Impressed on the Diaphragm.



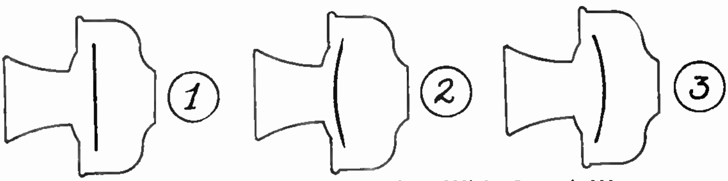


Fig. 5.—Illustrating How Diaphragms Swing With Sound Waves.

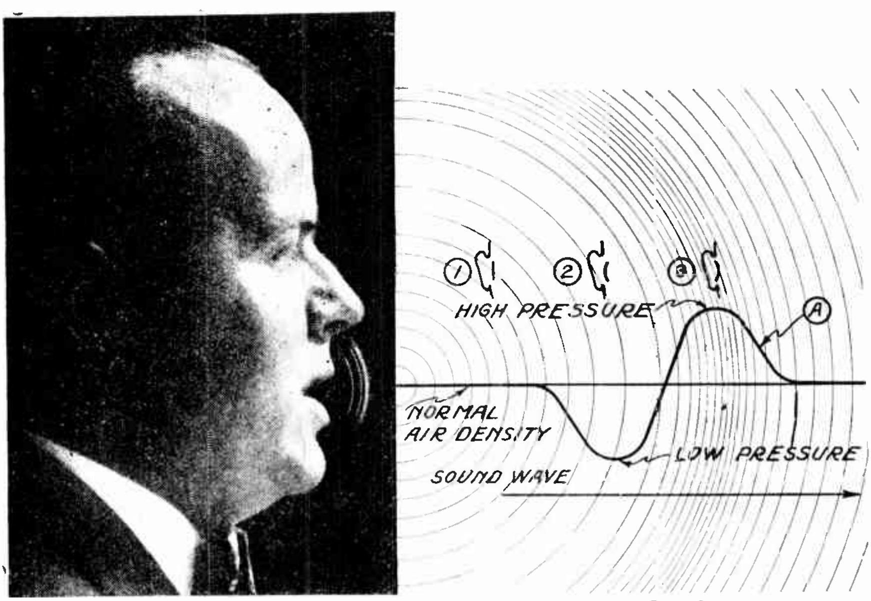


Fig. 6.—Illustrating What Happens When We Speak.

edge of the working principles of the ordinary telephone system, due to the fact that many of the problems involved in Radio telephony must be solved in the same manner that they have been solved in the development of the line telephony. Take for example, the transposition of the telephone wires as they go across the country. In order that a disturbance coming along will produce the same effect in one wire as the other, these wires are so arranged in their order to the whole line that the effects neutralize one another and thus the disturbance is eliminated. This is very much like the arrangement of the neutroformers in the neutrodyne type of receiver, where they are placed at certain angles, providing means of neutralizing each other and thus minimizing disturbances.

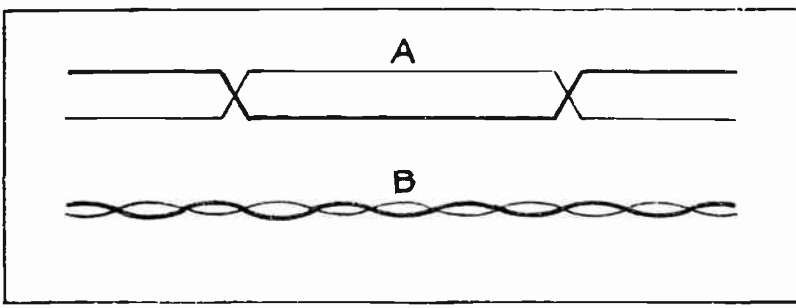


Fig. 7—Methods of Transposition

Take another example, for instance, the loading coil in the telephone line. Here, too, we have a similar example in the radiotelephony. That is, to say, we insert inductance coils and condensers to smooth out any ripple or disturbance that may come through from the source of power in the transmitters and receivers. This will show to the careful thinking student that a clear and accurate knowledge of line telephony is of great value to him in the solution of his radio problems.

Sources of Current in Telephony.—The current in a line is furnished in either of two ways—by the local battery system or by the common battery system. Rural telephone systems, are of the local battery type, that is, the battery which supplies the current to the transmitter is located at each telephone station. The battery current does not tranverse the line between stations but passes through the transmitter and the primary of a transformer. The transformer changes the modulations of the direct current produced by the transmitter into a current of higher voltage, thus giving better transmission.

In the common battery system a battery at some central point furnishes the current for a number of conducting lines. When a telephone connection between two points is made, the current from the common battery passes through the conducting lines between the points and through the transmitters where it is modulated by the voice speaking into either transmitter. The voltage of the common battery is high enough to supply the necessary current in all parts of the system in this method of telephony. The common battery system is always used in city installation.

Telephone Accessories.—Besides the essential parts necessary for telephone communication there are other devices utilized in a complete telephone system. For instance, a telephone switchboard is necessary so that one telephone circuit may be connected to any other telephone circuit in the same system. This may be done by an automatic device under the control of the person making the call. It is more usually done by an operator at the central station. The telephone bell is the means used to summon some one to the phone at a station. The bell is operated by a current different from that used in the telephone conversation.

Summary of Wire Telegraphy and Telephony.—Fig. 8 summarizes the various kinds of ordinary wire communication in common use. Note that in each type of communication there are the same elements: (1) A source of current; (2) a modulating device; (3) a receiving device; and (4) a conducting line.

The modulated current for each kind of communication is given to depict the actual type of current variation used.

The same types of modulating currents occur in the elementary transmitting circuits of a radio station and instead of going directly out into line wires, they act upon the high frequency oscillating currents produced by the transmitter and are thus sent out into space in the form of electromagnetic waves instead of currents that travel through the transmission lines of a telephone system.

Use of Alternating Current.—In all of the methods of electrical communication the signal or voice or any sort of sound is converted into a varying electric current and then changed back into a signal at the place where it is to be received. In the simple systems of telegraphy and telephony already discussed the electric current upon which the variations caused by the signal or voice are impressed is unidirectional, i. e., flows always in the same direction. Thus, in such systems the electric current variations which correspond to the signal or voice are really variations of a direct current (produced by a battery) which has a constant value except when variations in it are caused by the signal. The electrical circuits and apparatus must be such as to produce this direct current and facilitate its flow. The direct current may be thought of as a vehicle or carrier of the signals, since it is the variations of this current which constitute the signals.

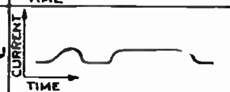
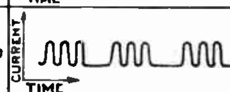
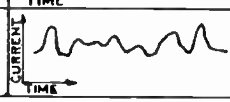
TYPE OF COMMUNICATION	SOURCE OF CURRENT	MODULATING DEVICE	RECEIVING DEVICE	CONDUCTING LINE	TYPE OF MODULATED CURRENT
TELEGRAPHY	BATTERY	KEY	SOUNDER	SINGLE WIRE WITH GROUND RETURN	
CABLE TELEGRAPHY	BATTERY	KEY	GALVANOMETER AND ACCESSORIES	CABLE WITH RETURN THRU SEA WATER	
BUZZER TELEGRAPHY	BATTERY	KEY AND VIBRATOR	TELEPHONE RECEIVER	SINGLE WIRE WITH GROUND RETURN	
TELEPHONY	BATTERY	MICROPHONE TRANSMITTER	TELEPHONE RECEIVER	COMPLETE METALLIC CIRCUIT	

Fig. 8—Summary of Wire Communication

The systems now to be considered differ from the systems already discussed in that the vehicle or carrier of the signals is alternating instead of direct current. While this introduces some complexity, the student should not regard it as making the subject exceptionally difficult. It is just as natural to use alternating current as the means for conveying signals as to use it for conveying power, and the latter use of alternating current is very common. The current brought into our houses by the electric power lines for lighting and other purposes is alternating current. Alternating current has many advantages over direct current; it is more easily generated in forms desired for use, and is more readily handled and transmitted over great distances.

Alternating current has very particular advantages as a means of conveying signals. Among these advantages are (a) Apparatus can be made selective, so as to receive only alternating current of a particular frequency, and thus many messages may be sent simultaneously by using alternating current of different frequencies and each receiving apparatus be free from interference from the others; and (b) alternating currents produce electric waves which spread out in all directions, thus making possible the transmission of signals without wires.

The use of alternating current as the vehicle for conveying signals is the method of pure radio communication. Perfected first in the development of pure radio, commonly called "simple radio," the method has made possible the development of line radio. The difference between radio and line radio is that in radio the alternating currents are converted into waves which are detached from the conductors, whereas in line radio the alternating electrical actions are guided along a conducting line between the transmitting and receiving points. Outside of this essential difference, radio and line radio are practically identical in principle, method, and practice.

Nothing has been said here as to how the signal is impressed upon the alternating current which carries it. This subject of modulation, together with other features common to pure radio and line radio, is explained in later text-books, following the discussion of radio waves. Thus, except for the early portion on the wave phenomena themselves, the radio principles which will now be given.

Production of Radio Waves.—Wherever there is an electric circuit in which alternating current is flowing an electric wave starts out just as a sound wave starts out from a vibrating tuning fork. A powerful sound can be produced by using a very large tuning fork, and similarly a powerful electric wave is produced by making some part of the electric circuit large in dimensions. The antenna used in radio work, as is well known, often consist of long conductors supported on very high towers. A mechanism for producing a radio wave, therefore, is simply an enlarged or extended portion of an electric circuit in which an alternating current is made to flow. In the space near the antenna, alternations of electric pressure are produced just as alternations of air pressure are produced around a tuning fork. At any instant the electrical condition of the space around an antenna which is sending out radio waves could be shown by a diagram such as Fig. 9. The arrow on the lines extending between the antenna and ground indicates that the electric pressure at a particular moment is in the direction indicated. When the current changes in direction, the direction of this electric pressure will be reversed and the electric pressure already mentioned will have handed on its effect to the surrounding space. Thus the effect of an electric pressure is passed on and spreads out through space, the direction of this pressure at any point constantly alternating as the direction of the current in the antenna producing it alternates. Lines of electric pressure alternating in direction are thus constantly spreading out from the antenna just as the ripples spread out on a pond. Something very similar to the ripples

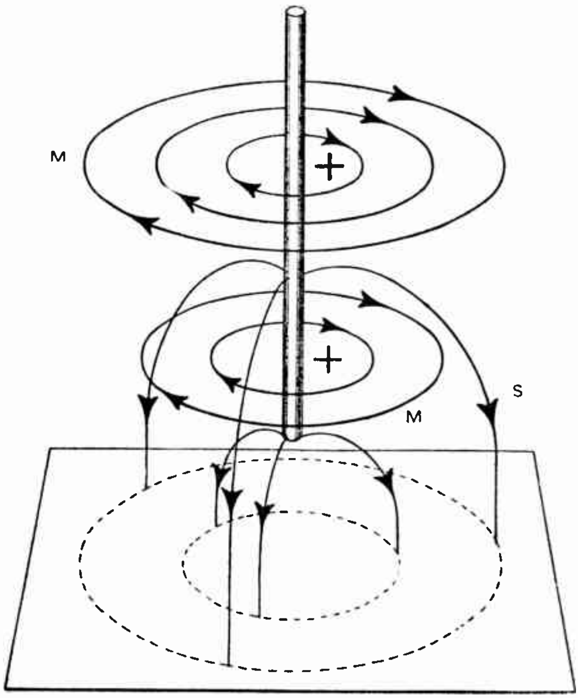


Fig. 9—Electro-Magnetic and Electro-Static Lines Formed About a Transmitting Aerial as the Current Moves Down in It

would be seen if, in some way, the alternations of electric pressure could be made visible and a person were to look down from above upon the antenna and the space around it. The waves of electric pressure spreading out and successively alternating in direction would look something like the lines shown in the upper part of Fig. 9. The waves spread out in all directions and extend to great distances.

It at once suggests itself that the waves will produce an effect at a point far distant from the source if there is any way of converting the electric pressure in the wave into electric current in a circuit placed at the distant point. In this way electric communication without connecting wires would be established.

Nature of Radio Waves.—We cannot see electric waves as we see ripples or the waves on a rope, but there is nothing specially mysterious about them. We can not see sound waves. If a tuning fork is struck, it gives off sound waves, which, starting at the tuning fork out into the air in all directions like the ripples referred to. Sound waves are produced by the motion of the metal prong of the tuning fork. As the prong moves back and forth it causes the air next to it to move back and forth. This motion is carried on to the surrounding air and so moves out to a great distance in the air just as the ripple on the pond spreads out. The slight to-and-fro motion of the air spreading out in this manner is called a sound wave.

Electric waves also consist of a certain kind of to-and-fro motion. Just as the motion of the tuning fork causes alternating pressure in the surrounding air, similarly whenever an alternating electric current flows in an electric circuit the to-and-fro motion of the current causes alternating electric pressure in the space next to the wire. This to-and-fro or alternating electric pressure in the space around the wire affects the surrounding space and spreads out in exactly the same way as a sound wave in air.

The electric waves are also called radio waves, and it is by means of them that radio communication is produced. It is an interesting fact that radio waves are really of the same kind as light waves. We are all familiar with light waves, and it should help to make radio waves less mysterious to know that they are both electric waves. The difference between light and radio waves is the frequency of alternation. Thus electric waves are much more common things than is sometimes supposed.

Use, Velocity, and Frequency of Electric Waves.—Electric waves are used for many purposes, their use depending on the frequency of the waves. This is shown by the following table showing the frequencies of the various kinds of electric waves. By frequency is meant the number of vibrations per second or the number of to-and-fro alternations of the electric pressure as the wave travels out through space.

Vibrations per second of waves produced by:
Commercial alternating currents: 25 to 500.
Ordinary telephone currents: 16 to 3,000.
Radio: 10,000 to 30,000,000.
Heat and light: 3,000,000,000,000 to 3,000,000,000,000,000.
X-rays: 3,000,000,000,000,000,000.

All of these waves travel at the same speed. These electric waves are of an entirely different nature from sound waves. Sound waves are not at all electrical; they consist of actual to-and-fro motions of the air particles and travel with a speed of about 1,000 feet per second. The speed at which electric waves travel is much greater than this; it is so great that the passage of any kind of electric wave is practically instantaneous. The various kinds of electric waves shown in the table are much alike in many ways, but they have some characteristic difference. Thus radio waves are different from light waves in that they go through ordinary walls of buildings and other obstacles which are opaque to light.

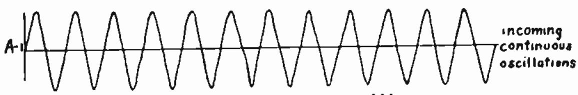


Fig. 10—Continuous Waves

The waves are radiated and spread out more effectively the higher the frequency. The ordinary low frequencies used in the alternating currents which light our houses alternate very slowly. In order to get a wave which will travel effectively through space, higher frequencies must be used; that is why the waves used in radio communication make a large number of vibrations per second.

It is to be noted that these frequencies are not, however, as high as the frequencies of light waves. Light waves travel in straight lines, which is one of their characteristic differences from low-frequency waves of alternating-current power, which follow along wires. Radio waves are intermediate in character between the two, and can travel in straight lines and also travel along conducting wires.

The fact that radio waves, which are able to travel out into space without conducting wires, are of high frequency is one of the important characteristics of radio communication.

Wave Reception.—Now think of what is happening at a distance from an antenna which is sending out waves. As the wave passes any point there is an alternation of electric pressure going on continuously at that point. The alternating electric pressure or wave action at that point could be illustrated by the wavy line of Fig. 10. The portions of the wave above the horizontal line correspond to the electric pressure in one direction, and the portions below correspond to the electric pressure in the other direction. This can be understood by thinking again of the ripple on the water. Suppose there is a cork or another floating object on the surface of the water at a distance from the place where the ripple starts. As the ripple takes place, the cork rises and falls, partaking of the to-and-fro motion of the surface of the water. Or consider the sound wave. As the sound wave passes out through the air, it will set in vibration any object which is capable of taking up the motion. Suppose, for instance, that a sound wave produced by a tuning fork passes a second tuning fork which is in tune with it; that is, having the same natural pitch or frequency of vibration as the first tuning fork. The to-and-fro motion of the air will start the second tuning fork into motion. This can be readily shown with two tuning forks, striking one of the forks, thus producing a sound wave. It can be proved that the second tuning fork is set into vibration by grasping the first with the hand so as to prevent its further motion. A sound from the second one can then be heard. The same thing is sometimes illustrated in a room. If a note is sung or produced on some instrument, a response may be heard from one of the strings of the piano, or from a loose portion of a chandelier or other resonant object in the room.

An electric wave can produce an effect at a distance in just the same manner. In any electric circuit the moving wave of electric pressure can produce an electric current alternating with the same frequency as the wave. The moving wave, just as a current, is accompanied by a magnetic field. This moving magnetic field produces an electromotive force in any conductor across which it cuts, just as an electromotive force is produced by any other case of relative motion between a conductor and a magnetic field. The electromotive force thus produced is what causes a current in the receiving antenna.

Comparison of Radio With Ordinary Wire Communication.—In the preceding sections the mechanism by which an electrical action can be made to affect a distant point without wire connection has been explained. The ether which fills all space can be considered to replace the wire connection. Thus, in wire communication we could have a system as represented in Fig. 11A, which shows a conducting wire line indicating a source of varied current with a detecting device. In radio communication the wires are eliminated so that the corresponding simplified system would be as represented in Fig. 11B, which shows the similar source of varied current and detecting device, each of these, however, being placed in a simple electrical circuit and the conducting wires between being eliminated. Both of these diagrams have been so greatly simplified that neither of them is really just like an actual telegraph or telephone system. Certain additional features must be used beyond what

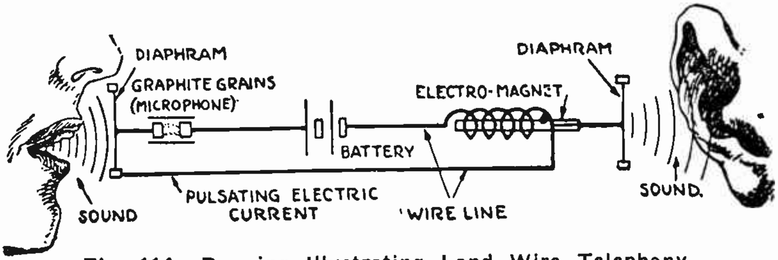


Fig. 11A—Drawing Illustrating Land Wire Telephony

is shown in either Fig. 11A or Fig. 11B to carry on telegraphy or telephony. More accurately, a species of telegraphy is possible by merely adding a key in either Fig. 11A or Fig. 11B. Wire communication of this kind would thus be the use of an alternating current generator as the source of power and a telephone receiver as the detector. The corresponding radio system would be the use of an alternating current generator of

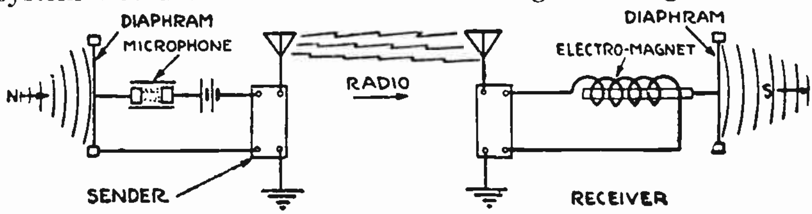


Fig. 11B—Comparison of Radio and Wire Communication

high but still audible frequency, together with a telephone receiver as the detector. As a matter of fact, simple systems of just this kind are not used because great advantages are secured by the addition of certain features which will now be discussed. Furthermore, these features not only improve telegraphic communication but are necessary for telephonic communication.

High Frequency and Tuning.—Some of the characteristic features of radio communication as actually carried on, other than its use of waves, will now be considered. As will be shown below, these are all characteristic of line radio as well as pure radio. The extremely simple system of radio communication indicated in Fig. 11B is not effective unless the alternating current used is of high frequency. Even then the current produced in the receiving circuit would be very small indeed unless the receiving circuit were electrically tuned to the transmitting circuit. As to the necessity of using high frequencies, it will be recalled that radio waves do not spread out or radiate effectively unless the frequency is high. The waves produced by an alternating current are of the same frequency as the current itself. The higher the frequency the more effectively do the waves leave the circuit at the transmitting end and spread out through space. If the frequency is only a few hundred or a few thousand per second, the waves received at a distance are very feeble.

The effect of a wave in producing current in a receiving circuit is very small unless the receiving circuit is in tune with the wave. That is, it must be arranged to respond to the frequency of alternation possessed by the first circuit and the wave which it sends out. This is just like what happens with the two tuning forks and the sound wave. The second tuning fork does not respond to the wave from the first unless the two are in tune. This can be shown by placing a bit of wax on one of the prongs of the second tuning fork, changing the pitch of that fork. When the first tuning fork is struck under these conditions it can readily be demonstrated that the second fork does not respond. In the same way the electrical arrangements in the receiving circuit which are used to receive radio waves must be such that the receiving circuit is electrically in tune with the radio wave. By this means the radio receiving circuit can pick out the particular wave which it is desired to receive and not be affected by other waves. This is fortunate, because otherwise the interference between different radio messages would be hopeless. It would be just as though every sound wave which passed through the air set absolutely everything which it touched into vibration.

Just as the frequency to which a tuning fork responds depends upon its mass and its elasticity, the frequency to which the electrical circuit responds depends upon two corresponding electrical properties called the inductance and capacity, respectively. The greatest current is produced in a receiving circuit when both the transmitting and receiving circuits are tuned—that is, arranged so that the product of the capacity and inductance is the same in each. The elements of a typical radio

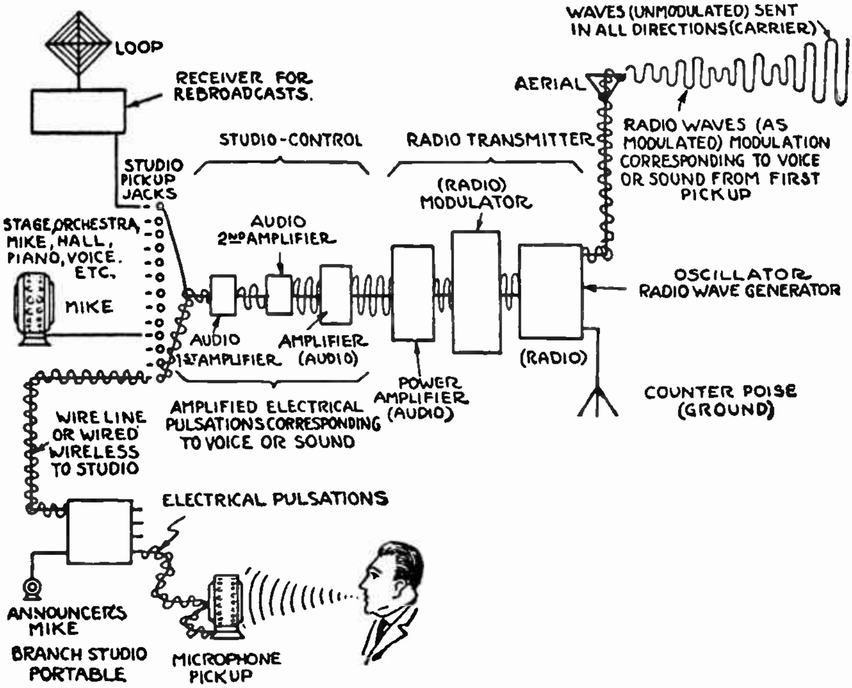


Fig. 12

circuit are thus rather more complicated than shown in Fig. 11B which should be replaced by Figs. 12 and 13. Both in the

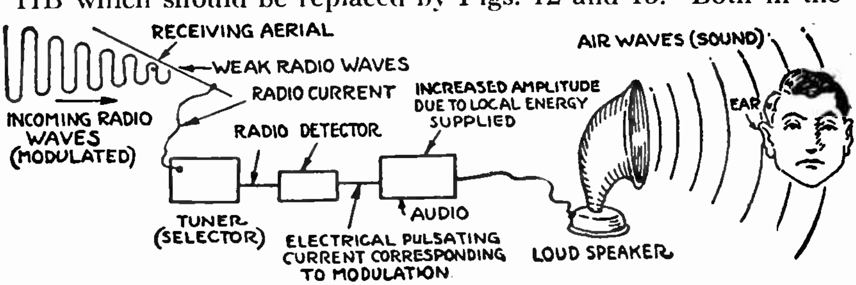


Fig. 13

transmitting circuit shown in Fig. 12 and the receiving circuit shown in Fig. 13, either the capacity or the inductance is made variable for tuning purposes.

Modulation and Rectification.—As just mentioned, the frequency of alternation of radio waves is very high. It is so high, in fact, that a sound wave of such frequencies could not be heard. Electric currents produced in a receiving circuit are of the same frequency as the wave frequency and tend to cause motions of the telephone receiver diaphragm. These motions are, however, of such great frequency that the diaphragm produces no audible sound. In order to permit the radio wave to be received and transformed into a sound, it is therefore necessary to break up the radio wave in some manner. Ordinarily this is done in radio telegraphy by interrupting the wave completely, not only consisting of a single regular series of alternations but of a succession of groups of such alternations; that is, instead of the continuous wave shown in Fig. 10 we use the interrupted wave or group of waves illustrated in Fig. 14 (A-2). The frequency of the interruptions or of the groups of waves is the frequency which can be heard. This process of varying the high-frequency wave, making it no longer a single regular series of alternations is called modulation.

Instead of breaking the wave up into simple groups of alternations, it is possible to modulate it or cause it to vary in a manner which follows the sound variations produced by the human voice. It is thus possible to make a radio wave carry a voice wave. This is the process of radio telephony. In order that satisfactory radiotelephony be possible, the radio wave must be of higher frequency than the frequency of the speech variations which modulate it. This is true because at the receiving end it is desired to hear the speech only and not the frequency corresponding to the wave itself. This supplies another reason why high frequencies must be used in radio.

Besides the reason given for the use of high frequency, there is another very powerful reason. When it is desired to carry on telephony, it is necessary that the alternating current, which produces the waves, be of a frequency to which the sense of hearing does not respond. This is necessary because if the waves were of an audible frequency, the current which they produce in the receiving circuit would produce a sound that would be heard and would interfere with the voice or other sound which it was desired to hear. The wave frequency must, therefore, be so high that a sound wave of such frequencies could not be heard.

There is another thing that is to be taken into account before it becomes possible to translate the received radio current into a sound that can be heard. When one of the groups of alternations shown in Fig. 14 acts on the telephone receiver it does not cause a motion of the diaphragm because each variation of the current in one direction is immediately followed by the current in the opposite direction, giving the resulting effect of the group of waves upon the telephone receiver diaphragm as no motion at all. It is therefore necessary, in order to convert the current into a sound, to use something else with the telephone receiver. This something else must be such as to make the current flow through the telephone receiver in only one direction. It must allow the electric current to flow through it in one direction and stop current which tries to flow through it in the opposite direction; that is, it must be some sort of electric valve. The effect of such an electric valve may perhaps be understood more clearly by taking away one-half

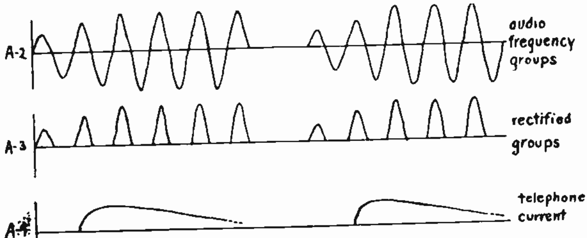


Fig. 14—Interrupted Waves, Rectification and Detection

of the wave as shown in Fig. 14 (A-3). This leaves only the upper halves of the little groups of waves and this is exactly what the electric valve does. The process is called "rectification." The result is that successive impulses of current flow through the telephone receiver and all of these tiny impulses in any one group add their effects together and produce a motion out of the telephone diaphragm. (See A-4). The interval between one group and the next permits the motion of the telephone diaphragm to subside and this intermittent motion causes what is heard as a note in the receiver.

THE MODULATION OF THE CARRIER WAVE

It is difficult for some students to understand the action that takes place when a voice wave is superimposed on a high frequency radio wave to produce the radio waves that go out into space to affect the millions of receivers that will in turn strip the wave of its carrier and reproduce the voice wave alone.

You know, of course, that the ordinary voice wave cannot be transmitted through space. The only type of wave that can be used effectively for that purpose must be of a high frequency. The high-frequency wave however, is useless in itself if it does not carry the variations that will reproduce sound in the phones of the receiver.

The logical conclusion, then, is to combine the two, the voice wave and the carrier wave. Perhaps the simplest way of explaining the action is to liken it to a courier and his horse. The horse can travel over great distances without much trouble, but it is not gifted with the ability to talk or deliver messages. A man can travel over short distances, but he has the ability to carry messages.

The electromagnetic properties of low frequency voice waves can be used to transmit messages without wires over comparatively short distances, but they cannot be made to carry them over great distances. The message-carrying properties of voice waves can be likened to the man and the distance-covering properties of the high-frequency radio waves can be likened to the horse. The ideal arrangement in both cases is a combination of the two; the man astride the horse which carries him to his destination in one case and the voice wave superimposed on the carrier or high-frequency wave in the other.

Modulation is the process of molding the high frequency carrier wave to the outline of the voice wave enabling the high frequency wave to travel through space with the variations of the voice wave.

The resultant wave when received at the receiving station is not a smooth voice wave, as is the case when voice currents are transmitted over wires without the aid of high frequency currents but to all practical purposes the difference between the smooth voice waves and the slightly "chopped up" voice waves, resulting from stripping the carrier wave of its superimposed voice waves, is so slight as to be negligible.

A somewhat similar action takes place in projecting motion pictures on the screen. Most people know that in a moving picture every movement is pictured on the film as a series of progressive positions of the movement. In other words, every moment is broken up into a number of different positions of the member that is making the movement.

When each of these positions is projected in quick succession on the screen by the moving picture projector, the effect produced is that of a continuous motion because the eye is not quick enough to follow each separate motion, but blends the separate, individual pictures into a smooth continuous movement.

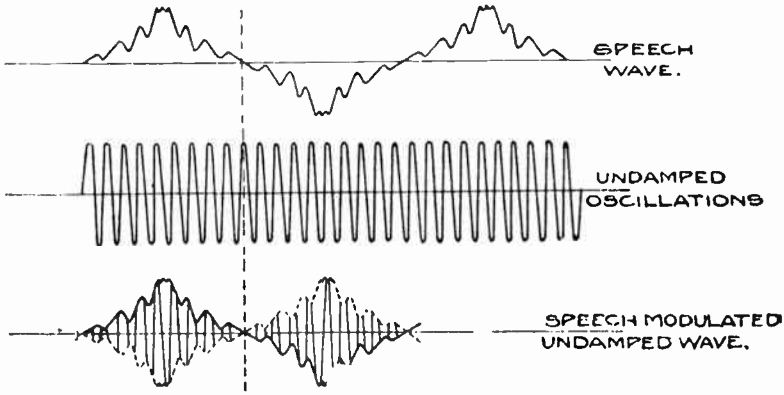
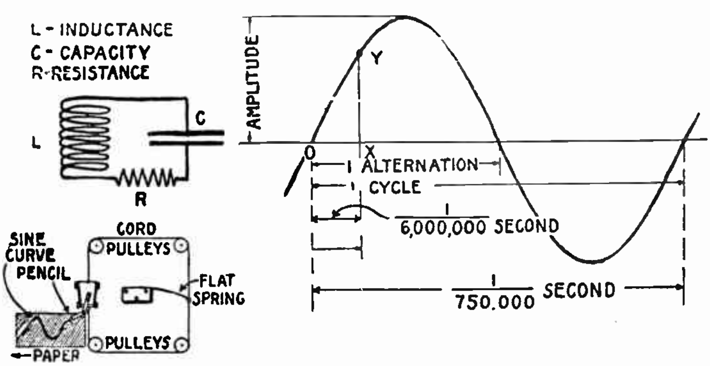


Fig. 15—Carrier Radio Wave Modulated by Sound Waves

Detailed explanations of the molding action of the voice waves on the carrier waves will be taken up in later text-books.

We will now turn our attention to the use of Radio Telephony in one of the broadest and most popular fields—the sending out of concerts by Radio involves a type of modulation



To the Left, An Oscillating Electric Circuit, with an Oscillating Mechanical Circuit Drawn Underneath for Comparison. To the Right, an Electric Current Wave.

Fig. 16

which must be accomplished either through the waves that come from the human voice or those which come from some musical instrument. These waves from the voice act upon the diaphragm of a microphone transmitter and in turn vary the intensity of the radio frequency waves being produced by the transmitting outfit. The top part of Fig. 15, illustrates a voice wave and the middle waves are those produced by the high-frequency oscillating transmitter while the waves at the bottom are the modulated waves which are sending out the concert into space. These various varying disturbances created in the atmosphere pass over the receiving aerial and produce a like effect on the receiving set of the listener-in. We will now turn our attention to the broadcasting station and have a simple explanation of the apparatus used and the part it plays in sending out its interesting entertainments to the multitude of listeners-in.

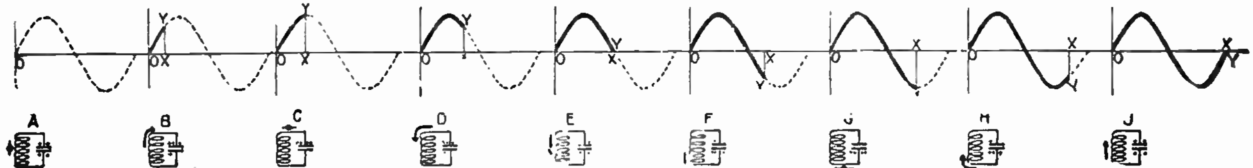
RADIO BROADCASTING

From the Studio to the Ear

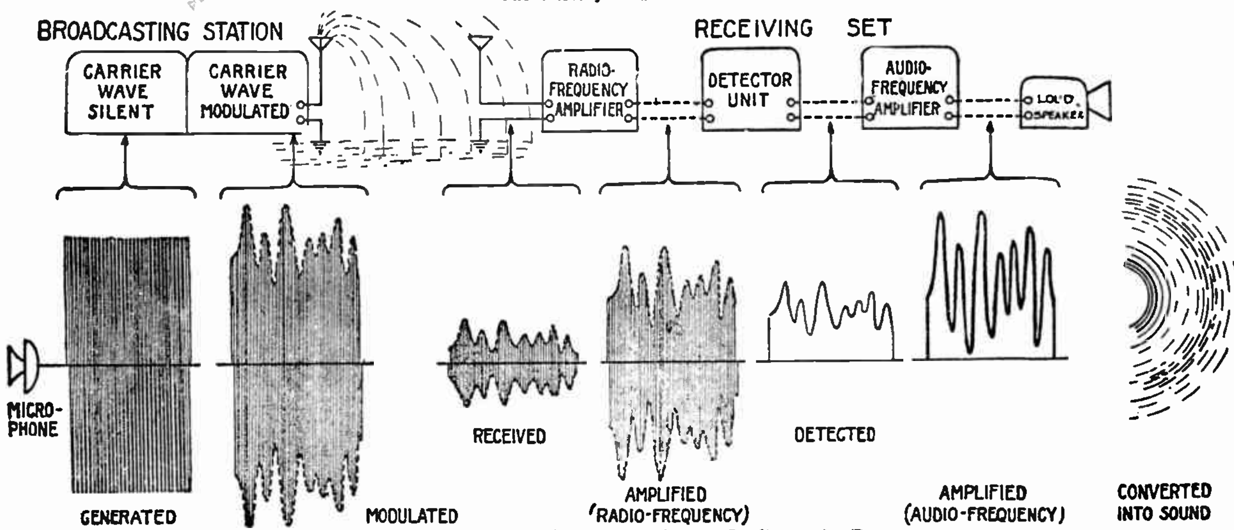
In Fig. 17 we have illustrated the conditions at nine different points during the cycle. At A the circuit is dead; there is an equal charge on the upper and lower plates and no current is flowing. At B the current has commenced to flow upward, through the coil, in the direction of the arrow, and a charge is accumulating on the upper condenser plate, as indicated roughly by the plus marks. In position C the charge (represented by XY) has reached its maximum, and the current has stopped flowing. At D the current has reversed and is flowing back to the lower plate. This continues through E and F, until at G the charge has reached its maximum in the reverse direction, and again no current is flowing. At H the current has started flowing upwards again, and at J we are back to our starting point, ready to begin another complete oscillation or "cycle."

It is this process which occurs 750,000 times per second in a radio set which is receiving from a broadcasting station operating on 750 kilocycles—or, as we say more familiarly, on 400 meters wave length. Since all radio waves travel 300,000,000 meters per second, if there are 750,000 of them arriving each second we can find the length of the wave by dividing 300,000,000 by 750,000, the result being 400.

If the charges are flowing in and out of the condenser according to the sine-wave law as described above, then the variations of the electrical current as it flows up and down through our inductance will also be represented by a similar sine curve. Let us now imagine if oscillations of this character were steadily



The History of an Oscillation



How Radio Travels from the Radiocast Studio to the Ear

Fig. 17

following each other out of a powerful electric generator at a broadcasting station, we have a good understanding of what is represented by the series of waves shown below on page 25 as "generated."

These generated waves, although powerful, could not be heard if passed through a telephone, for they arê far too rapid. They represent, however, the output of a broadcasting station when no sound is being made before its microphone. When the announcer begins to speak, the sound waves from his voice are carried over the wires to the radio transmitting station, where they are impressed upon the radio frequency or "carrier-wave" as it is generated, causing its outline to be no longer uniform, but is moulded to the shape of the waves from the speaker's voice. This "modulated" current is then forced into the broadcasting antenna, sending out electromagnetic waves, which have impressed upon them the "audio-frequency" vibrations of the speaker.

The current produced in the receiving antenna (shown as "Received") is of this same form, and if it is then passed through a Radio-Frequency Amplifier it is still of the same form, but stronger. This current then goes through the detector unit, after which it has approximately the form shown as "Detected." The original oscillations have disappeared, and we have instead a current flowing in one direction only, but varying in strength, or "pulsating," according to the shape of the sound waves. Passed through an "Audio-Frequency Amplifier," it becomes strong enough to energize the magnets in a loudspeaker, and cause the diaphragm to vibrate and send out waves in the air which reproduce, more or less faithfully, those originally created in the studio.

KILOCYCLE-METER CONVERSION TABLE

The Department of Commerce specifies radio station assignments in both kilocycles and meters. The tendency of radio engineering practice is to use and express frequency in kilocycles rather than wave length in meters. "Kilo" means a thousand, and "cycle" means one complete alternation. The number of kilocycles indicates the number of thousands of times that the rapidly alternating current in the antenna repeats its flow in either direction in one second. The smaller the wave length in meters, the larger is the frequency in kilocycles. The numerical relation between the two is very simple. For approximate

KILOCYCLES TO METERS, OR METERS TO KILOCYCLES

Meters	Kilocycles	Meters	Kilocycles	Meters	Kilocycles	Meters	Kilocycles
10	29980	720	416.4	1430	209.7	2140	140.1
20	14990	730	410.7	1440	208.2	2150	139.5
30	9994	740	405.2	1450	206.8	2160	138.8
40	7496	750	399.8	1460	205.4	2170	138.1
50	5996	760	394.5	1470	204.0	2180	137.5
60	4997	770	389.4	1480	202.6	2190	136.9
70	4283	780	384.4	1490	201.2	2200	136.3
80	3748	790	379.5	1500	199.9	2210	135.7
90	3331	800	374.8	1510	198.6	2220	135.1
100	2998	810	370.2	1520	197.2	2230	134.4
110	2726	820	365.6	1530	196.0	2240	133.8
120	2499	830	361.2	1540	194.7	2250	133.3
130	2306	840	356.9	1550	193.4	2260	132.7
140	2142	850	362.7	1560	192.2	2270	132.1
150	1999	860	348.6	1570	191.0	2280	131.5
160	1874	870	344.6	1580	189.9	2290	130.9
170	1764	880	340.7	1590	188.6	2300	130.4
180	1666	890	336.9	1600	187.4	2310	129.8
190	1578	900	333.1	1610	186.2	2320	129.2
200	1499	910	329.5	1620	185.1	2330	128.7
210	1428	920	325.9	1630	183.9	2340	128.1
220	1363	930	322.4	1640	182.8	2350	127.6
230	1304	940	319.0	1650	181.7	2360	127.0
240	1249	950	315.6	1660	180.6	2370	126.5
250	1199	960	312.3	1670	179.5	2380	126.0
260	1153	970	309.1	1680	178.5	2390	125.4
270	1110	980	305.9	1690	177.4	2400	124.9
280	1071	990	302.8	1700	176.4	2410	124.4
290	1034	1000	299.8	1710	175.3	2420	123.9
300	999.4	1010	296.9	1720	174.3	2430	123.4
310	967.2	1020	293.9	1730	173.3	2440	122.9
320	936.9	1030	291.1	1740	172.3	2450	122.4
330	908.6	1040	288.3	1750	171.3	2460	121.9
340	881.8	1050	285.5	1760	170.4	2470	121.4
350	856.6	1060	282.8	1770	169.4	2480	120.9
360	832.8	1070	280.2	1780	168.4	2490	120.4
370	810.3	1080	277.6	1790	167.5	2500	119.9
380	789.0	1090	275.1	1800	166.6	2510	119.5
390	768.8	1100	272.6	1810	165.6	2520	119.0
400	749.6	1110	270.1	1820	164.7	2530	118.5
410	731.3	1120	267.7	1830	163.8	2540	118.0
420	713.9	1130	265.3	1840	162.9	2550	117.6
430	697.3	1140	263.0	1850	162.1	2560	117.1
440	681.4	1150	260.7	1860	161.2	2570	116.7
450	666.3	1160	258.5	1870	160.3	2580	116.2
460	651.8	1170	256.3	1880	159.5	2590	115.8
470	637.9	1180	254.1	1890	158.6	2600	115.3
480	624.6	1190	252.0	1900	157.8	2610	114.9
490	611.9	1200	249.9	1910	157.0	2620	114.4
500	599.6	1210	247.8	1920	156.2	2630	114.0
510	587.9	1220	245.8	1930	155.3	2640	113.6
520	576.6	1230	243.8	1940	154.5	2650	113.1
530	565.7	1240	241.8	1950	153.8	2660	112.7
540	555.2	1250	239.9	1960	153.0	2670	112.3
550	545.1	1260	238.0	1970	152.2	2680	111.9
560	535.4	1270	236.1	1980	151.4	2690	111.5
570	526.0	1280	234.2	1990	150.7	2700	111.0
580	516.9	1290	232.4	2000	149.9	2710	110.6
590	508.2	1300	230.6	2010	149.2	2720	110.2
600	499.7	1310	228.9	2020	148.4	2730	109.8
610	491.5	1320	227.1	2030	147.7	2740	109.4
620	483.6	1330	225.4	2040	147.0	2750	109.0
630	475.9	1340	223.7	2050	146.3	2760	108.6
640	468.5	1350	222.1	2060	145.5	2770	108.2
650	461.3	1360	220.4	2070	144.8	2780	107.8
660	454.3	1370	218.8	2080	144.1	2790	107.5
670	447.5	1380	217.3	2090	143.5	2800	107.1
680	440.9	1390	215.7	2100	142.3	2810	106.7
690	434.5	1400	214.2	2110	142.1	2820	106.3
700	428.3	1410	212.6	2120	141.4	2830	105.9
710	422.3	1420	211.1	2130	140.8	2840	105.6

calculation, to obtain kilocycles, divide 300,000 by the number of meters; to obtain meters divide 300,000 by the number of kilocycles. For example, 100 meters equals approximately 3,000 kilocycles, 300 m equals 1,000 kc, 1,000 m equals 300 kc, 3,000 m equals 100 kc.

For highly accurate conversion the factor 299,820 should be used instead of 300,000. The table below gives accurate values of kilocycles corresponding to any number of meters and vice versa. The table is based on the factor 299,820, and gives values for every 10 kilocycles or meters. It should be particularly noticed that the table is entirely reversible; that is, for example, 50 kilocycles is 5,996 meters, and also 50 meters is 5,996 kilocycles. The range of the table is easily extended by shifting the decimal point; for example, one can not find 223 in the first column, but its equivalent is obtained by finding later in the table that 2,230 kilocycles or meters is equivalent to 134.4 meters or kilocycles, from which 223 kilocycles or meters is equivalent to 1,344 meters or kilocycles.

TEST QUESTIONS

Number your answer sheet 31 and add your **student number.**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. When and by whom was the first workable Radio telephone presented?

2. Mention a few facts about the first Trans-Atlantic Radio Telephony tests.

3. State where one early installation was made, where land line service and Radio were combined for practical use.

4. Show by aid of a simple drawing the essential parts used to send voice sounds over a two-wire telephone system.

5. What type of electric current furnishes the energy for wire telephone transmission?

6. Show by a sketch the magnetic and static lines formed around a vertical one wire antenna.

7. Give value of current frequencies to show the range used both for telephone and radio purposes.

8. Describe by use of a drawing, voice modulation on Radio Transmitters.

9. What is a carrier-wave?

10. Explain your understanding of Fig. 17.

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TRANSMITTING VACUUM TUBES

When Dr. DeForest placed the grid in the two element Fleming Valve in 1907, it is doubtful whether he visualized the far reaching effect of his invention and the important role it would play in the future development of the Radio industry. He perhaps thought that it would play an important part in the development of more sensitive receiving sets, due to its amplifying characteristics, but it is hardly possible to believe that he realized that within fifteen years it would be the most important component in radio transmission, and that around this invention would be built the huge Radio industry as we know it today.

During the five years following its invention, the three electrode vacuum tube was successively improved and gradually its use as a detector and amplifier spread. It was not until 1913, when the action of the three-electrode vacuum tube began to be studied carefully, that it was found it provided a very effective means of generating undamped electric oscillations. Although DeForest's discovery in 1907 was fundamental and far reaching, the use of the triode (three element vacuum tube) was limited to reception and its use in transmission hinged upon the invention of its use in a regenerative receiving set and as a generator of undamped oscillations.

This seems to have become clearly understood about the beginning or middle of 1913 and it gave a fresh impetus to the study of the properties of the thermionic valve (vacuum tube). There is some question as to who first conceived the idea of regeneration, Dr. DeForest and E. H. Armstrong each claiming it to be his own creation. However, it seems clear that the first person to publish a definite statement adapting the triode to transmission purposes was Alexander Meissner, an engineer in the employ of the Wireless Telegraph Company of Berlin, Germany. Lieutenant C. S. Franklin and Captain H. J. Round of Marconi's Wireless Telegraph Company were two of the early English inventors, experimenting with the triode as a generator of oscillation.

The three-element thermionic tube is essentially a metallic filament lamp with an added metallic grid and plate sealed within a glass bulb. Hence all the knowledge and experience gained in the evolution of the metallic filament electric lamp used for illuminating purposes, was available in the production of the thermionic tube, or valve as it is sometimes referred to.

Nevertheless, the difficulties of manufacture are very much greater; partly by reason of the more complicated structure which has to be sealed within the glass bulb, but chiefly by reason of the difficulty of adjusting the vacuum to a required exact pressure or else creating an especially high vacuum, and freeing all the masses of metal and glass surfaces entirely from adhering or absorbed air. A vacuum which is good enough for an incandescent lamp is not nearly good enough for the ordinary vacuum tube now in use.

A further difficulty arises from the fact that we have not merely to pass through the lead-in wires a current for rendering the filament incandescent, but we have to pass a discharge current through the vacuous space between the plate and filament which, in the case of transmitting tubes of high power, may be a current under very high electromotive force. Another difficulty which arises in making the glass bulb is the rapid increase in electric conductivity of glass which takes place as the temperature rises. Cold glass is a good insulator, but at 300 degrees Centigrade one kind of glass may have ten times the conductivity of another sample. Very hot glass is an electrolytic conductor.

One of the greatest problems of construction therefore is that of leading these currents in and out of the elements within the glass bulb. There are not many metals which can be employed for the actual sealing-in wires. Platinum wire has been nearly always used, with glass bulbs, because it is possible to manufacture a brand of lead glass which has the same coefficient of volume expansion as platinum, and to which platinum adheres when red hot, and does not crack out on cooling. The greatest drawback to this metal, however, is that platinum is very expensive.

Although many alloys have been invented and patented as substitutes for platinum, it can hardly be said that any of them form a really satisfactory alternative. The present practice is to reduce the actual amount of platinum required by devices of construction, as follows:

The bulbs of thermionic tubes are made in nearly all cases of a heat-resisting lead-glass containing a high percentage of lead oxide, with a small percentage of silicic acid. Silica bulbs have, however, been used with success in some cases. The glass bulb is formed with one or two inset tubes or stems, the inside ends of these tubes being squeezed together while the glass is soft, and through this "pinch" the lead-in wires pass, and the bottom or open end of the stem sealed into the bulb. The advantage of this inset tube is that the filament, grid and plate, whatever form they may take, can be mounted on the stem, which later is then introduced into the bulb, and the junction made by melting together the edges of the glass bulb and stem. Fig. 1 shows the construction of a simple form of the three-element thermionic tube using this construction.

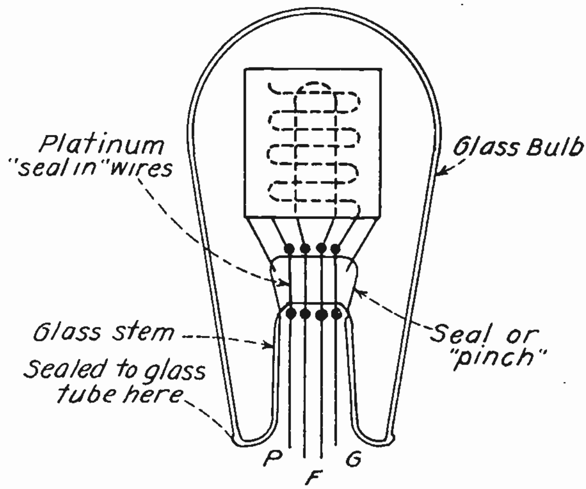

Fig. 1—Constructional details of a three-element vacuum tube.

The wires which support the filament, grid and plate within the glass tube are generally of nickel, and are welded to the short platinum wires at the squeeze or pinch. The short platinum wires extend through the pinch where they are welded to copper wires which pass down the inset stem and make contact with the prongs on the base.

In the case where the filament forms a loop, it may sometimes be desirable on account of the length of the filament, to support it at its upper end by a small spring to take up slack and keep the filament taut when it is rendered incandescent, and therefore expanded in length.

Up to the present time three general types of filaments have been employed in the construction of thermionic vacuum tubes, viz., (1) hard drawn tungsten wire, (2) the coated filament consisting of platinum-iridium alloys coated with oxides of barium and strontium, and (3) thoriated tungsten wire.

The above types are listed in the order in which they were introduced, the hard drawn tungsten type being the first and the thoriated tungsten being the latest type to be employed. In preparing hard drawn tungsten wire, pure tungsten is reduced from oxide of tungsten by heating in a hydrogen gas flame. The tungsten thus obtained is in minute granules and these have to be welded together into a solid ingot of tungsten by alternate heating to a high temperature in an electric furnace, and hammering to weld the particles together. The ingot so prepared is then drawn down into wire of the correct size in the usual way.

The production of the oxide-coated metallic filament is obtained by coating a thin narrow platinum-iridium strip with a mixture of oxides of strontium and barium. In this type the filament is generally a narrow flat strip instead of a round wire. This type of filament was introduced during the war and possessed the advantage of giving the necessary electronic emission at a much lower temperature of the filament, hence requiring less filament current than in the hard drawn tungsten type.

The third type of filament is the thoriated tungsten type often referred to as the thoriated filament or XL type. This discovery allowed a still further reduction in the amount of filament current required by supplying the necessary electronic emission at a still lower temperature of the filament itself. In the preparation of this filament, nitrate of thorium is mixed with the oxide of tungsten before reduction of the latter by hydrogen to the metallic state. The so prepared thoriated tungsten, after being drawn into wire, is subjected to a heat treatment by raising it to 2600 degrees Centigrade for a short time, and then lowering it to 2000 degrees Centigrade. The thorium, present to the extent of about one per cent., then seems to work its way to the surface of the wire, and thus greatly increases the electron emission at a lower temperature. This type of filament is extensively employed in receiving tubes and in some types of transmitting tubes.

The final important step in the construction of vacuum tubes is the operation of exhausting the bulbs, on which the future performance of the tube so greatly depends. In the quantity production of vacuum tubes, the glass bulb, when received from the glass blower with all the elements, filament, grid and plate sealed in, has at some convenient place on it, and joined to the glass bulb, a small glass tube through which the air in the glass bulb passes while being exhausted. The small glass tube is then sealed to a large glass tube or manifold, which may have openings for exhausting several bulbs at once. The large glass tube or manifold is enclosed in a metal box, or oven heated by gas flames, and the other end of the manifold connects to a special exhaust pump. The oven is heated to about 1000 degrees Fahrenheit or 540 degrees Centigrade. The temperature of the oven is gradually raised to this point as the exhaustion proceeds, and is necessary to remove all the adhering films of air from the glass surfaces and the surfaces of the elements.

In addition, a small transformer, or some source of current, is provided, one terminal of the secondary circuit being connected to one terminal of the filament, and the other to the grid and plate. Also a suitable battery and rheostat is employed to heat the filament and raise its temperature as the vacuum is increased.

The operation which has then to be conducted is first to make a fairly good vacuum in the bulb by starting the exhaust pump and exhausting the air so that the vacuum is in the order of say a fraction of a millimeter of mercury. The bulbs are then gradually heated to set free the adhering air from the glass, and the filament temperature is slowly raised to extricate the absorbed air from it and get rid of the positive ions which are emitted at low temperatures. The vacuum is still further improved until it approaches something like .001 millimeter of mercury pressure, and then the high tension transformer is brought into operation and a current passed between the grid and plate to filament by means of the electron stream thrown off by the filament. This emission by the filament and the passage of current causes an ionization of the residual air within the bulb, which usually is accompanied by a blue glow around the elements of the tube. The vacuum must then be increased still more while keeping all the above mentioned currents flowing, and increasing the heating of the bulb still more, almost to the softening point of the glass bulb. At a certain high vacuum, of about .000001 millimeter of mercury, the blue glow disappears, and the grid and plate become red hot. This is due to the fact that practically all gases are removed, the electrons can expend very little energy in ionizing air molecules, and therefore expend most of their energy in bombarding the metal grid and plate which makes them red hot. This extricates the absorbed air from them more thoroughly and the process must be continued until it is all removed, so that the tube will stay "hard" and not admit air and gases when it cools and is put in use. The vacuum which should then exist is near .00001 or .000001 of a millimeter of mercury, or about one hundred-millionth to one thousand-millionth of an atmosphere. One atmosphere equals approximately 14 pounds per square inch pressure.

The transformer or other source of current, which furnishes the current for the electron bombardment must give a voltage higher than the plate voltage which is applied to the tube when in use. The bombardment should not be begun until the vacuum is very high, because the ionization of the residual air produces massive positive ions which are drawn back onto the incandescent filament and may destroy it. In fact, one of the greatest difficulties of tube manufacturing is that the filament has to be maltreated and extreme precautions must be observed or else the life of the filament may be shortened.

TYPES OF TRANSMITTING TUBES

Transmitting vacuum tubes operate upon the same general principle as any other form of vacuum tube but are larger and are designed to carry greater currents so as to deliver a large amount of power. Some of the receiving tubes are used as transmitting tubes where exceptionally small power is required. The lowest power transmitting tube that is in general use in transmitting stations is the UX-210 type of tube which is also quite frequently used in power amplifiers of receiving sets. The following description of the several types of transmitting tubes will serve to acquaint the student with their characteristics.

THE UX-210—CX-310 TUBE

The UX-210 or CX-310 is a low power transmitting tube that will normally deliver approximately 7½ watts. When used as an oscillator and without being overloaded, the plate voltage should be 350 volts. With this voltage applied to the plate and a normal grid voltage, the plate current consumption will be approximately 60 milliamperes. This tube can be overloaded considerably by applying a higher plate voltage but the life of the tube will be shortened considerably.

The XL type of thoriated filament is used in this tube and when 7½ volts are applied the filament current is 1.25 amperes.

Either alternating or direct current may be applied to the filament and in some cases and under certain conditions alternating current will tend to prolong the life of the filament.

The amplification constant of the tube is 7.5. When the above voltages are applied to the tube, the plate impedance is normally 3500 ohms. The mutual conductance of this tube is approximately 2150 micromhos when the tube is acting as an oscillator and under normal conditions. When oscillating the plate current will be approximately 70 milliamperes with a zero grid bias, and if the bias is increased to minus 45 the plate current will be cut off entirely.

Fig. 2.—CX-310

THE UV-203-A TUBE

The UV-203-A tube is a 50-watt tube having the same general characteristics as the UV-203, but having a lower filament consumption. This tube is normally supplied with 1000 volts on the plate and at this plate voltage a plate current of 125 milliamperes will flow when the tube is oscillating.

The filament is of the XL thoriated type and requires 3¼ amperes at 10 volts.

The amplification constant of this tube is 25; the plate impedance 5000 ohms and the mutual conductance approximately 5000 micromhos.

With a zero grid bias, the plate current is approximately 120 milliamperes and the cut-off point—that is, the amount of negative grid voltage that is required to reduce the plate current to zero, is minus 150 volts.

The main use of the UV-203-A tube in transmitting is as an oscillator and in some cases as a voice frequency amplifier or modulator. The UV-203-A is shown in Fig. 3.

THE UV-211 TUBE

The UV-211 is a low impedance 50-watt tube having the same general physical appearance and dimensions as the 203-A and requires the same plate voltage, the same plate current is consumed, and the same filament voltage and current.

As the UV-211 is a low impedance tube the amplification constant is, of course, somewhat smaller than in the 203-A. The amplification constant is 12 and the plate impedance is 1900 ohms. As the plate impedance is low, the mutual conductance of the tube, therefore, is slightly higher being approximately 6300 micromhos. Since the plate impedance is lower, there will be a much greater plate current flowing at zero grid bias—that is, 320 milliamperes.

The UV-211 was designed to supply a low impedance 50-watt tube where a considerable amount of power output is required. It is used as an amplifier for this purpose and as an oscillator or modulator in some types of circuits.

THE UV-204-A TUBE

The UV-204-A is a 250-watt tube requiring a plate voltage of 2000 and consuming 200 milliamperes plate current when oscillating. This tube is an outcome of the UV-204, but is supplied with the XL thoriated filament and consumes 3.85 amperes at 11 volts on the filament. The amplification constant is 25 and the plate impedance 5000 ohms with a mutual conductance of 5000 micromhos. With a zero grid bias applied to this tube and the tube oscillating, the plate current is approximately 280 milliamperes.

The maximum plate dissipation of this tube is 250 watts.

The UV-204-A tube is a general purpose tube and can be used either as an oscillator, modulator or amplifier. When employed as an amplifier, it is usually found in a very high power station as a voice amplifier. It is also used as a radio-frequency amplifier when using several stages of radio-frequency amplification in order to amplify the output of a low power oscillator.

Fig. 4 shows a view of this tube and it will be noticed that this tube is different from the preceding ones in that the plate terminal is not brought out at the base as in some of the previously described ones such as the UV-203-A or 211. The tube is usually mounted in an upright position with special blocks or mountings having springs making contact with the exterior connection of the elements and holding the tube in place. The two small outer prongs at the top of the tube are for the filament and the flat central blade is the grid connection. The plate connection

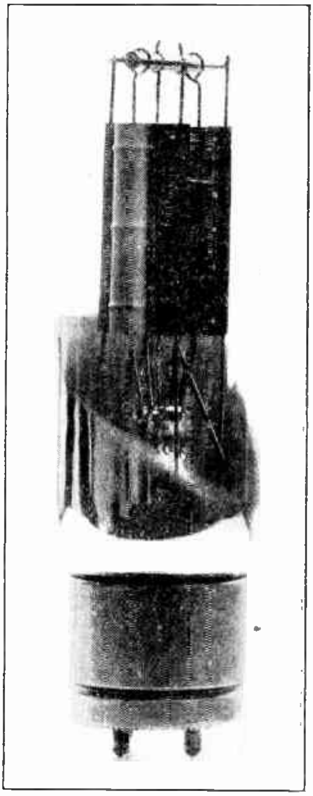

Fig. 3.—Radiotron UV-203A—UV-211

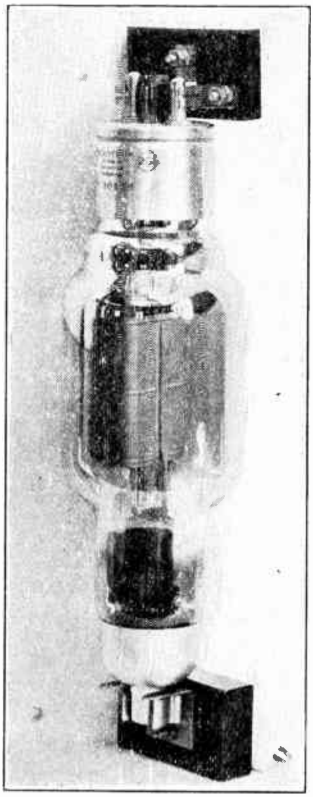

Fig. 4.—Radiotron UV-204A

is brought out and terminates in a metal cap having a small tubular projection which can be seen at the opposite end of the tube. (See Fig. 4.) The plate terminal is brought out at the opposite end in order to keep the high plate voltage as far away as possible from the filament and grid terminals.

THE UV-206 TUBE

The UV-206 is an older type 1-kilowatt tube but is still in general use. This tube requires 15,000 volts on the plate and when oscillating consumes 100 milliamperes. The filament is of tungsten and requires 14.75 amperes at 11 volts. It is of the Hi-Mu variety having an amplification constant of 300 approximately with a plate impedance of 115,000 ohms and a mutual conductance of 2800 micromhos.

The maximum plate dissipation of this tube is 350 watts.

The main use of the UV-206 is in the last power stages where a high plate voltage is at hand. In some cases this tube is used as an intermediate amplifier where a high plate voltage is present for use with other high power tubes. When such is the case it is possible to supply the plate voltage for this tube from the same source that is used for some of the higher power tubes in the last stages without requiring an intermediate voltage for separate use with this tube alone. The UV-206 tube is shown in Fig. 5.

THE UV-851 TUBE

The UV-851 tube is a general purpose tube having an output rating of 1 kilowatt and is similar in appearance and construction to the UV-204-A but is larger in its physical dimensions. This tube requires a plate voltage of 2000 and when oscillating the normal plate current is 875 milliamperes. In this tube the XL thoriated filament is used and it consumes 15.5 amperes at a filament voltage of 11.

The amplification constant is 20, being very much lower than that of the UV-206, and naturally the plate impedance will also be very much lower. In the UV-851, the plate impedance is 850 ohms and the mutual conductance is 2350 micromhos. The maximum plate dissipation is 750 watts.

THE UV-208 TUBE

The UV-208 is a 5-kilowatt tube requiring a plate voltage of 15000 and consuming 500 milliamperes when oscillating. A tungsten filament is used requiring 24.5 amperes at 22 volts. The amplification constant of this tube is 220 and the plate impedance 88500 ohms. The mutual conductance is 2500 micromhos. With a zero grid bias applied, the plate current is 1.8 amperes and with a negative grid bias of 85 volts, the plate current is reduced to zero.

The maximum safe plate dissipation is 350 watts.

The UV-208 is a general purpose power tube and may be used either as an oscillator, amplifier or modulator and when used in conjunction with the UV-206 it can be supplied with the same plate voltage thus eliminating the necessity of a separate source of plate voltage supply. The UV-208 is shown in Fig. 7.

THE UV-207 TUBE

The UV-207 is a general purpose 20-kilowatt water-cooled tube. The tubes previously described were air-cooled tubes and

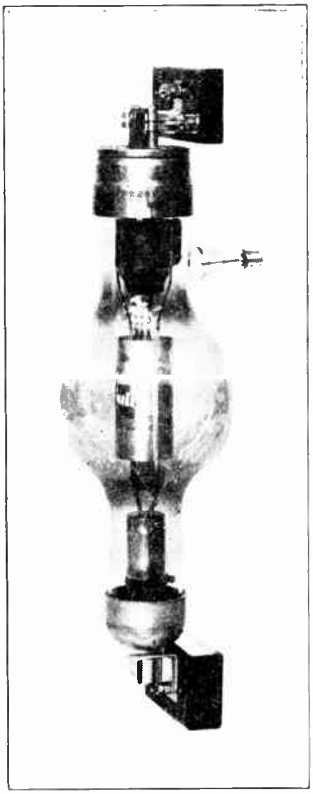

Fig. 5.—Radiotron UV-206

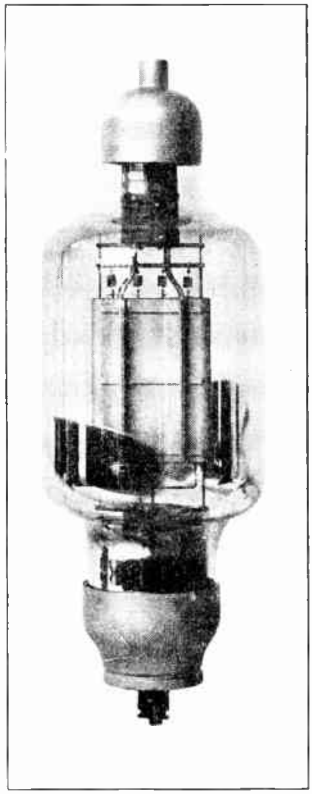

Fig. 6.—Radiotron 851

it was not necessary in designing such tubes to provide other than the natural circulation of air for the cooling of the tubes. In this type of power tube the heat generated by the elements is so great that the natural flow of air will not properly cool the tube and it was necessary in designing such tubes to provide a special construction so as to dissipate the heat generated. By referring to Fig. 8, it can be noticed that the construction of this tube is entirely different from the ones previously described.

Instead of all the elements being enclosed within a glass bulb, a copper tube is provided with a glass bulb sealed to one end of the copper tube and the other end of the copper tube is closed, being thus closed when the copper tube is molded and machined. The copper tube becomes the plate or anode and the grid and filament are supported inside this copper tube by the glass stem inside of the main glass bulb. The filament connections come out at the top of the glass bulb, while the grid connection comes out through a glass stem at the side of the glass bulb. Since the outer surface of the anode is exposed, it is usual to place the copper tube portion in a jacket which extends up to the beginning of the glass bulb and through this jacket a sufficient amount of water under pressure can be circulated to keep the plate and other elements of the tube within the desired temperature limits. It thus becomes apparent that one side of the water supply is in direct contact with the plate voltage supply and special precautions must be used to prevent short circuiting of the plate supply. Chemically pure water is a very good insulator and in order to further insulate the high voltage plate supply and prevent the by-passing of radio-frequency currents, the water supply to the tube usually passes through a rubber hose which is coiled in the form of a solenoid. Whatever radio-frequency current may be passing in the water itself is dissipated due to the fact that the coil forms a radio-frequency choke. Sometimes the water used in cooling the anode is derived from a special water system which does not come in contact with the ground.

The UV-207 tube requires a plate voltage of 15000 volts and when oscillating consumes 2 amperes. A tungsten wire filament is used and 52 amperes are required at 22 volts. The amplification constant of this tube is 20 and the plate impedance 3000 ohms with a mutual conductance of 6600 micromhos. The plate current cut-off is reached when a negative voltage of 920 is applied to the grid.

Short Wave Tubes

THE UV-852 TUBE

Considerable difficulty is encountered when operating the ordinary low power transmitting tubes on very high frequencies corresponding to something like 20 or 40 meters, due to the fact that in the former types the element leads coming out through the stem of the tube are so close together that flash-overs are often encountered. By flash-over is meant that the frequency of the current is very high and the voltage is sufficient to break the gap between the leads, a spark jumping directly between the leads. In some cases, these flash-overs result in puncturing the stem of the glass thus allowing air to enter the glass bulb and rendering the tube useless. In order to get away from this condition, it has been necessary to design and develop special tubes for short wave work.

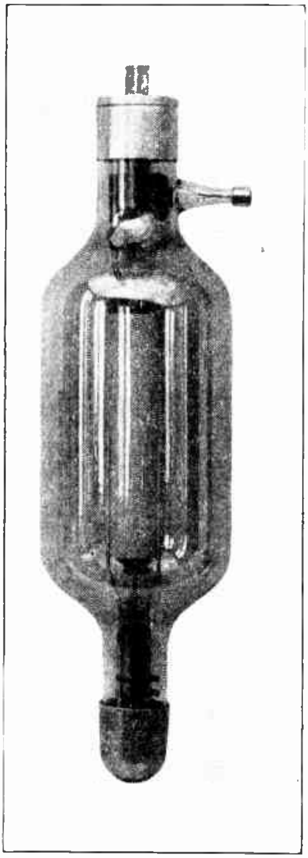

Fig. 7.—Radiotron Model UV-208

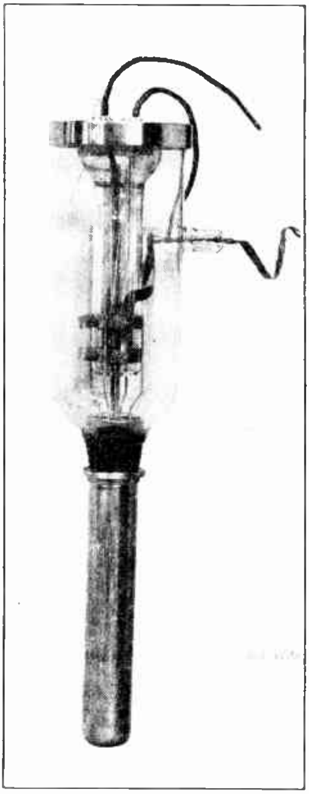

Fig. 8.—Radiotron UV-207

In Fig. 9 will be seen a view of such a short wave tube. It can be seen that this tube is of a "T" construction instead of the long tubular construction used in the other tubes. In the UV-852 the filament leads are brought out through one of the stems terminating in an ordinary UX base. The plate is of unusual construction in that it has large fins so as to radiate the heat that is generated by the plate. The leads from the plate are brought out at the side of the tube and the grid connection comes out at the top portion of the tube. It will be noticed that in each case there are two leads, each coming from the grid and the plate, and these are usually twisted together so as to form a larger current carrying wire.

This tube has a rated output of 100 watts and requires 2000 volts on the plate and consumes 75 milliamperes. The filament requires 3.25 amperes at 10 volts. The amplification constant is 12 and at a zero grid bias, the plate impedance is 6000 ohms and with a negative grid bias of 100, the plate impedance is 9000 ohms.

The maximum safe plate dissipation is 100 watts.

TUBE POWER RATING

The method of rating all American made tubes is by determining their power output. The power output is determined by the amount of power in high-frequency oscillating current that can be fed to an antenna system because this is the only part of the power that is radiated. It would be very hard to compute power in watts by the commonly used formula $P = E \times I$ because of the difficulty in obtaining a voltage reading. The voltmeter is a shunt meter and the antenna is a series circuit and any high resistance series connection such as a voltmeter would result in a false reading of the ammeter. For this reason, another more convenient form of the Power formula is used: $P = I^2 R$. This is easily derived from the formula $P = E \times I$

$$E = I \times R \text{ by ohms law}$$
$$P = I \times R \times I$$
$$P = I^2 R$$

Thus, with the latter rule, we only need to know the current reading of the antenna ammeter and the radio-frequency resistance of the antenna to compute the Power output in watts.

For example, suppose we are able to place 2 amperes into an antenna system having a R.F. resistance of 25 ohms, then $2 \times 2 \times 25 = 100$ watts Power.

The R.F. resistance of an antenna system is computed by first placing the antenna coil as usual in the circuit and getting an accurate reading of the antenna ammeter. A dummy antenna circuit consisting of a calibrated variable resistance is then introduced in place of antenna and ground and the power applied and the resistance varied until the ammeter reads exactly as it did formerly. The resistance of this dummy circuit is the same as that of the antenna system.

EFFICIENCY OF THE TUBE GENERATOR

We must next consider the question of the efficiency of the three-electrode tube as a generator of electric oscillations.

By this term "efficiency" is meant the ratio, expressed as a

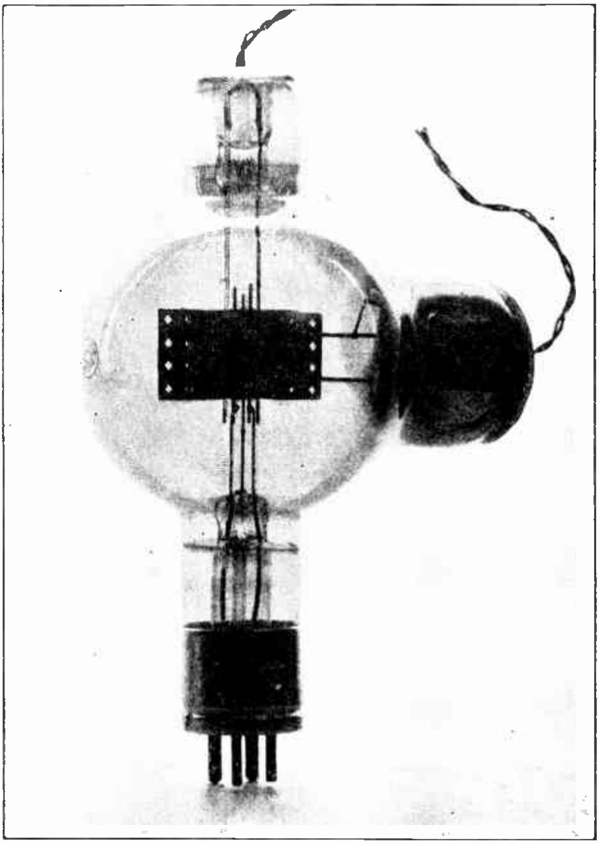

Fig. 9.—Radiotron Model UX-852

percentage, of the electrical power given to the external anode circuit in the form of alternating current, to the total power applied to the tube in the form of direct current. This last power is divisible into two parts, viz., the power expended in heating the filament which in watts is the product of the filament—ampere current and filament voltage, and the power in the form of high voltage direct current given to the plate—filament circuit of the tube. In high power transmitting tubes, the filament power is small compared with the plate current power, and is generally neglected and does not enter into the calculation of the efficiency of the tube as a generator.

It can be shown by mathematical calculation that when the triode is used as a generator of a pure sine wave alternating current that the efficiency of the tube under these conditions is limited to 50 per cent. As a matter of fact, it may not be more than 40 per cent.

If this were the only condition under which the tube could be worked as an oscillator, it would hardly be more efficient than some of the other forms of generators previously used. It fortunately happens, however, that we are able to obtain from the thermionic tube a much higher efficiency than 50 per cent. by an accurate adjustment of the grid and plate voltages and circuits. It is obvious that the dissipation of energy in the tube itself, which is the principal cause of the inefficiency, is due to the bombardment of the anode by the electrons emitted by the filament which dissipates part of their energy as heat in this impact.

If, however, we give the grid a certain direct current negative potential, so that during the oscillations of the grid potential which are superimposed, the plate current is reduced to zero for the whole of the time the grid is negative, the result will be an improved efficiency of transformation. In this case the anode will only be bombarded by electrons for half the period.

If we supply a tube with a normal load of 2000 volts and it draws 75 milliamperes, the power input (disregarding the filament entirely) would be $2000 \times .075 = 150$ watts. If we are then able to get an output of 100 watts as stated above, the tube is $66\frac{2}{3}\%$ efficient— $\frac{100 \text{ output}}{150 \text{ input}} = \frac{2}{3} = 66\frac{2}{3}\%$. This is considered a high efficiency for a tube. In the example given, it will be noticed that 50 watts were lost. This loss in power due to the heating of the plate is called plate dissipation. This dissipation is equal to input — output and should never exceed that figure specified by the manufacturers. The higher the output, the less becomes the plate dissipation and the greater the efficiency of the tube.

If we know the exact efficiency of a tube, we may determine its rated power in watts by input $\times$ efficiency % ; for example, if we supply a tube with 2000 volts and 75 milliamperes, we would have an input of 150 watts if the efficiency is 50%. We would have 75 watts output $150 \times .50 = 75$ watts.

MUTUAL CONDUCTANCE

The mutual conductance of a tube is the value obtained by dividing the amplification factor by the plate resistance. Since this value is the opposite of resistance, the unit is the "mho" or the word ohm reversed. The "mho" is, however, too large for practical use so the micromho is used or 1 millionth of a "mho." For example, the UV-207 20 k.w. tube has 3000 ohms plate impedance and an amplification constant of 20, therefore, $\frac{20}{3000} = .006600$ mhos or 6,600 micromhos. Thus, a high "mu" (mutual conductance) tube could be one having a high constant and low plate impedance. If the constant of a tube is doubled and the plate impedance also doubled, the mutual conductance would be unchanged.

THE VACUUM TUBE AS A GENERATOR OF OSCILLATIONS

A three electrode vacuum tube, if supplied with the proper continuous current power and if properly connected to a circuit having a natural period of oscillations, will, under certain conditions, generate alternating current power of the frequency fixed by the inductance and capacity of the circuit to which it is connected.

The action is nearly analogous to the system which drives the balance wheel of a watch. The mainspring furnishes power by a continuous force, but the escapement system serves to feed energy into the moving balance wheel in such a way as to maintain it in a state of oscillation, the period being fixed by the mass of the wheel and the stiffness of the hairspring.

The same principle applies to a vacuum tube circuit acting as an oscillator. Let us take Fig. 10 as a concrete example and analyze the occurrences that take place in this circuit. In considering the tube as an oscillation producer, we may neglect the constant or steady part of the currents or voltages and fix our attention only on the varying or alternating components. Within limits, a tube will oscillate more easily when a combination of power, grid voltage, and plate voltage is selected so as to make the result of an operation of arithmetic as small as possible This mathematical operation is $P \div Eg \times Ep$.

In the above operation, P represents the power. Eg represents the grid voltage. Ep is the plate voltage. The sign $\times$ denotes the mathematical operation of multiplying. The sign $\div$ denotes the operation of dividing.

The effective value of the periodic potential difference of filament and grid is called the "grid voltage," and denoted by Eg. The same for filament and plate is called the "plate voltage," Ep, and the periodic part of the plate current is denoted by Ip (see Fig. 10). If G is the mutual conductance (Mutual Conductance $=$ Ip $\div$ Eg), then Ip $=$ Eg $\times$ G. (The ratio of the change in plate current to change in grid potential producing it, under constant plate voltage.) If at any moment, the plate is positive with respect to the filament, there is an output of power (Watts $=$ Volts $\times$ Amperes) from the tube, represented by P (power) which equals Ep $\times$ Ip, and, therefore, Ep $\times$ Eg $\times$ G. Hence, if the tube is to act as an oscillation generator, we must have P $\div$ Eg $\times$ Ep $=$ G or G $=$ P $\div$ Ep $\times$ Eg. The mutual conductance, G, must equal some value as derived from the characteristic curve. The smaller, within limits, the value of P $\div$ Eg $\times$ Ep, the more easily will the tube oscillate. The frequency of oscillations is governed by the amount of the inductance, L, and the capacity, C, in the oscillatory circuit and is determined from the formula F (frequency) equals 1 divided by 6.28 times

$$\sqrt{LC}$$

It is important to note that the oscillatory circuit LC responds to currents of the same frequency as its fundamental as if it were nearly a non-inductive circuit, and the current therefore in the LC circuit is in step with impressed voltage or E. M. F.

There must be a certain proper coupling between the grid and plate circuits so as to induce a certain voltage in the grid circuit and also this induced voltage must be in such phase or relation that it will act at the proper time interval if self-sustained oscillations are to take place. Since the plate current is at a maximum when the grid voltage is positive and at a maximum, and since the time rate of change of the plate current is nearly 90 degrees different in phase from the current itself, it is easy to see that if the plate circuit is coupled through an air core transformer to the oscillatory circuit, the induced voltage, and hence current induced in the oscillatory circuit, will be 90 degrees in phase behind the plate current. If, then, the oscillatory circuit is coupled through another air core transformer with the grid circuit, the E.M. F. in the latter, and therefore the grid potential, will lag 90 degrees behind the oscillatory circuit current, and therefore 180 degrees behind the plate current. But by a proper connection of the circuits, the grid potential may be caused to be positive and at its maximum when the plate current is maximum, and to be a zero potential when the plate current has its mean value, and a negative maximum when the plate current is at its minimum value. This secures the right phase relation of the grid potential and plate current. Over and above the statements as to the phase relations of the currents, potentials and electromotive forces in the plate, grid and oscillatory cir-

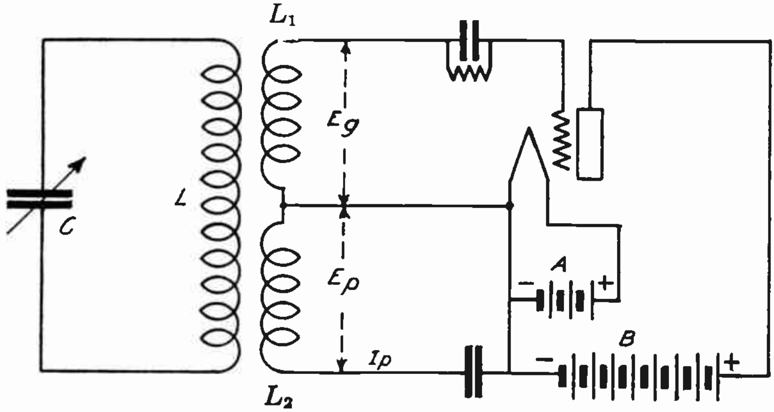

Fig. 10.—Theoretical oscillating circuit

cuits, we have to explain how it comes to pass that the battery in the plate circuit provides energy to maintain the oscillations.

The oscillatory and plate circuits possess resistance in their metallic connections which, small though it may be, dissipates energy and damps out free oscillations. Hence, in order that the oscillations may be maintained, the plate battery must provide power equivalent to the I^2R losses in the several circuits, where I is a current and R the ohmic resistance of the circuit in which it flows. The resistance of the plate circuit is partly metallic or constant, consisting of that of the wires and internal battery resistance, and partly due to the resistance of the highly-rarefied gas or of the vacuous space between the plate and filament. This latter part has a conductivity which is a function of the current through it, and it increases with the current within certain limits. Corresponding, then, to the rising part of the characteristic curve, we may draw a conductivity curve which is concave upwards, showing that the conductivity of the vacuous portion of the circuit increases with the current. Hence, if we consider that the normal current sent by the plate battery through the plate circuit is first increased by a certain amount and then decreased by an equal amount, the work done by a battery of constant E. M. F. will be increased in the first case by a larger amount than it is decreased in the second case, provided the tube is working at a suitable point on the characteristic curve. It follows from this that when the plate current oscillates more power is drawn from the battery than when the plate current remains steady or constant.

Part of this excess power is transferred by the coupling to the oscillatory circuit and serves to maintain oscillations in spite of the damping due to resistance, and the impulsive electromotive force necessary to counteract the damping is applied just at the right instant and in the right direction—viz., when the current in the oscillatory circuit is just beginning to flow. We may therefore consider the result of the periodically varying grid potential to be that the conductivity of the vacuous space between the plate and filament is thereby changed so that it is increased when the grid is positive and decreased when the grid is negative, but in such fashion that for equal increments and decrements of the plate current the battery is called upon to give more power during the increase than during the decrease, although on the whole yielding an increase of power while the current oscillations last. This excess of power furnishes that required to supply the energy loss due to the resistance of the circuits in which oscillations are taking place.

In order to explain more particularly the conditions under which we can obtain transformation efficiencies greater than 50 per cent, we shall assume a certain arrangement of the tube circuit as follows:

Referring to Fig. 11, the plate battery B has its negative terminal connected to the filament of the tube (V.T.), and the positive terminal is connected through a choke coil, "choke," to the plate P. The plate P is also connected to the filament through the low-resistance inductance coil L, and across this inductance coil is connected a condenser C. The grid G of the tube is connected to the filament through a coil L1 which is coupled inductively to the plate coil L, so that alternations in the direction of the current in all serve to give the grid potentials of the appropriate kind to maintain the alternating current in L. The charged grid may then be regarded as a kind of trap which serves to permit or stop the rush of electrons from the filament to the plate maintained by the battery B, at a positive potential. This trap is, of course, worked by the alternating current in the coil L.

Let us assume that the grid is negatively charged which is equivalent to the trap being shut. The battery is then sending an electron or negative current through the coil L from the filament to the plate end.

Suppose then that the grid suddenly becomes positive, or the trap opens. There is then a rush of electrons inside the tube from the filament to the plate, and this lowers the potential of

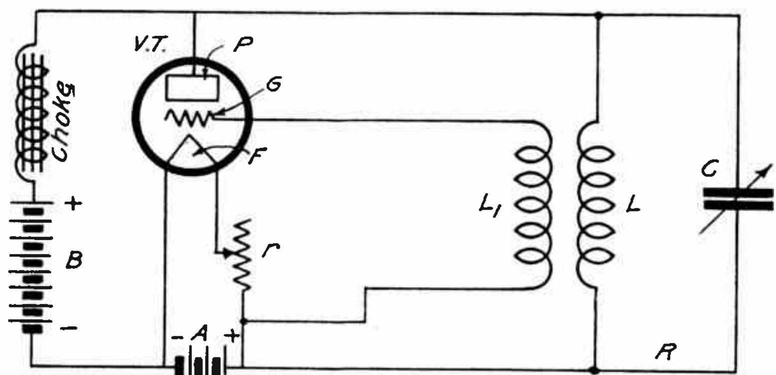

Fig. 11.—Theoretical circuit for explaining oscillating currents. Note the plate blocking condenser is intentionally left out in order to explain the circuit properly.

the plate and correspondingly raises that of the filament. This rush constitutes the internal plate current of the tube.

At the same time there is a movement of electrons in the coil L, toward the filament. This constitutes the external plate alternating current or one phase of it. Let us suppose, then, that the potential of the grid is suddenly made negative again, or the trap shuts. The flow of electrons through the tube is at once arrested. The coil L has, however, considerable inductance, and the electron stream in it toward the filament is not at once arrested, but tends to flow on and charge the filament side of the condenser C with negative electricity. The result of this is to raise the potential of the anode P rather above its steady potential due to the plate battery B.

This current in L is, however, presently reduced to zero and reversed in direction, and the battery B then sends an electron current through L from the filament end to the plate end. Superimposed upon the battery current, there is a current due to the discharge of the condenser C, which acts in the same direction. It will be seen, therefore, that the steady or direct potential difference of the plate and filament has superimposed on it an alternating potential difference which alternately raises the potential of the plate above or reduces it below the steady potential due to the plate battery.

In addition, there is an intermittent rush of electrons through the tube, this rush only taking place during one-half of the period, when the grid is made positive in potential compared with the filament. Lastly, there is an alternating current in the inductance coil L, which comprises a certain rush of electrons toward the filament end during the time the grid is positive and a slower or more steady current of less maximum value in the opposite direction during the time the grid is negative.

Consider in the next place the power given to or taken from the external current and dissipated against the plate of the tube. During the time the grid is positive, the anode is being bombarded by electrons and energy being dissipated as heat. Owing to the added direct current negative potential of the grid, this bombardment only takes place during the half period that the grid is positive in potential. During this time power is being drawn from or given up by the external inductance condenser circuit. At the reversal of the grid potential, the plate potential then rises above its steady value, and the electron current in the tube is stopped while power is given back to the external tube circuit in larger amounts than it was taken from it during the previous half period.

There is, therefore, a give and take of power to and from this external circuit with, on the whole, a balance of power given to it. The dissipation of energy against the plate due to the tube electron stream is confined to one-half period.

CLASSIFICATION OF CIRCUIT

There are only a few kinds of oscillating tube circuits, though there are almost endless variations of each kind. It is not necessary to give a detailed study to each of the variations as the study of the fundamental classes will enable one to readily understand the action that takes place.

From previous study it can be understood that in such a circuit as shown in Fig. 12, regenerative amplification can be accomplished. If an A. C. voltage of some kind is impressed on the LC circuit, the potential of the grid will be varied accordingly and these variations will in turn cause changes in the plate current. By having a coil L1 in series in the plate circuit so that the changing plate current causes a changing magnetic field in L1, we can further amplify the signal by placing the coil L1 near L so that the changing field of L1 reacts on L and induces a voltage in it. There is a certain amount of ohmic resistance in the grid circuit of the tube and by supplying energy from the plate circuit so that the effective resistance in the grid circuit is overcome, increased amplification is obtained. If the coupling between L and L1 is further increased so that the induced voltage in L is enough

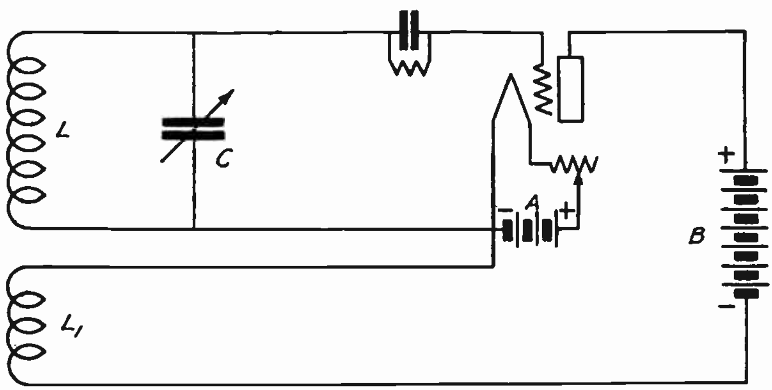

Fig. 12.—Regenerative circuit

to reduce the total effective resistance of the grid circuit to zero, then the alternating voltage which was formerly applied to L can be dispensed with. The tube will act as a generator of sustained oscillations due to the fact that we have a disturbance in the grid circuit and it is repeated in the plate circuit, and since the coil in the plate circuit is in inductive relation to the coil in the grid circuit, then any changes in the potential of the grid circuit will cause changes in the plate current. This in turn is caused to produce a voltage in the grid circuit and this action continues with the tube acting as a generator of self-sustained oscillations.

It can be noticed in Figure 12 that one end of the coil L1 connects to the negative terminal of the A battery and also one terminal of the inductance L connects to the same terminal of the A battery. Since this is the case, there is no reason why we cannot have such a circuit as shown in Fig. 13 in which only one coil is used. In making such a change it is, however, necessary to take a few precautions, otherwise the two circuits are practically the same. In this case the condenser C is connected across the end terminals of the coil with a tap from near the center of the inductance L going to the negative terminal of the filament. The positive terminal of the B battery is connected through a radio-frequency choke to the plate of the tube and the negative terminal of the B battery is connected to the negative terminal of the A battery. Should we try to connect the plate directly to the other terminal of the inductance L, a short circuit of the B battery would result due to the fact that the negative terminal of the B battery connects to the negative terminal of the A battery and to a mid-point of the inductance L. It is, therefore, necessary to insert a condenser C1 in series between the lead going from the

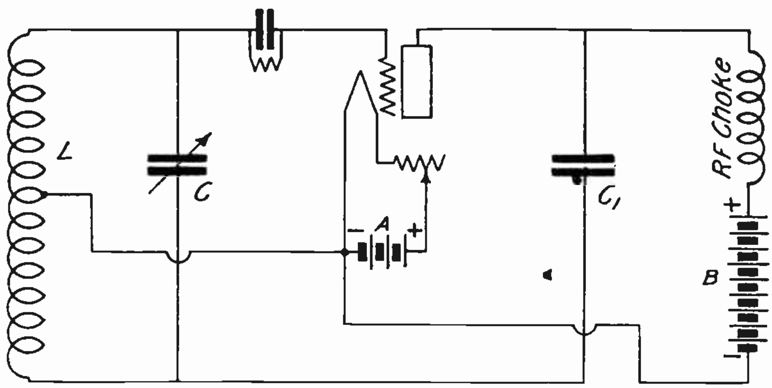

Fig. 13.—Hartley circuit

plate of the tube to one end of the inductance L so as to prevent the B battery from being short circuited. Such a condenser is necessary in this type of circuit and is often referred to as a plate blocking condenser. The alternating component or changing part of the plate circuit passes through this condenser and it is this energy that is fed into the grid circuit which causes the changing potential of the grid which is necessary in order to have sustained oscillations.

This type of oscillating tube circuit is known as the Hartley type, and derives its name from its inventor. This is one of the simplest types of oscillating tube circuits and is widely used by both amateurs and commercial stations throughout the world.

In the Hartley circuit a radio-frequency choke coil is inserted in the B battery lead to the plate so as to force the alternating component of the plate currents to choose the path through the plate blocking condenser so that it can be placed directly in the grid circuit instead of fluctuating through that part of the plate circuit composed of the plate battery. A grid leak and condenser is also used. However, the grid leak may be connected directly from the grid to the negative side of the filament supply and in a great many transmitting circuits this is the connection which is used in actual practice.

When an antenna and ground connection are desired so as to adapt this circuit to actual practical conditions, the antenna and ground connections may be made directly to the inductance L at the proper point or the antenna and ground may be connected to an inductance which is placed in inductive relation to the oscillatory circuit composed of L and C.

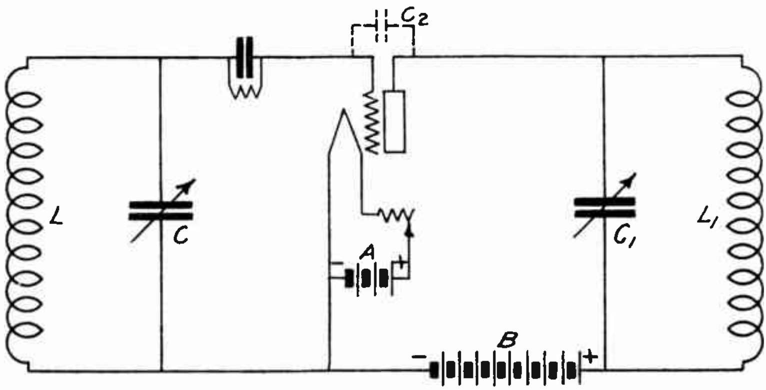

Fig. 14.—Tuned plate, tuned grid circuit

TUNED PLATE TUNED GRID CIRCUIT

In considering Fig. 12, it was stated that in order for oscillations to be maintained it was necessary to place the coil L1 near L so that the variations in the field strength of L1 could induce a voltage in L which would overcome the effective resistance of the grid circuit. If L1 is removed so that there is no coupling between L and L1 then it is impossible for the changes in plate current to induce a voltage in the grid circuit unless some other conditions are carried out. However, if the inductance of L1 is increased to the point where the frequency of the plate circuit is the same as the frequency of the grid circuit, then a transfer of energy from the plate circuit to the grid circuit will take place due to the inter-electrode capacity existing between the plate and grid of the tube. In Fig. 14 the coil L1 is not in inductive relation with L but the inductance of L1 has been increased and it has connected across it a condenser C1. If L and C1 are similar and C and C1 are similar then it is possible to tune the two circuits to the same frequency. Whenever the two circuits are in resonance, the required feed back energy that is necessary to sustain oscillations is secured through the capacity represented by C2 as existing between the plate and grid of the tube. Actually there is not any condenser connected in the exterior part of the circuit between the grid and plate but C2 merely characterizes such a capacity. Any variation in the potential of the grid will cause a corresponding change in the plate current and since the negative terminal of the B battery makes one connection to the coil L and condenser C, there is a capacity existing between the grid and plate. The alternating component of the plate current is then impressed on the capacity C2 and directly affects the

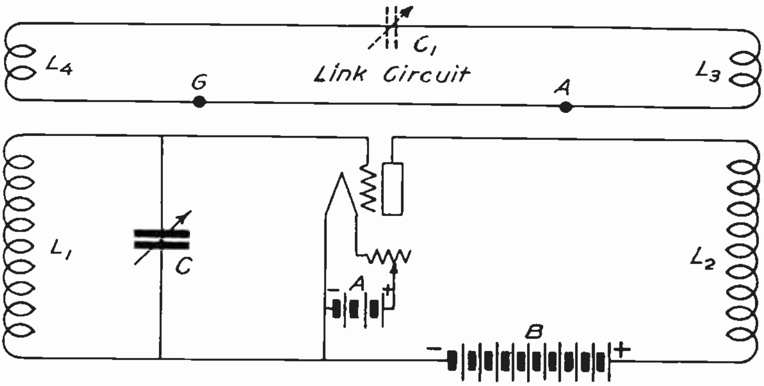

Fig. 15.—Meissner circuit

potential of the grid, causing it to assume a positive and negative potential with respect to the normal potential. This then furnishes the desired variations in the grid potential and the corresponding changes in the plate current which are necessary in order to sustain oscillations.

The discovery of this type of oscillating tube circuit is accredited to Major Armstrong and is often referred to as the Armstrong Tuned Plate Tuned Grid Circuit.

THE MEISSNER CIRCUIT

In discussing the requirements necessary in order to obtain sustained oscillations with the tuned plate tuned grid circuit, it was necessary to bring the plate circuit into resonance with the grid circuit in order to secure the desired feed back through the plate to grid capacity of the tube. In the event that sufficient inductance and capacity is not inserted in the plate circuit then sustained oscillations cannot be obtained. There is, however, at our command another method of producing the desired feed back without having the plate circuit tuned to resonance with the grid circuit or without having to place the plate coil directly in inductive relation with the grid coil.

The discovery of this arrangement is credited to Meissner and it is commonly referred to as the Meissner Circuit.

In Fig. 15 we have an arrangement whereby changes in the plate current will induce a voltage in the grid circuit and cause the desired results. Here we have a transformer combination of L2 and L3. The plate coil L2 passes power to L3 and the current flows through the pair of wires to L4. Since L4 and L1 make up a second transformer combination any current that circulates

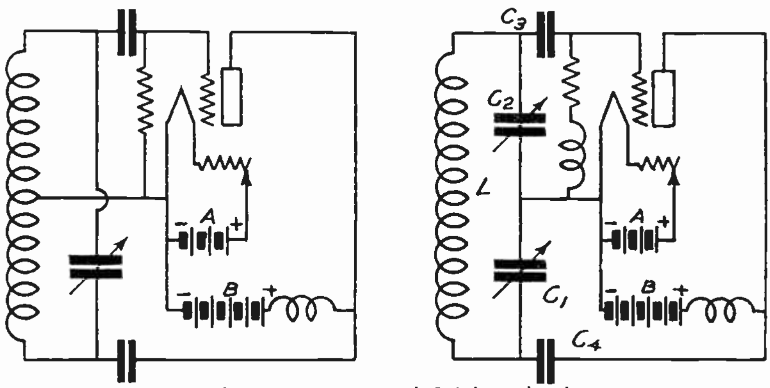

Fig. 16.—Hartley and Colpitts circuits

in the so-called "link" circuit consisting of L3 and L4 will induce a voltage in L1. This, then, gives us the desired coupling between the plate and grid circuits and the tube will act as a generator of sustained oscillations. The weakness of this arrangement is that the link circuit with its two coils is not a tuned circuit and therefore the oscillatory currents do not flow easily through the link circuit. This circuit can be further improved by placing a condenser in series in the link circuit as indicated at C1 so as to tune this circuit and make it responsive to a definite frequency. It will be noted that in the Meissner circuit the link circuit is neither a grid nor plate circuit but is a third separate circuit which furnishes the coupling between the plate and grid circuits. In actual operation the antenna is connected to the point A and the ground to the point B dispensing with the connection between these two points.

THE COLPITTS CIRCUIT

The Colpitts circuit is another type of oscillating tube circuit in which the capacity existing between the plate and grid of the tube is depended upon to furnish the necessary feed back. In the tickler feed back and Hartley systems magnetic feed back was depended upon, whereas in the Armstrong tuned plate tuned grid circuit and the Colpitts circuit a capacity feed back is employed.

In Fig. 16 the Hartley and Colpitts circuits are shown in order to bring out the similarity between the two circuits. In the Hartley circuit the filament is connected to an approximate center tap on the inductance, while in the Colpitts circuit it is connected to the wire joining the two condensers C1 and C2. The opposite ends of the inductance L are at opposite potential while the filament is at an "in between" potential, the exact amount of which depends upon the setting of the two condensers. Notice that in one circuit the grid leak is connected from the grid directly to the filament with a small radio-frequency choke in series so as to keep the radio-frequency losses down as much as possible. In the Colpitts circuit, this arrangement is strictly necessary so as to provide a circuit path for the D. C. grid bias. A leak connected across the grid condenser in the usual way would not have any useful effect since there would be a gap in the path of the grid current, the gap caused by the tuning condenser C2. In the Hartley arrangement we could, of course, put the leak across the grid condenser and omit the grid choke if desired. In both circuits it is necessary to have a plate blocking condenser. In the Colpitts circuit a short circuit of the plate supply would not occur if the plate blocking condenser were omitted, but a bad effect would be obtained due to the fact that the plate voltage would be applied to the condenser C1 and this is not a desirable feature. So, in the ordinary arrangement a plate blocking condenser is used.

The greatest disadvantage of the Colpitts circuit is the fact that two variable condensers are used and in changing the wavelength of the circuit it is necessary to change the setting of both condensers. For instance—suppose that we wish to change slightly the wavelength of the Colpitts and Hartley circuits. For the Hartley circuit, we have only to change the capacity of the tuning condenser and the wavelength is changed. It is not that simple for the Colpitts circuit. If the capacity of C1 is changed, the wavelength is changed—but it is necessary to readjust C2 also. Changing the capacity of C2 in turn changes the wavelength a little and we must reset C1 to get the right wave-length again. From this it can be seen that there is an "interlocking" adjustment whereby the setting of condenser C2 depends upon the setting of condenser C1 and vice versa. In the commercial form of this type of circuit, fixed condensers are sometimes employed for C1 and C2 and a variable inductance is used instead of variable capacities. This is an ideal arrangement where the transmitter is subject to vibrations or very rugged construction is desired.

As stated in the beginning of the explanation of the oscillating tube circuits, there are a variety of modifications, but it will be found that by comparing these circuits to the ones described the others can be classified under these main types.

TEST QUESTIONS

Number your Answer Sheet No. 32—2 and add your
Student Number

Never hold up a set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we will be able to work together much more closely, you'll get more out of your course and better lesson service.

1. Name the three essential parts of a vaccum tube.
2. Name the three general types of filaments that have been employed in vacuum tubes.
3. What is the plate voltage, filament voltage, plate current and filament current of the UV-851 tube?
4. What is the meaning of the term "flash-over" as applied to transmitting tube?
5. What determines the frequency generated by a vacuum tube?
6. Why is the radio-frequency choke coil placed in the plate circuit of the Hartley transmitter?
7. Draw a circuit diagram of a Hartley oscillator.
8. How is the energy fed back from the plate circuit to the grid circuit in the Tuned Plate Tuned Grid oscillator?
9. Is it necessary for the plate and grid circuits in the grid tuned plate transmitter to be in resonance?
10. Draw a circuit diagram of a Colpitts oscillator.


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POWER SUPPLY APPARATUS FOR TRANSMITTING TUBES

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Complete Course in Practical Radio

National Radio Institute Washington, D. C.

POWER SUPPLY APPARATUS FOR TRANSMITTING TUBES

From our previous studies we have learned how the vacuum tube could be used as a generator of oscillations. In this use of the vacuum tube we made mention of the necessary plate, filament and grid voltages. However, we did not go into detail as to how these voltages were secured and the apparatus necessary in providing these voltages.

The purpose of this lesson is to explain in detail how these voltages are secured; also the apparatus necessary to make these applicable for use with the vacuum tube as a generator of oscillations.

When studying receiving sets and receiving tubes we found that it was necessary to supply the plate with **direct current.** If the plate voltage supplied to radio or audio frequency amplyfying tubes in a receiving set is alternating or pulsating, there will be a humming or throbbing noise present in the loud speaker output. It is the same with the tubes that are generating the oscillations in a transmitting set, except that the output is not connected to a loud speaker. Nevertheless, the net result is the same.

If alternating current should be applied to the plate of a tube generating oscillations, the plate current would be flowing only one-half the time. When the alternating current was trying to flow in the opposite direction it would be blocked. Therefore the wave generated and sent out by the transmitter would be pulsating or interrupted. If the frequency of the A. C. applied to the plate were 60 cycles per second then there would be 60 groups of waves sent out each second with spaces between each group equal to 1/120th of a second. This would cause a humming noise in the output of the loud speaker at the receiver. From this it can be understood that the tube acting as the generator of oscillations at the transmitting station must be supplied with direct current. This direct current must be as nearly constant as possible.

Just previously we learned that if alternating plate current is applied to the generator tube (commonly called the oscillator tube) groups of waves are sent out. It therefore seems reasonable that if the plate current furnished the oscillator tube is direct, but varies in value (that is, it is not constant), we should expect practically the same results at the receiving station. Such is the case. A humming noise would be heard in the loud speaker of the receiver, the frequency of which corresponds to the frequency in variation of the oscillator plate current.

Here we have a simple but very important fact. Remember this always for it is one of the basic principles of radio transmission. Any variance in the oscillator plate current causes corresponding variance in the plate current of the amplifying tubes at the receiving set. If the varying current applied to the oscillator tube is at an audio frequency, then an audible sound will be heard at the loud speaker. If the oscillator plate current varies at some radio frequency then no sound will be heard in the speaker because it is above the range of audibility.

The intentional varying of the oscillator plate current at an audio frequency so as to cause some audio frequency sound to be heard at the receiving set loud speaker or headphones, is called modulation. We learned how the receiving set made use of this modulation in order to reproduce sounds. Later when we study this subject in another text we shall see just how it is accomplished at the transmitter.

In the preceding paragraph we said that modulation was the intentional varying of the oscillator plate current. From this we could infer that there are forms of undesirable modulation. This is also the case.

Most of us have noticed a slight humming noise in the loud speaker when the receiver is tuned to some transmitting station and no one is speaking, singing or playing before the microphone. All stations do not have this. The transmitting station should not always be blamed for in some cases the receiving set is at fault. When it does originate in the transmitter, it is the result of a fluctuating voltage being applied either to the grid or plate of some tube or tubes. Later we shall see the reason for this.

This undesirable modulation is generally spoken of as "a ripple in the carrier wave" or "noisy carrier." The carrier or carrier wave is the wave that is transmitted by the ether and is the result of the oscillator tube impressing high frequency oscillations on the antenna. In Fig. 1 is shown how the carrier wave is represented together with the modulated carrier, and a carrier with a ripple in it.

From our preceding lesson we learned that transmitting tubes require high plate voltages and in some cases considerable current. For instance the UV-207 twenty kilowatt tube requires 15,000 volts on the plate and consumes on the average of two amperes when oscillating. It is not therefore reasonable to expect that this much power can economically be supplied by batteries. Some low power transmitting stations have used batteries for this purpose, but ordinarily other apparatus is employed.

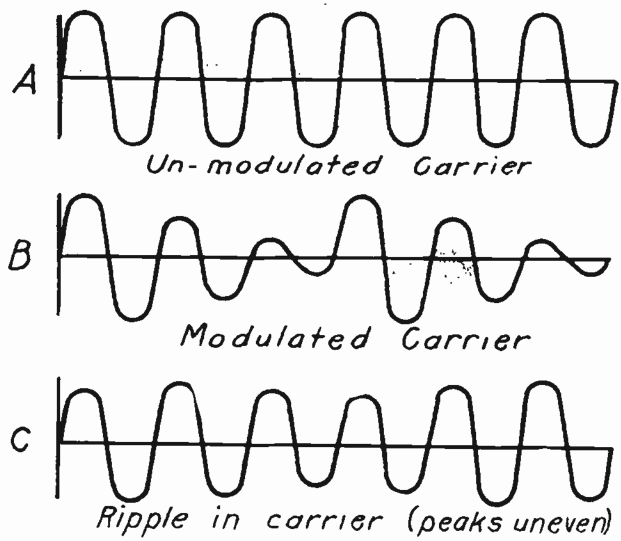


Fig. 1

Before taking up the detailed study of how the plate current supply is obtained let us first consider the filament supply.

THE FILAMENT SUPPLY

From our study of the previous lesson we learned something of the voltage and current that is required by the filament of large transmitting tubes. We shall now learn how this is supplied. But before doing so let us learn more about the nature of the filament and some of its characteristics.

The filament inside a power tube is one of the most precious parts of the whole transmitting set, due to the high cost of large transmitting tubes. Having as it does, only so many hours to live and this life in some cases being quite costly, extraordinary care should be observed to prolong the filament life. There are several ways in which this may be effected and the more important methods will be explained here.

Either alternating or direct current may be used to heat the filament, but as we shall later see, alternating current presents some desirable characteristics over the use of direct current. In small receiving tubes direct current is usually furnished by a battery but owing to the greater amount of filament current required for transmitting tubes, this source of supply cannot be successfully used except for the smallest types. When using this form of filament supply direct current generators of the correct power output are relied upon. Where the local lighting company furnishes alternating current, an alternating current motor is used to drive the direct current generator, thus converting the power. Such an arrangement is known as a motor-generator, one form of which is illustrated in Fig. 2.

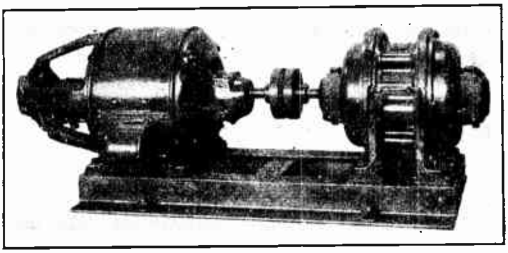


Fig. 2—Filament motor-generator set

When using alternating current for the filament supply there are two general means of securing the correct voltage and current. We can use a step-down transformer and reduce the voltage of the local power supply to the correct amount. Also we can again use a motor-generator driving the motor with the current obtained from the power mains and using the motor to drive an alternating current generator, or alternator as it is usually referred to, to supply the low voltage alternating current. This method is widely used by high power stations where large power tubes are used owing to high current at a low voltage required by the power transmitting tubes.

Let us now see why alternating current presents some advantages over direct current for a filament supply. It has been determined by theory and experience that the life of a filament will be considerably lengthened if it is heated by A. C. instead of D. C. When direct current is used as a source of supply the current flows through the filament in one direction only. Due to the voltage drop along the filament, the negative end of the filament is at the highest potential, since this is the end the electrons enter in passing through the filament. The electrons in the filament wire itself are then gradually driven towards the positive end and in time the negative end becomes partially inactive as far as electron emission is concerned. Thus there is not a constant and equal emission along the filament as it ages. Furthermore since the plate current flows through the filament the unequal distribution of emission is further increased.

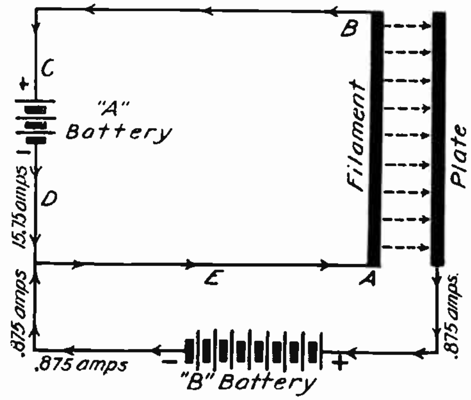


Fig. 3

In small receiving tubes the plate current is generally very small while in power transmitting tubes the plate current is considerable, being as high as two amperes in the 20 K. W. (kilowatt) type. The plate current has therefore quite an effect on the filament in transmitting tubes. Where a high plate current is present, the emission of electrons from various parts of the same filament differs very much. The filament current (hence filament temperature) is much greater at one end of the filament than at the other. As the filament does not give appreciable emission until it is quite hot, we may have a condition such as shown in Fig. 3. In this figure the arrows indicate the direction of electron flow. The filament is shown straight in order to further demonstrate the case.

The 1 K. W., UV-851 tube has a normal plate current of .875 ampere and a filament current of 15.75 amperes. From Fig. 3 it can be seen if a filament ammeter is placed at either C or D and the filament current adjusted to 15.75 amperes it would seem that the filament was being operated properly. According to the above conditions if the ammeter was placed at E the filament ammeter would register 16.625 amperes on account of the plate current flowing through this part of the circuit. End B of the filament is at a much lower temperature than end A, and is contributing a smaller amount of the plate current, as its emission is lower due to lower temperature. End A on the other hand, is furnishing most of the plate current and is also being operated at a higher temperature. The effect is, of course, to overheat that part of the filament where the current is greatest, causing it to burn out at that point before it should.

Most tube manufacturers take this into consideration in rating the tube so that the tube should be operated with the proper filament current including the plate current, but still this leaves the other end of the filament operating at a lower temperature.

When supplying the filament of a transmitting tube with A. C. and the plate circuit with D. C., if the negative side of the plate supply and grid return are connected directly to one of the filament terminals, there will be as previously explained, a crowding of current in the part of the filament next to this terminal. The alternating filament heating current in this part of the filament will alternately aid and oppose the plate current. As a result the plate current will be slightly modulated or varied, which will cause the emitted wave from the station to have a decided modulated A. C., hum, even if pure D. C., is used for the plate supply current.

THE FILAMENT CENTER TAP

In order to obviate the troubles just mentioned, the negative terminal of the plate supply and grid return should be connected to the midpoint of the filament. This would cause the plate current arriving on the two halves of the filament to become balanced so that the filament alternating current would no longer modulate the plate current. The crowding of current at any one point on the filament would also be much less.

The filament has only two connections, one at each end. In order to secure the advantage of this scheme other arrangements must be made.

The simplest arrangement for obtaining the desired result is shown in Fig. 4(A). Here a resistance is connected across the filament with the midpoint forming the common connection for filament, grid return and the negative terminal of the plate voltage supply. Since this resistance is across the filament supply transformer a current will flow through this resistance. Therefore it must be high enough to prevent any great amount of current from flowing. On the other hand the plate current must also flow through this resistance and it must not be so high as to interfere with the plate current flow.

A better arrangement is shown in Fig. 4(B). In this case the secondary of the filament transformer has a center tap. The grid return and negative terminal of the plate supply are then connected to this tap. An important point which should always be remembered is that the secondary of the filament must be designed to withstand the high-plate voltage, since the positive terminal of this high voltage connects to the plate and the negative terminal to the secondary center tap of the filament

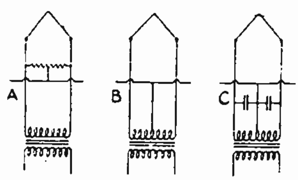


Fig. 4—The center filament tap

transformer. This voltage being applied to the filament transformer, the plate current must pass through at least a part of it. In designing such a transformer this must be considered and the insulation of the winding and the insulation between core and winding must be sufficient to withstand this voltage without breaking down.

Both of the methods so far described have some disadvantages. It is not desirable to uselessly waste energy by connecting a resistance across the filament and thus inserting resistance in the grid return and path of the plate current. Neither is it desirable to force all radio frequency currents in these circuits to flow through the filament transformer secondary winding. The result of such procedure is usually punctured insulation of the secondary winding.

By inserting by-pass condensers having a lower reactance than the secondary to the flow of these radio frequency currents they can be kept out of the secondary winding. This arrangement is shown in Fig. 4(C). This method is in general use and offers the best solution to the problem. The capacity of the by-pass condensers should not be lower than .002 mfd., and any capacity between this and 1 mfd. will suffice. If the filament transformer is located some distance from the tubes, the by-pass condensers should be connected near the socket terminals so as to by-pass the radio frequency currents without having them flow through all the filament wiring.

PLATE SUPPLY OF TUBE

The plate supply system to transmitting vacuum tubes is one of the most important units of the whole transmitting system. We have previously seen that this plate supply must be continuous direct current with as little variation in the amount of current flowing as possible. For very small transmitting sets, batteries either of the dry cell or storage type are sometimes used. However, as the size of the transmitting equipment is increased, the use of batteries for plate supply becomes less desirable. There are a few broadcasting stations that use batteries as the plate supply, but most of these stations are owned by battery manufacturing concerns who desire to demonstrate the fact that it is possible to use batteries. The disadvantage of having to keep storage cells charged and the great number required, can easily be appreciated. It is necessary to have two sets of batteries so that when one is being charged, the other can be in operation and vice versa.

We can, therefore, disregard this form of plate voltage supply except in conjunction with very small transmitting stations. Practically speaking, the *three types* of plate voltage supply now in general use are divided as follows: *Motor-generator*, *pre-rectified alternating* current, and *self-rectified circuits*.

MOTOR-GENERATOR SYSTEM

Where low voltage direct current only is available, a motor-generator is a necessity in order to step up the voltage to the required amount. Suppose the commercial lighting current is 110 volts direct current. In this case, the motor-generator would be a necessary adjunct if the plate supply voltage is higher than this amount. Since power tubes require considerable voltage on the plate and since a direct current cannot be stepped up by means of a transformer, we must rely upon a motor-generator. For amateur work, the motor-generator presents a very feasible plan for obtaining the high-voltage plate supply. This applies even though alternating current is available. We shall learn later that in order to convert alternating current into direct current for the plate supply, some form of rectifier and filter are necessary. When using a motor-generator, the high voltage plate supply can be obtained regardless of the form of commercial current available.

For commercial work, such as in commercial code stations or broadcasting stations, the use of a motor-generator for this form of plate supply is limited to some of the smaller power sets. When using a voltage on the plate of the transmitting tube much greater than 3,000 volts, the size and cost of the motor-generator

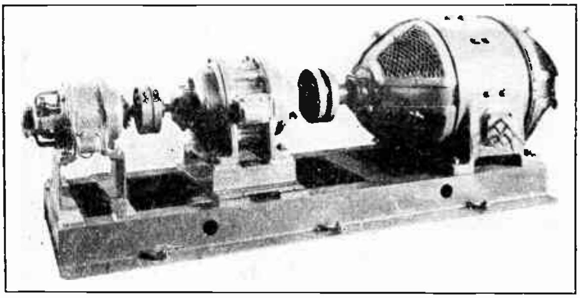


Fig. 5—Three-unit plate motor generator set

increase considerably. For instance, in the case of the 207 type of transmitting tube, a plate voltage supply of 15,000 volts is required. A 15,000 volt direct current generator capable of generating enough current would not only be very large, but its cost would be considerable. There is a slight loss in the transformation of energy and the motor-generator is not excepted. The motor of the motor-generator would, therefore, consume a great deal of current. In most cases, it is desirable to eliminate as much rotating machinery as possible. Rotating machinery sometimes creates considerable vibration and this might be an undesirable feature around a transmitting station.

In Figure 5 is shown a typical motor-generator suitable for use with some of the smaller transmitting tubes either for amateur, commercial code or broadcasting station use.

PRE-RECTIFIED CIRCUITS

This form of plate supply is by far the most practical for large transmitting stations where the plate voltage is very high. Its most desirable characteristics are: Freedom from rotating machinery and vibration; ease of operation when once installed; very little attention required while in operation; and ease of starting and stopping the operation of the system.

The pre-rectified system of plate voltage supply consists essentially of apparatus which may be divided into three general classifications as follows: The power transformer, the rectifier, and the filter. Each of these will be taken up in order and described in detail.

SELF-RECTIFIED CIRCUITS

Self-rectified circuits use alternating current on the plates of the tubes and they rectify it as they use it. Instead of rectifying the current before it reaches the transmitter or an oscillator by means of special rectifying tubes and filter systems, it is fed directly to the three element tubes and rectified while used. Usually two tubes are used in a self-rectified circuit so that full wave rectification will result.

The circuit shown in Fig. 5(A) has two tubes wired in a Hartley oscillator circuit, one functioning for each half of each cycle, and the circuit is sometimes called a back to back circuit because of this particular arrangement. Other circuits, such as the Colpitts, tuned plate tuned grid, etc., may be wired with a back to back self-rectified system of this kind, if desired.

THE POWER TRANSFORMER

The function of the power transformer is to change electric power at one voltage and current to power at another voltage and current. The transformed power may be greater or less than the voltage of the source depending upon the use of the transformer and the line voltage and plate voltage desired. Since transmitting tubes generally require a plate voltage higher than the voltage of the source, a power transformer generally assumes a step-up voltage ratio.

The input winding connects to the source of supply and is called the primary winding. The output connects to the load or rectifier and filter and this winding is called the secondary. Any transformer may be used for either step-up or step-down work by reversing the connections to the primary and secondary. To avoid confusion when referring to a transformer it is always best to refer to the transformer windings as high voltage or low voltage windings instead of primary and secondary unless it be known whether the transformer is of the step-up or step-down variety.

The exact characteristics of the transformer are governed by the type of current supplied to the input winding. Most transformers that amateurs build are for use on 110 volts 60 cycle supply. The number of turns necessary on the 110 volt winding depends upon the quality of the iron core used and on the cross section to the core. Silicon steel is best for the transformer core material. Various types of iron and steel possess different characteristics with regard to the density of the lines of force per square inch in the core material. A silicon steel core which has the capability of 50,000 lines per square inch should be used. This

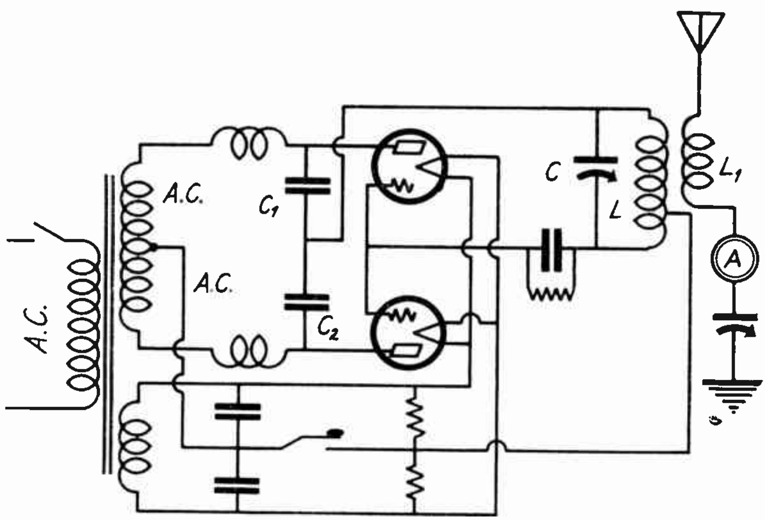


Fig. 5(A)

is the basis of the flux density (number of lines of force per square inch) that is used in all of the calculations following. The size of the wire used in the windings depends on the current consumed in the input and the current expected to be drawn from the output winding. This will vary with the load (that is, the amount of power consumed and withdrawn from the transformer).

A circular mil is the area of the cross-section of a wire 1/1000th of an inch in diameter. When a small transformer is built to handle a continuous load, the copper wire in the winding should have an area of 1,500 circular mils for each ampere to be carried. For intermittent use, 1,000 circular mils per ampere is permissible. The diameter of the wire and the circular mils of such wire can be obtained from an ordinary wire gauge which is supplied by most wire manufacturers and is shown in a great many texts.

The transformer uses a little energy to supply losses in the core and windings. Due to the resistance of the windings, and to the magnetic leakage path, the voltage of the secondary may drop materially under load. Poor regulation, as this is called, is sometimes useful in a special transformer. In filament heating and plate supply transformers, the windings are arranged compactly, making good solid joints in the core, using large low resistance wire in the windings, and keeping the length of the magnetic path fairly short and of good cross-section. This will keep the secondary voltage quite constant under load.

A table is given showing the best size wire and core to use

TABLE 1

DESIGN DATA FOR CLOSED CORE TRANSFORMERS

Input (Watts)	Full-load Efficiency	Size of Primary Wire	No. of Primary Turns	Turns per Volts	Cross-Section Through Core
50	75%	23	528	4.80	1¼" x 1¼"
75	85%	21	437	3.95	1⅜" x 1⅜"
100	90%	20	367	3.33	1½" x 1½"
150	90%	18	313	2.84	1⅝" x 1⅝"
200	90%	17	270	2.45	1¾" x 1¾"
250	90%	16	248	2.25	1⅞" x 1⅞"
300	90%	15	248	2.25	1⅞" x 1⅞"
400	90%	14	206	1.87	2" x 2"
500	95%	13	183	1.66	2⅛" x 2⅛"
750	95%	11	146	1.33	2⅜" x 2⅜"
1000	95%	10	132	1.20	2½" x 2½"
1500	95%	9	109	.99	2¾" x 2¾"

for particular transformers. The figures in the table refer to 60-cycle transformers. The design of 25-cycle transformers is very similar. A slightly higher flux density is permissible. Because the frequency is much lower, the cross-sectional area of the iron must be greater (or the number of turns per volt correspondingly larger). Otherwise, the inductance of a certain number of turns will be too low to give the required reactance at the reduced frequency. If one builds the core so that its cross-section is 2.1 to 2.2 times the value of area worked out from the table, the same number of turns of wire may be used in a primary coil for 25-cycle operation.

Suppose it is desired to build a plate transformer for two UX-210 (7½ watt) tubes. The general practice is to supply two of these tubes with about 100 milliamperes at 500 volts. Allowing about a 50% voltage drop in the rectifier and filter, this means that the voltage supplied by the output winding should be approximately 750 volts. A transformer built for this voltage can be used with a resistance in the input winding to make an additional voltage drop if it is necessary to work with just one tube or lower voltages to prevent heating. With one tube the current required will be less and the regulation will be better. Since the voltage output of the transformer must be 750 and the current consumed is approximately 100 milliamperes, then 750 times .100 equals 75 which is the output wattage of the transformer.

The table gives us the probable efficiency of about 85% or 90% for small transformers of this size. It will be noticed as the size of the transformer is increased, the efficiency will jump considerably. An efficiency greater than 95% is hardly ever obtained.

The number of turns in the secondary winding is governed by the number of turns in the primary and the desired secondary voltage (in this case 750). Before the number of secondary turns can be found out, we must know how many turns per volt there are in the primary. This can be found by dividing the number of primary turns by the primary voltage which is given directly in the table. The number of turns for the secondary can now be found by multiplying this figure by the desired secondary voltage. As the power output of the transformer is 75 watts, the number of secondary turns can now be found (750 times 3.95 equals 2963 turns). The size of wire to be used in the secondary depends on the secondary current and the current density can be found in the same way from a wire table. For this lay-out of equipment, look for a size of wire for the secondary that will safely carry 100 milliamperes (.1 ampere). This will be found to be No. 30 B & S gauge wire. It is a good idea to add three to five per cent of the number of secondary turns to the winding to make up for the voltage drop that will occur at full load due to the transformer losses and regulation (105% times 2963 equals 3110 turns.)

Another convenient formula which can be used to roughly determine the details for a given transformer can be obtained from the following:

$$T = 7.5 \times \frac{E}{A}, \qquad A = 7.5 \times \frac{E}{T}, \qquad E = \frac{TA}{7.5}$$

In the above formula, the letter T represents the number of turns of wire, E equals the voltage applied to the winding, A equals the area of core in square inches, and 7.5 is a constant that is used when the frequency of the current applied is 60 cycles per second. If the frequency is 25 cycles per second, then the constant 9 should be used instead of 7.5, and when the frequency is 12 cycles, 25 should be used.

Although this is a very crude formula and cannot be used when designing complicated transformers, it will serve the purpose of the average person desiring to design a small power transformer for his own use. For instance, suppose that it is desired to design a 10-to-1 transformer to be used for a filament lighting transformer and that the area of the core is 2 inches square. This would give us an area of 4 square inches. From the above formula in which

$$T = 7.5 \times \frac{E}{A}$$

we can find the number of turns necessary. If the voltage applied to the primary is 110 volts, we then have

$$T = 7.5 \times \frac{110}{4} \text{ which equals 206.}$$

This is the number of turns that will be necessary for the primary when using a cross-section area of 4 square inches for the core. If we use a step-down transformer having a ratio of 10 to 1, then there should be one-tenth the number of turns in the secondary as in the primary, or 20.6 turns in the secondary.

It must be borne in mind that the usual step-up power transformer employed consists of a center tap secondary. In this case it will be necessary to use twice the number of turns in order to gain the full voltage required due to the fact that the transformer is tapped at the center. Thus, there are only one-half as many turns acting for each half of the cycle as there would be if the transformer were not center tapped.

THE RECTIFIER

The function of the rectifier is to convert alternating current into as near continuous direct current as possible. Very few rectifiers will convert alternating current into direct current which does not have some varying characteristic or pulsation.

Also, different forms of rectifiers possess different characteristics, some being very good rectifiers while others are very poor.

There are two forms of rectifiers in general, the single wave and the full wave types. In the single or half wave type, a pulsating direct current is the result. By looking at Figure 6(B) it will be noticed the current is flowing only one-half the time and corresponds to only one-half the cycle as represented in the alternating current. The result then of the half-wave rectifier is that it cuts off the alternating current when it tries to reverse and flow in the opposite direction. This leaves a pulsating direct current. In the full wave type of rectifier both halves of the alternating current are made use of. The connections are so arranged that when the alternating current tries to reverse its direction of flow, it is made use of to have more nearly a continuous direct current. This is clearly shown in Figure 6(C).

There are two general types of rectifiers which are in

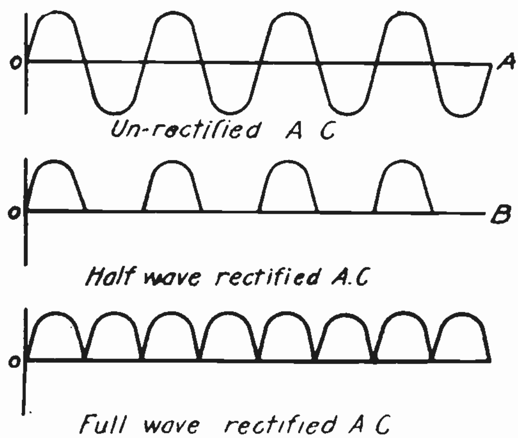


Fig. 6

use at the present time. There are several other forms of rectifiers and these are not nearly as widely used and our discussion will be confined to these two major types as follows: The chemical or electrolytic rectifier and the tube rectifier.

THE CHEMICAL OR ELECTROLYTIC TYPE

The chemical or electrolytic rectifier is a very cheap type and is widely used by amateurs desiring to hold down the cost of the apparatus. It is used very little in commercial work for several reasons, such as the bulkiness of the jars required, the inefficiency of the system, and the care required while in operation and maintenance.

For an amateur station, the electrolytic rectifier is one of the best. It is bulky and sloppy, but works well. It usually consists of a jar in which some chemical substance is used as an electrolyte and two rods or plates of different metallic characteristics. One very simple type of electrolytic rectifier consists of a chemically pure aluminum rod and an iron or lead rod and a solution of soda or borax as an electrolyte.

Chemically pure aluminum is hard to obtain, while the lead or iron element is plentiful and cheap. In designing a chemical rectifier, sufficiently large jars should be used to prevent undue heating of the solution. Allow forty or fifty volts to a jar and a current density of not over forty milliamperes per square inch of aluminum sheet. Chemical rectifiers of this type are very cheap and are easy to filter. They must go through a process of forming before they are ready for operation and special care must

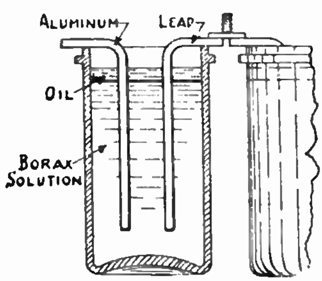
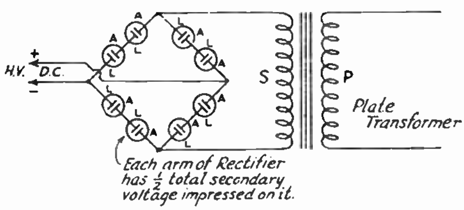


Fig. 7—Cross-section of an electrolytic rectifying jar

be used in first forming an electrolytic rectifier, especially if the cells are formed in series across a high voltage transformer. When the rectifier jars are connected across a source of voltage such as the transformer secondary, current will be quite high until the film which forms on the plate is partially completed. Lamps or other resistances in series, closing the circuit for a few moments at a time, should be incorporated in the forming process until the current drawn from the transformer or other voltage source is not above its rated capacity. The maximum current density should not exceed the normal operating density and the jars must not be allowed to heat as the film on the aluminum plate begins to break down at about 120 degrees Fahrenheit. If there is sparking, the rate must be reduced, as the film on the aluminum will be destroyed as fast as it is made. A well-formed aluminum electrode will be smooth and have a thin, dull, white surface.

There are several electrolytes or solutions which may be used in the rectifier. A dilute solution of sodium bicarbonate (ordinary baking soda) gives good results and is quite inexpensive. A ¼" layer of transformer oil should be poured on top of the solution to reduce evaporation. Sodium-ammonium phosphate and sodium-potassium tartrate are also good but more expensive. The use of borax requires a saturated solution—that is, as much borax should be dissolved in the water as the water will take. If baking soda is used, there will be a heavy, white precipitate formed at the aluminum electrode which will settle at the bottom. As this does not appear after the aluminum is formed, an old solution can be used for forming and the



BRIDGE-CONNECTED LEAD-ALUMINUM RECTIFIER

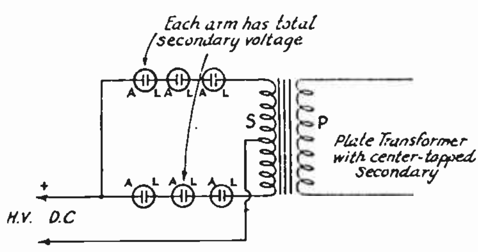
Fig. 8

electrodes put in a clean solution afterwards. Lead and iron are not satisfactory for use as auxiliary electrodes in an aluminum rectifier that has an organic solution, but they work well with a borax solution or with a dilute baking soda solution. A carbon auxiliary electrode is satisfactory when an organic rectifier solution such as tartrate, acetate, or citrate is used.

When a good large filter is used, there is a "back voltage" or counter electromotive force from the charge left in the filter condenser which has an effect in the rectifier circuit as soon as the circuit is broken. When a key is used as in a code station, this condition becomes more pronounced. This counter voltage is applied to the rectifier at the same time the transformer is applying high voltage alternating current to it. This may make the voltage per jar too high so that some of the aluminum film breaks down, sparking and making a noise that does not filter out easily. A few more jars added to a rectifier will usually cure this trouble permanently. The transformer voltage that causes break-down is always at the peak of the A. C. cycle which is nearly one and one-half times the effective value of voltage at which A. C. circuits are rated.

It has been found that in the construction of chemical rectifiers of the lead aluminum type that the safe current density per square inch of plate surface is 40 milliamperes. This means that if more than 40 milliamperes flow out or in each square inch of plate surface of the rectifier jar, over-heating and other troubles will result. Therefore, if we must pass 200 milliamperes through a chemical rectifier we must supply 5 square inches of plate surface to safely carry this amount of current.

There is also a limit to the safe maximum voltage which can be applied to one jar of a chemical rectifier system, and in this particular case is 50 volts. If we have a voltage supply of 550 which we are rectifying we divide this by 50, giving 11 jars in the series. When using 11 jars only 50 volts will exist across the terminals of each one. These are constants only with respect to the lead aluminum borax rectifier.



CONNECTIONS OF CHEMICAL RECTIFIERS

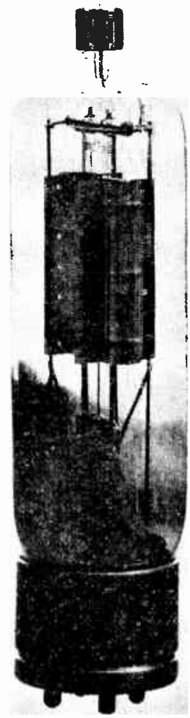
Fig. 9

Diagrams of connections are shown in Figures 8 and 9. An example of designing an electrolytic rectifier might also be useful. Suppose we have two UX-210 tubes to supply and each normally takes 45 milliamperes of plate current; that makes 90 milliamperes which they are using. Our transformer, let us say, gives us 550 volts on each side of the center tap. Assuming 100 milliamperes maximum load, 100 divided by 40 gives us 2½ square inches of aluminum that must be immersed in each jar to carry the current. 550 divided by 50 makes 11 jars necessary for each leg of the rectifier. We should use 12 jars to give the necessary 10% safety factor. Some jelly tumblers may be pressed into service to hold the solution. A small rack and some wooden pieces holding the electrodes and jars will complete the outfit.

TUBE RECTIFIERS

A vacuum tube rectifier has a somewhat greater first cost and replacement cost than an electrolytic rectifier. It does not require any forming process or much care while in operation. It is also convenient and in large transmitting stations occupies less

UV-214 Rectron

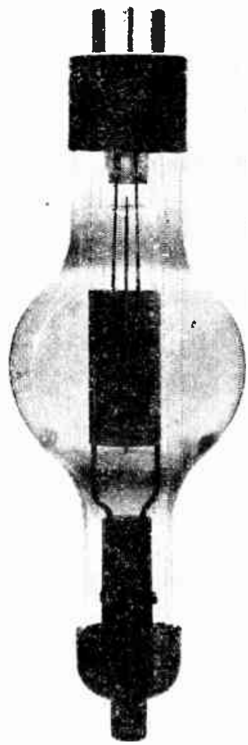


UV-217-C Rectron

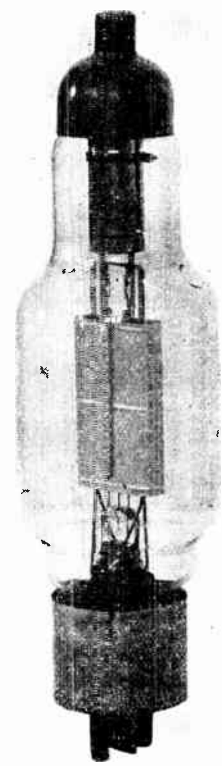
space than some of the other types of rectifiers. In fact, in the large installations the vacuum tube is depended on as the rectifier. The electrolytic rectifiers for small amateur stations have condenser characteristics and are cheaper in first cost. The tube rectifiers come next in ease of filtering.

The two-element vacuum tubes for rectifying are known as Rectrons. The filament gives off electrons when heated and current can only flow through the tube in one direction. The rectifying circuit is similar to that used in the chemical rectifier. The filaments are always at plate potential and the low voltage winding of the filament transformer must be insulated from the high voltage. Separate filament transformers should be used for the rectifier and oscillator tubes.

The Rectron tubes are manufactured in appropriate sizes for use with the corresponding oscillator tube and the two element Rectron costs about three-fourths as much as the same size



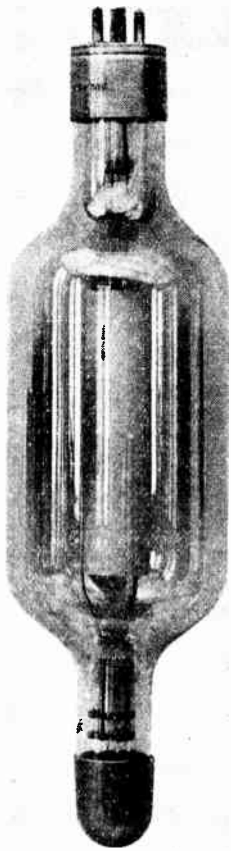
UV-218 Rectron



UV-1651-A Rectron

three element oscillator tube. The efficiency of the electrolytic and tube rectifier is rather low, for which the loss in heating the rectifier solution and the plate of the Rectron, and the power consumed by the filament of rectifying tubes is responsible. Tube rectifiers have a larger voltage drop across the rectifier unit than have chemical rectifiers.

Most of the first cost in connection with tube rectifiers goes into the extra filament heating equipment. For a sending set using one or even two UX-210 tubes, a couple of 216-A Rectron tubes will be an excellent investment. Since tubes requiring less filament current have come on the market, all types of tungsten filament tubes have become of less importance.



UV-219 Rectron

In very low power sets some of the gaseous conduction rectifier tubes that are used in "B" eliminators may be used as rectifier tubes. Even the whole "B" eliminator assembly may be used if the voltage required by the transmitting tube is low enough to come within the scope of the eliminator.

A table giving the characteristics of the various Rectron tubes is shown on this page.

THE FILTER

As previously explained, the function of the filter is to smooth out any alternating current fluctuation that may be present either in the rectified output current or in the current supplied from the motor-generator. This fluctuating current is often referred to as the ripple.

Direct current generators operating under normal conditions have three sources of disturbance, i. e., commutator ripple, slot ripple, and the noise of the moving contact. The armature windings are a series of coils around the iron armature, forming one large coil, with taps brought out to the commutator segment.

TABLE II

Tube Number	Voltage Input	Voltage Output	Normal Plate Current amps.	Plate Dissipation	Max. Plate Current amps.	Filament Volts	Filament Current amps.	Filament Type	Height Inches	Diam. Inches
UX-213	440				.065	5.0	2.00	XL		
UV-214	18000	15000	3.0	10 K.W.		22.	52.	Tung.	18.75	4.1
UV-216	550				.06	7.5	2.35	Tung.		
UX-216B	550				.065	7.5	1.25	XL		
UV-217A	1500		.20		.20	10.0	3.25	XL		
UV-217B	5000	5000	.075	100 W.		10.0	3.25	XL		
UV-217C	3000		.150	100 W.		10.0	3.25	XL	8.5	2.0
UV-218	16000	15000	.166	350 W.		11.0	14.75	Tung.	15.6	5.0
UV-219	17500	15000	.833	1 K.W.		22.0	24.50	Tung.	22.4	6.0
UV-1651	2500			250 W.		11.0	14.75	Tung.		
UV-1651A	2500			200 W.						

Voltages induced between the commutator segment are not equal, and vary as the armature revolves. When certain coils are nearest the field poles of the generator, the induced voltage is maximum and when a particular armature coil is at right angles to the fields, the voltage is minimum. This is very similar to the series-parallel battery connections where there are different voltages present in different parts of the circuit. As a brush leaves one segment and passes to the next segment of the commutator, the voltage changes slightly. The resultant ripple in the voltage is known as commutator ripple.

As each slot of the armature passes a pole tip, there is a slight interruption of the field at this point. Each surge in the field slightly changes the value of the voltage induced in the coils. The resultant ripple is known as slot ripple.

The infinitesimal sparking on the commutator caused by microscopic unevenness in the surfaces of both the commutator and the brushes produces an audible noise in the transmitter. This noise is generally not very even due to the fact that the unevenness of the brush and commutator surfaces does not cause regular sparking.

For the commutator ripple, the frequency can be determined as follows:

$$FC = \frac{\text{number of segments x RPM}}{60}$$

The frequency of the slot ripple may be determined from the following formula:

$$Fs = \frac{\text{number of slots x RPM}}{60}$$

The ratio of ripple voltage to maximum voltage for rectified alternating current generally equals about 100%. When using small motor-generators, the average ratio of total disturbance as just outlined in the previous paragraphs is in the neighborhood of 9/10 of 1%.

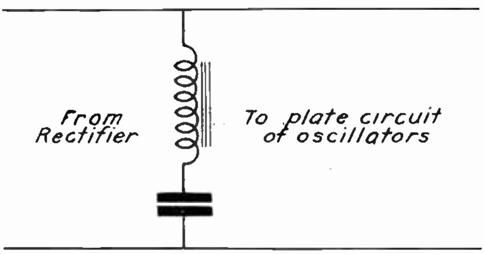


Fig. 10—Series resonant circuit

The simplest effective step towards ripple reduction is the condenser across the line. The direct current with a slight ripple component finds two separate paths back to the voltage source; one through the condenser and the other through the load impedance. Both paths offer impedance. If the low impedance is the plate circuit of the vacuum tube, this impedance will be in the order of 10,000 ohms for the smaller tubes. This impedance insofar as a ripple frequency is concerned remains constant. The path through the condenser is different, since its impedance will decrease as the frequency increases. That is, the higher the frequency, the more ripple current it will by-pass. The 1 mfd. condenser across a small generator with a commutator ripple of

2802 and a slot ripple of 934 will produce very satisfactory results. The function, then, of the condenser is to by-pass any remaining alternating current or ripple voltage.

Since the function or the reaction of an inductance inserted in a line is that of a choking effect, we can further increase the function of the filter by inserting an inductance in series with the line after the condenser across the line. The amount of ripples suppressed by the inductance depends upon the frequency of the ripples and the value of the inductance.

There are several forms of filters. In Figure 10, we have what is known as the series resonant circuit and in Figure 11, we have a parallel resonant circuit. A choke and a condenser connected in series as shown in Figure 10 will offer high impedance to all frequencies except one, i. e., resonance frequency (Fr). The formula for the resonant frequency can be obtained from the

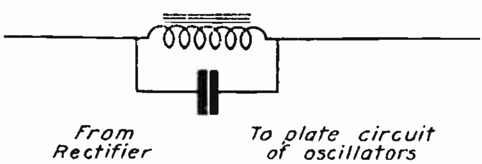


Fig. 11—Parallel resonant circuit

well-known formula where

$$F = \frac{1}{2\pi\sqrt{LC}}$$

This resonant frequency, practically speaking, will pass with an impedance of the resistance of the choke only, which is better than with a condenser alone if the resistance is small, but the impedance will be high for frequencies above and below resonance. When an inductance and capacity are connected in parallel as in Figure 11, the reversed characteristics of Figure 10 will prevail. In Figure 11, all frequencies will pass except those near resonance. For resonant frequency, it will be a dead stop except to supply the losses which are, technically speaking, negligible.

The effective application of these resonant circuits in a basic form to generators is rather limited. One for slot ripples and one for commutator ripples will be required, either one of which will be very effective in reducing moving contact disturbances. They are so very discriminate that a slight variation of speed, such as caused by varying the load, would require adjustment.

In a circuit containing constant values of inductance and capacity in series, the distribution of the voltage across the various elements will be dependent upon the impressed frequency—that is, in Figure 12, for a constant ripple voltage, the voltage across the condenser will vary for various frequencies. The ripple voltage across the condenser is the ripple voltage across the tube. For high impedance loads across the condenser, such as a tube, this voltage rises to several times the value of the initial voltage. The peak of this rise is reached at a frequency slightly less than resonance. With increased frequency beyond resonance, this voltage decreases rapidly, soon becoming

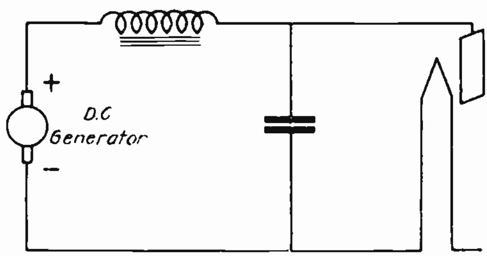


Fig. 12

a small fraction of the impressed voltage. The amplitude of the fluctuation of the current through the plate circuit will vary with the voltage.

In Figure 13 we have the so-called T type of filter. It consists essentially of two inductances in series with a condenser connected across the line from the midpoint of the two inductances. It would at first thought seem that the addition of this inductance would further reduce the voltage across the plate. It does reduce this voltage, but it also increases the frequency of the cut-off point—that is, the point at which the filter chokes refuse to pass current at a certain frequency.

The PI type of filter is illustrated in Figure 14 and is one of the simplest and most economical types of filters. For the motor-generator type of supply, it is ideal. Properly built, it is the most effective of the smoother type; that is, its filtering effect is not critical. It functions at all frequencies above the cut-off or resonance point. The lower this cut-off point and the sharper and more rapid the reduction beyond this point, the better the filter is. This means that as large condensers and chokes as are practical, from an economical standpoint, should be used. A general idea of the functioning of this type may be obtained by considering it to be divided into two parts. A is a condenser across the generator or voltage supply terminals. Its effect on the plate circuit is small. Its effect on the minute ripples in the generator is tremendous. It breaks them down, lowering them to a negligible amount. B takes what little disturbance is left and reduces it due to the choking effect of the inductance and the by-passing effect of the second condenser. One or two, 1 mfd. condensers and a 1 to 10 henry choke, makes a good filter for telegraphy and telephony work when using a motor-generator as a source of voltage supply. Larger condensers and chokes will, of course, increase the filtering effect and become necessary when using rectified alternating current.

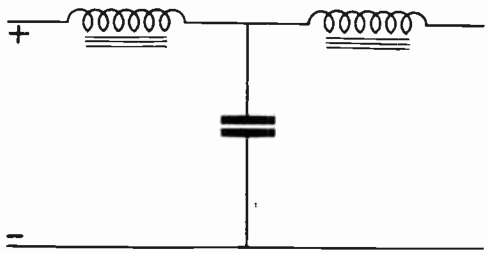


Fig. 13—T type of filter

The single section of the PI type of filter as shown in Figure 14 should be adequate when using small motor-generator sets. For rectified alternating current, several sections are generally necessary. There are some combinations such as belt-driven generators. With surges caused by belt slots, the separately excited generator with a large ripple in the excited path, or the generator bushing with an A. C. supply in series with it, will need a little more elaborate filter. This may be accomplished by adding other similar filter sections in series with the first. The first section reduces the disturbance a certain per cent. The next section reduces the ripple that the first passes, approximately the same per cent that the first reduced the original ripple. This action continues with each added section. The sections should be added value for value, that is, the inside condensers will be twice the outside ones and the inductances should all be equal.

The PI type of filter just described while excellent for continuous waves and some forms of phone modulation is not suitable for the Heising modulation. As we shall learn in a later lesson, the large condensers at the output side of the filter tend to short circuit the modulated voice frequency. This may be overcome by the addition of a small choke, 5 to 10 henries, in the plate lead directly after the filter, followed by a small condenser not over .005 mfd. across the line.

The condensers used in the filter are generally purchased ready to install. In some cases, it is necessary to build the chokes or inductances used in the filter. The Table No. III, shown on page 28, will give the average constructor some valuable information in regard to constructing chokes to be used in filters to accomplish certain results.

Wire with thin insulation should be used to make an economical design. Large wire uses up a great deal of space without giv-

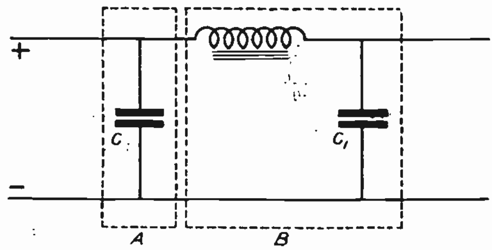


Fig. 14—P1 type of filter

ing much inductance. It is best to wind directly on the core with just a single layer of tape between if possible. More insulation will be required for chokes that are to be placed in a high voltage supply line, but this should not be any thicker than is absolutely necessary. Before starting a winding on the core, put some cotton strips along it and fasten some heavy cardboard or thin micarta end flanges in place. After winding the coil, the tape can be tied over the coil to keep the wire from spreading. Too much tape should not be put on or the coil will not keep cool under load conditions.

The wire sizes in the table are conservative and 10% more current can be passed continuously and even more than this intermittently. Heavy flexible leads should be soldered to the ends of the coil and taped down to prevent their breaking off.

TABLE III

Current Capacity Amps.	Core Size Cross Section	Inductance Henrys	No. Turns (N)	Feet of Wire	Resistance (D.C.)	Weight of Copper	Core Dimensions Long Piece	Core Dimensions Short Piece	Pounds
			All wound with 33 enamelled wire						
0.05		0.5	1600	400	82.5	1.0oz	½x1.6	½x .50	0.30
		1.0	2300	615	127.0	1.5oz	½x1.7	½x .55	0.31
	½x½	5.0	5200	1670	345.0	4.0oz	½x1.92	½x .75	0.37
		10.0	7600	2640	545.0	6.5oz	½x2.1	½x .85	0.41
		15.0	9500	3510	725.0	8.5oz	½x2.2	½x .85	0.43
		5.0	3500	1310	271	3.25oz	¾x2.4	¾x .75	1.0
		10.0	5000	2000	411	5.0oz	¾x2.5	¾x .75	1.0
	¾x¾	15.0	6300	2630	544	6.5oz	¾x2.6	¾x .75	1.05
		20.0	7600	3280	678	8.0oz	¾x2.7	¾x .85	1.1
		50.0	14000	7000	1445	1LB 1oz	¾x3.0	¾x1.0	1.25
		10.0	3800	1760	364	4.25oz	1x3.0	1x .75	2.1
		15.0	4800	2310	478	5.5oz	1x3.0	1x .75	2.1
	1x1	20.0	5700	2800	580	6.75oz	1x3.1	1x .75	2.2
		50.0	11000	6130	1270	15.0oz	1x3.5	1x1.0	2.5
		100.0	18000	11000	2280	1LB 10oz	1x3.8	1x1.1	2.75
	2x2	100.0	8900	7700	1590	1LB 3oz	2x5.5	2x1.0	14.5
			All wound with 30 enamelled wire						
0.10		0.5	1600	450	46	2.2oz	½x1.6	½x0.63	0.31
	½x½	1.0	2300	700	72	3.5oz	½x1.75	½x0.70	0.35
		5.0	5200	1950	200	9.5oz	½x2.10	½x0.95	0.43
		1.0	1500	540	56	2.7oz	¾x2.10	¾x0.63	0.87
	¾x¾	5.0	3500	1470	151	7.2oz	¾x2.5	¾x0.80	1.05
		10.0	5000	2250	230	11.0oz	¾x2.6	¾x0.95	1.12
		5.0	2600	1250	130	6.1oz	1x2.8	1x0.75	2.0
	1x1	10.0	3800	1940	200	9.5oz	1x3.0	1x0.85	2.2
		15.0	4800	2550	260	12.5oz	1x3.1	1x0.90	2.25
		10.0	1900	1500	160	7.5oz	2x4.66	2x0.60	11.5
		15.0	2400	1900	200	9.5oz	2x4.75	2x0.66	12.3
	2x2	20.0	2900	2400	250	11.5oz	2x4.85	2x0.75	12.5
		50.0	5300	4600	480	1LB 6.5oz	2x5.50	2x0.95	14.0
		100.0	8900	8300	860	2LB 8 oz	2x5.90	2x1.15	16.0
			All wound with 26 enamelled wire						
0.25	½x½	0.5	1600	550	22.5	7oz	½x2	½x .85	0.40
		1.0	3200	1350	55	1LB 1oz	½x2.5	½x1.10	0.50
	¾x¾	0.5	1000	390	16	5oz	¾x2.3	¾x0.71	0.96
		1.0	1500	640	26	8oz	¾x2.5	¾x0.83	1.05
	1x1	1.0	1100	530	22	6.5oz	1x2.9	1x0.75	2.10
		5.0	3700	2260	92	1LB 12oz	1x3.6	1x1.20	2.7
		5.0	1300	1050	43	13oz	2x4.9	2x0.80	12.7
	2x2	10.0	2000	1750	71	1LB 6oz	2x5.2	2x1.0	13.8
		15.0	3300	3060	125	2LB 6oz	2x5.5	2x1.1	14.7
		20.0	4000	3820	156	2LB 15oz	2x5.6	2x1.2	15.2
		10.0	1300	1510	62	1LB 3oz	3x6.9	3x0.8	39
		15.0	1600	1900	77	1LB 7oz	3x7.0	3x0.85	40
	3x3	20.0	1900	2300	93	1LB 12oz	3x7.1	3x1.09	41
		50.0	5000	6600	270	5LB 2oz	3x7.8	3x1.35	46
		100.0	8400	12000	485	9LB 3oz	3x8.3	3x1.65	50
			All wound with 23 enamelled wire						
0.50	½x½	0.5	3200	1700	35	2LB 10oz	½x3	½x1.45	0.62
	¾x¾	0.5	1480	735	15	1LB 2oz	¾x2.9	¾x1.1	1.26
		1.0	3000	1800	37	2LB 13oz	¾x3.5	¾x1.5	1.6
		0.5	800	410	8.5	0LB 10oz	1x3.0	1x0.85	2.2
	1x1	1.0	1600	945	19	1LB 8oz	1x3.5	1x1.0	2.5
		5.0	7800	7000	143	10LB 14oz	1x5.2	1x2.2	4.2
		1.0	560	460	9.4	0LB 12oz	2x4.9	2x0.75	12.7
	2x2	5.0	1800	1700	35	2LB 10oz	2x5.5	2x1.15	15.0
		10.0	3800	4100	83	6LB 6oz	2x6.2	2x1.5	17.3
		5.0	860	1000	21	1LB 10oz	3x7.1	3x0.85	40.0
		10.0	1840	2350	48	3LB 10oz	3x7.5	3x1.15	43.5
	3x3	15.0	2620	3500	71	5LB 7oz	3x7.8	3x1.4	46.0
		20.0	3500	4850	99	7LB 8oz	3x8.1	3x1.5	48.0
		50.0	8700	14000	282	21LB 8oz	3x9.3	3x2.3	58.0
		100.0	16700	31000	620	47LB 5oz	3x10.5	3x3.1	68.0

TEST QUESTIONS

Number your Answer Sheet No. 33—2 and add your **Student Number**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

No. 1. What is modulation?

No. 2. Give the plate voltage and plate current of a UV-207 tube.

No. 3. What is a motor-generator?

No. 4. Draw a diagram illustrating the best way to connect the grid return and the negative of the plate supply to the filament of a transmitting tube using A. C. on the filament.

No. 5. Name three types of plate voltage supply generally used for transmitting tubes.

No. 6. Give three advantages of the pre-rectified system of plate supply.

No. 7. Name the two general types of rectifiers.

No. 8. What should be the size of the aluminum electrode of a chemical rectifier if it is desired to obtain 80 milliamperes of current from the cell?

No. 9. Name the three sources of disturbance which affect the output of a motor-generator.

No. 10. Draw a diagram of the filter described in this lesson which is best suited for filtering the output of a motor-generator.

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To transmit speech by Radio, it is necessary to have a source of radio-frequency energy and a means of varying this energy in accordance with the variations in speech frequency. Controlling the radio-frequency energy in this manner is known as "modulation."

Two simple types of telephone transmitters are shown in Fig. 1, C is a variable condenser. L is an inductance coil,

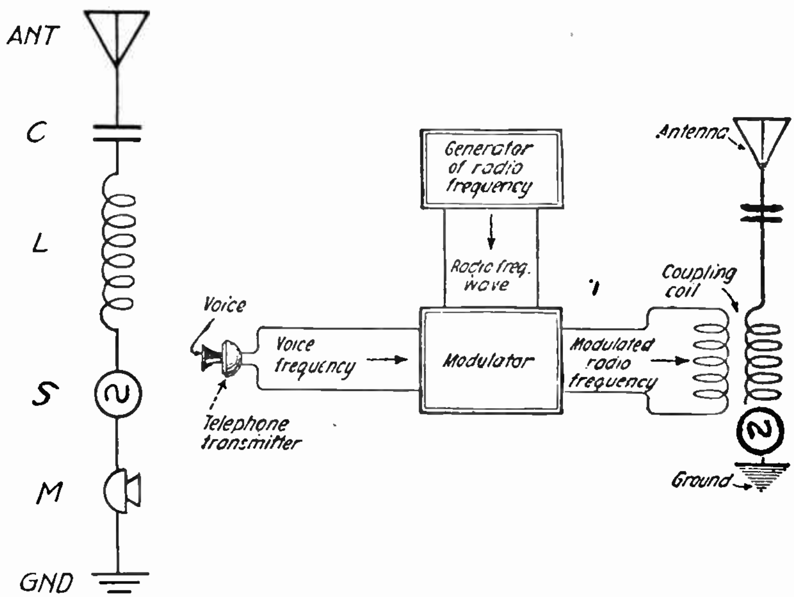

Fig. 1—The diagram to the left shows the parts for a simple type of Radio phone transmitter, while the picture above illustrates the actual apparatus installed in the Broadcasting Station.

S is a source of radio-frequency energy. M is a microphone, and GND the ground or earth connection. The microphone may be of the ordinary carbon granule type and since a clear understanding of its functioning is necessary in order to better understand the facts which are to follow, a description of the construction and functioning of this piece of apparatus will be considered at this point, in detail.

Figure 4 is a cross-sectional view of the carbon granule type of microphone. This diagram gives a good idea of the construction of the microphone when stripped of details. The elastic diaphragm, D is mounted on the rubber ring support AA, which in turn is held against the metal frame of the microphone case, B. The elastic diaphragm is mechanically connected to a carbon block, T_1 which is placed opposite another similar carbon block, T_2. The chamber between the carbon blocks is filled with small carbon granules, C. This chamber is sealed by means of the mica washer, E, and the insulating nut, F. The wall of the chamber containing the carbon granules is covered with a strip of paper, G. The two carbon blocks T_1 and T_2 are the electrical terminals of the microphone. If a source of emf. is applied to the two terminals of the microphone, a current will flow through the carbon granules. If the source is of constant polarity (D. C.) the flow of current will be unidirectional. If the source is of constantly changing polarity (A. C.) the current will flow first in one direction and then in the other. The value of the current will depend upon the potential applied and the resistance of the carbon granules. As long as the diaphragm remains in one position, the current will be constant but it is a property of these carbon granules in the microphone to vary in resistance as the mechanical pressure exerted upon them is varied. As the pressure is increased (an inward movement of the diaphragm), the resistance is decreased and as the pressure is decreased (an outward movement of the diaphragm), the resistance is increased. Hence, the current flowing through the microphone is increased or decreased. When speaking into the microphone, the diaphragm vibrates in synchronism with the frequency of the sound waves produced by the voice. The resistance varies in synchronism with the voice frequencies and it follows that the current flowing through the carbon granules within the microphone, varies in similar manner. The type of microphone just described is very sensitive to changes of pressure on the diaphragm. The current carrying capacity of such a device is very small due to the fact that a limit is soon reached where arcing occurs between granules, the contact points of which become red hot and the microphone becomes useless. The average resistance of a unit of this type is between 50 and 100 ohms. The current carrying capacity is about 0.1 of an ampere. The power capacity is a maximum of $.1^2 x 100$ or 1 watt. There are some special low resistance microphones (10 to 20 ohms) which have a current carrying capacity of .5 ampere and a maximum power capacity of $.5^2 x 25$ or 5. watts.

Going back to the circuit diagram shown in Figure 1. When the microphone is not being spoken into, the diaphragm remains stationary and exerts a constant pressure on the carbon granules, the resistance remains constant and the radio-frequency current in the antenna circuit is of constant amplitude as shown in Fig. 2. If the diaphragm of the microphone

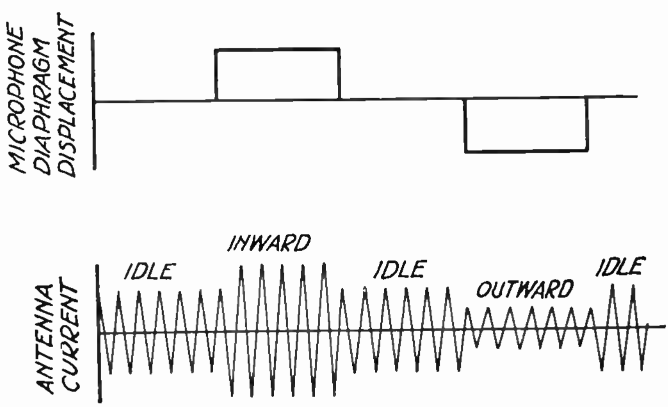

Fig. 2—This illustrates the change in amplitude for the Radio-frequency or carrier wave when the microphone diaphragm is moved inward and then outward by a fixed amount.

is depressed inward, the pressure on the carbon granules increases, the resistance decreases and the amplitude of the antenna current increases and remains constant at this value as long as the diaphragm is maintained in that position. When the diaphragm is released, the resistance will return to normal and the antenna current will return to its normal value. Again, if the diaphragm is pulled outward, the pressure decreases, the resistance of the carbon granules increases and the antenna current subsequently decreases and remains at this lower value as long as the diaphragm is held in the outward position. Then, of course, when the diaphragm is released, the resistance will return to normal and the antenna current will again reach its normal value.

For the sake of simplicity at this point in the discussion, let us assume that a 1,000 cycle tuning fork is set vibrating and placed in front of the microphone. Due to the sound waves from the tuning fork, the diaphragm of the microphone will vibrate at a frequency of 1,000 cycles. Looking at Fig. 3. if the line, NN, represents the normal position of the microphone diaphragm when idle, then the sine curve superimposed upon the straight line, NN, represents the action of the diaphragm when the tuning fork is placed in front of the mouthpiece. The diaphragm attains its maximum inward and outward positions 1,000 times per second and the resistance of the carbon granules will vary accordingly. The antenna current will go from maximum to minimum and back to maximum again 1,000 times per second and it follows that the radiated energy will vary accordingly.

The radio-frequency is the "carrier-frequency." The radio-frequency current is the "carrier-current." The frequency of the microphone diaphragm, which in this case is 1,000 cycles per second, is the "modulating frequency."

From the foregoing, it is obvious how it is possible to modulate the carrier current by the voice and transmit speech. Instead of placing the tuning fork in front of the microphone, it is simply necessary to talk into the mouthpiece, which in that case would vibrate in accordance with the complex air vibrations produced by speaking.

Figure 3-A illustrates a modulated carrier-wave. When a letter is spoken into the microphone, it varies the amplitude of the carrier-wave (b); in other words, it cuts off the peaks of the radio-frequency waves; (a) represents the voice-frequency.

Each sound going into the microphone has a frequency or vibration all its own, and the part illustrated by (c) shows that the peaks of the radio waves have been chopped off according to the audio-frequency vibration of the microphone.

The oscillator tube in a broadcasting station sets up the carrier-frequency. This frequency is continuous and does not vary and it is governed by the amount of capacity and inductance in the oscillator circuit. For example, a 400 meter broadcast station, the carrier-frequency is 750 kilocycles.

The modulating frequency is that frequency impressed upon the carrier by the microphone and the modulator tube. This modulating frequency depends upon the nature of the sound being impressed upon the microphone, which may vary from as low as 30 cycles to as high as 10,000 cycles per second.

The ordinary range of the voice in frequency is from approximately 100 cycles to 5,000 cycles per second.

The complex vibrations of the microphone due to speech may be resolved into an infinite number of harmonic components of different frequencies, different amplitudes and bearing certain phase relations to each other. Theoretically, the number of these components is infinite, but practically, only those having a frequency of between 300 and 2,000 cycles per second have an amplitude great enough to be considered. The amplitudes of the others are so small that they are negligible.

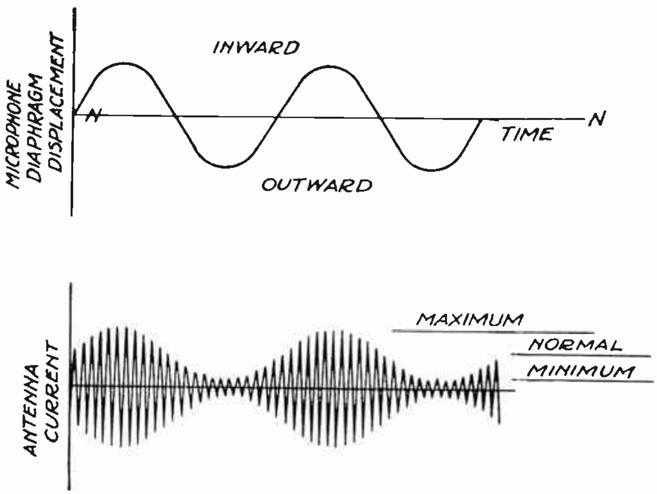

Fig. 3—This illustrates the change in amplitude of the radio-frequency waves when the microphone is acted upon by a tuning fork.

The following is a principle which is of very great importance in radiotelephony as well as wire telephony: As long as the amplitude of the harmonic components of the transmitting microphone diaphragm vibrations are reproduced in the receiving telephone diaphragm vibrations (bearing the same ratio to one another that they had at the start, without any reference whatever to phase relations) the speech, which caused the vibrations, will be faithfully reproduced in the receiver without any distortion.

We have seen from the foregoing that it was necessary, in order to transmit speech by Radio, to have a source of radio-frequency current of constant amplitude (C. W.), and a system of modulation. Of the various sources of radio-frequency, the following have been most generally used for radiotelephony:

The Alexanderson Alternator. The Poulsen Arc.
The Fessenden Alternator. The Vacuum Tube.

DIFFERENT TYPES OF VACUUM TUBE TRANSMITTING CIRCUITS

The vacuum tube may be used in many types of circuits to generate radio-frequency currents. *A discussion of the*

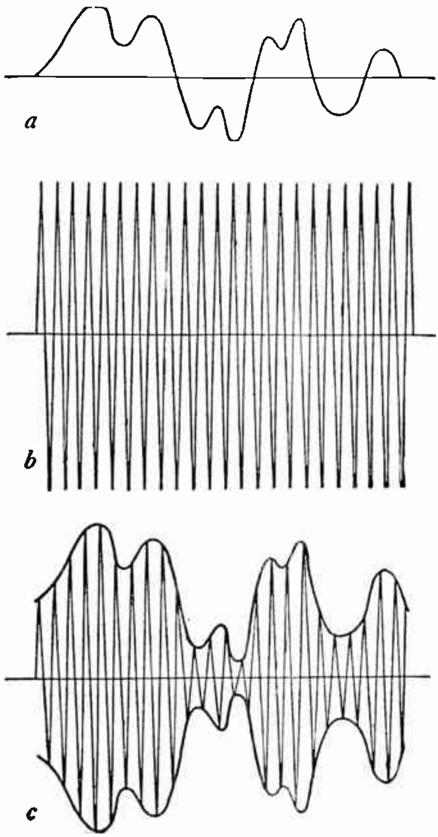

Fig. 3-A—The wave forms of Radio. "a" is the voice frequency from the microphone. "b" is the radio-frequency or carrier-wave from the generator unit. "c" is the resultant modulated radio-frequency (carrier) wave delivered to the aerial by the modulator unit.

fundamentals of the most important of the different types of oscillatory circuits follows. The various types are usually designated by the names of their inventors and fundamentally they are all the same. The circuits that we are going to consider at this time are of the self-excited type. The fundamentals of all of the oscillatory circuits of this type are, the vacuum tube; the power source ("B" battery); the load circuit (transmitting antenna), and a means of feeding back power to the grid circuit for its excitation. The circuits follow in the order of their importance.

MEISSNER CIRCUIT

The "Meissner" circuit is named after Dr. A. Meissner, of the Telefunken Company, of Berlin, and is shown in Fig. 5. The D. C. plate supply flows through the inductance, Lp. The constants of the plate circuit determine the frequency of the oscillations generated by the tube, namely, the inductance, Lp and the capacity, Cp, Cg and Rg are the grid con-

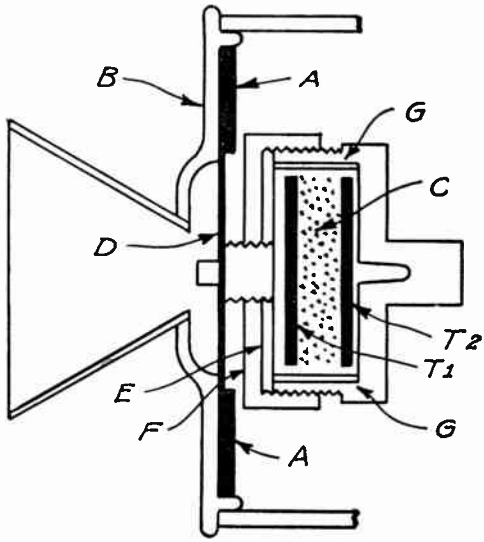

Fig. 4—This illustrates a cross-sectional view and the constructive features of a carbon type of microphone.

denser and grid biasing resistance, respectively. The former is of sufficiently high capacity to offer a low resistance to the flow of the radio-frequency currents being generated by the tube and is, therefore, a "by-pass" for these currents. It blocks off all D. C. in the grid circuit to such a point that it is necessary for this D. C. grid current to flow through the biasing resistance, Rg. There is a flow of direct current in the grid circuit due to the passage of electrons from the filament to the grid just as there is a flow of direct current in the plate circuit due to the flow of electrons from the filament to the plate. Of course, the grid current is much smaller than the plate current. This grid current flows through the resistance, Rg, towards the grid and there is a drop in voltage across this resistance as shown in the Fig. 5, the end of the resistance near the grid being negative and the other end positive. Since the positive end of the biasing resistance is connected to the negative filament lead, the grid has a negative bias, the amount of which depends upon the value of the biasing resistance and the grid current flowing in the circuit. Using a 250 watt tube, type UV-204, the grid resistance might be 10,000 ohms and the grid

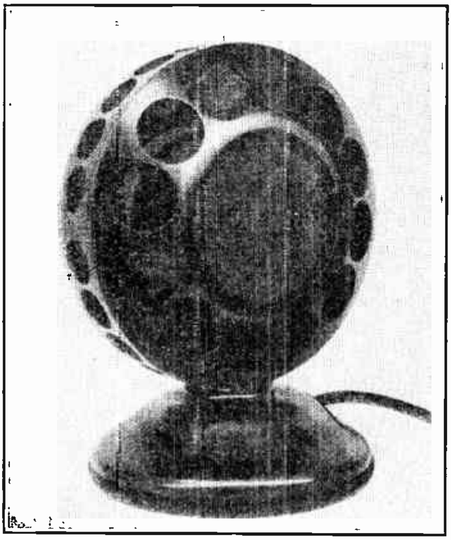

Fig. 4-A—A Microphone transmitter as used in Radio broadcast stations.

current about 30 milliamperes, consequently there would be a drop of 300 volts across the biasing resistance and the grid would be 300 volts negative. The grid coil, Lg, is inductively coupled to the plate coil, Lp, and it is by this means that energy is fed back to the grid for its excitation. Due care must be taken to have the proper phase relation in obtaining this feed-back for the grid excitation or the feed-back action may tend to block oscillations rather than maintain them. If either the grid coil or the plate coil is reversed from the position it should be in, the alternating current fed back to the grid will be 180 degrees out of phase with the pulsations in the plate circuit and there will be a bucking action rather than a boosting action, hence oscillations will not be maintained. The grid circuit as shown is simply an untuned pick-up circuit but may be tuned to the frequency of the plate circuit by shunting a capacity of the proper value across the grid coil, Lg. The antenna coil is inductively coupled to the plate circuit and is tuned to the frequency of that circuit. This circuit is very flexible and by means of the coupling between the plate circuit and the antenna circuit, the transfer of power from the tube to the antenna circuit can be taken care of. The adjustment of the feed-back is conveniently made and does not depend upon the voltage drop across a reactance in the load circuit as in the case of the Hartley and Colpitt's circuits.

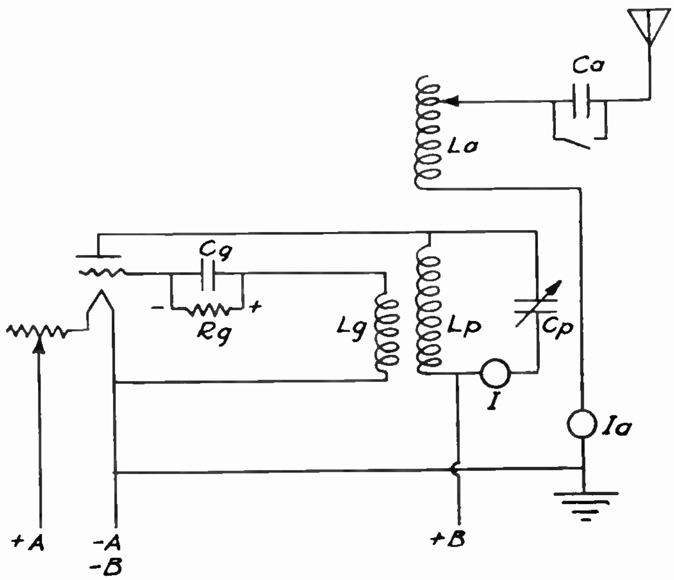

Fig. 5—Wiring diagram for the Meissner transmitting circuit.

TICKLER-COIL CIRCUIT WITH INDUCTIVE PLATE COUPLING

In Figure 6 the "Tickler" coil circuit with inductive plate coupling is shown. The antenna circuit consists of the antenna, the series condenser, Ca, the inductance, La, the ammeter, Ia and the ground. The plate is connected to the positive side of the high voltage plate supply through the inductance, Lp. The grid radio-frequency circuit is coupled to the antenna circuit through the condenser, Cg. The grid leak circuit is composed of the radio-frequency choke coil, Xg, and the grid biasing resistance, Rg. The choke coil keeps the radio-frequency currents out of the grid leak circuit. Without this choke coil, there is a loss of 20 watts in a 5,000 ohm grid leak when using a 250 watt tube, which is 8 per cent. of the normal power. This loss is due to the passage of radio-frequency currents through this biasing resistance. When the choke coil, Xg, is used, the loss is decreased to .5 watts which is .2 per cent of 250 watts. The amount of grid excitation is determined by the capacity, Cg, and the point at which the grid is tapped on the coil, La. The coupling between

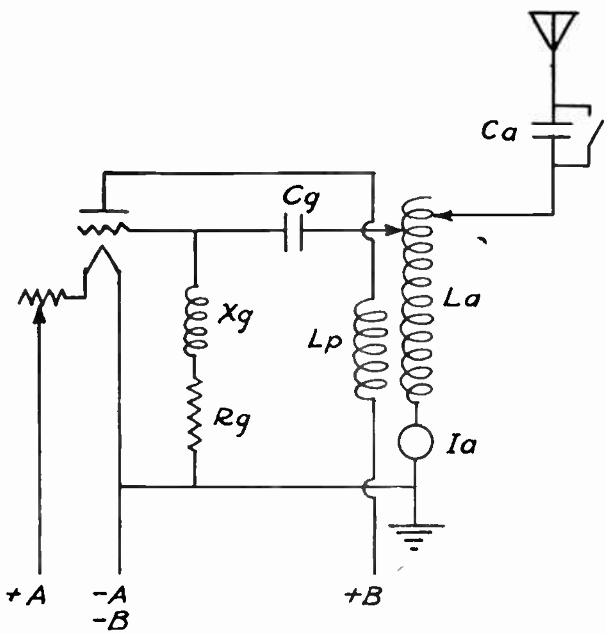

Fig. 6—Transmitting circuit diagram for the tickler coil type of circuit with inductive plate coupling.

plate and grid due to the coil, Lp, maintains the oscillatory condition. The constants of the antenna circuit determine the frequency of the oscillations generated by the tube.

TICKLER-COIL CIRCUIT WITH INDUCTIVE GRID COUPLING

In Figure 7 the "Tickler" coil circuit with inductive grid coupling is shown. The antenna circuit shown here is the same as in the previous case. The plate potential is supplied through the radio-frequency choke coil, Xp. The purpose of this coil is to isolate the radio-frequency in the plate circuit from the high potential plate supply. The plate is connected to the antenna coil, La, through the blocking condenser, Cp. The purpose of this condenser is to keep the inductance coil, La, from short circuiting the D. C. plate source. Rg and Cg are the grid biasing resistance and grid condenser, respectively, and function as previously described. The grid excitation is derived by means of the grid coupling coil, Lg. The grid circuit as shown in the figure is an untuned pick-up circuit but may be tuned to the frequency of the antenna by shunting a capacity across the coil, Lg. Obviously, these last two circuits described are not as flexible as the Meissner circuit which was described first.

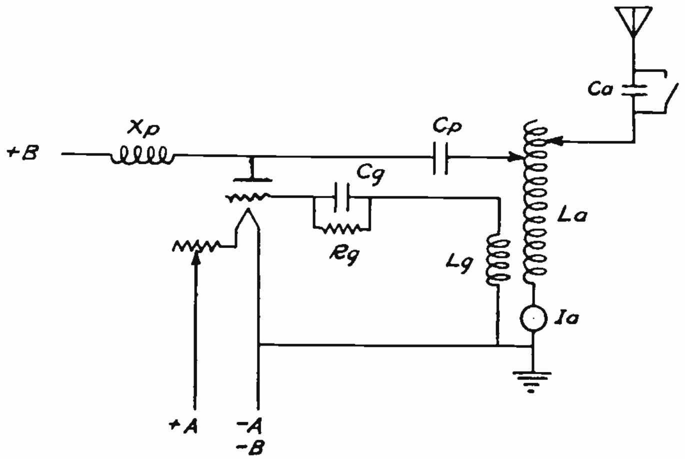

Fig. 7—Transmitting circuit diagram for the tickler-coil type of circuit with inductive grid coupling.

REVERSE FEED-BACK CIRCUIT

The Armstrong tuned plate or reversed feed-back circuit named after its inventor, Mr. E. H. Armstrong, is shown fundamentally in Fig. 8. In this circuit, the oscillatory condition, feed-back from plate circuit, is obtained by means of the small capacity coupling between the plate and the grid within the tube itself. This small condenser is formed by the grid and plate electrodes. It is important to note that the plate and grid coils are not inductively related but may be widely separated from each other. The only coupling between the plate and grid is the capacity coupling within the tube. The feed-back effect increases as the wave-length is shortened and depends upon the value of the grid plate capacity. The action may often be improved and controlled by connecting a variable condenser of small capacity (.0001 mfd.) between the plate and the grid. The principle of this circuit is different from any yet described. The important advantage of the Armstrong circuit is that the oscillations occur when the plate circuit is in resonance with the grid circuit. The frequency of these oscillations depends mainly upon the constants of the grid circuit but the constants of the plate circuit do have some effect upon the generated oscillations. This is an important point because by connecting the antenna to the plate circuit as shown in Fig. 9, the change in the antenna capacity due to swinging will not materially affect the frequency of the radiated oscillations as in those circuits where the antenna circuit

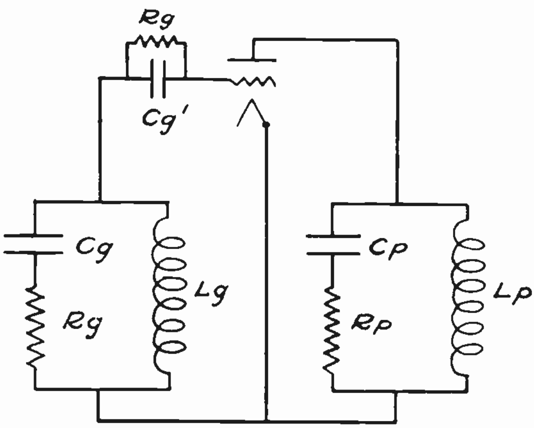

Fig. 8—The Armstrong tuned plate or reversed feed-back elementary circuit.

is directly associated with that circuit whose constants determine the frequency of the oscillations generated. The constant frequency advantage of the master-oscillator system is embodied to some extent in this circuit. Figure 9 shows the method of connections for transferring energy, generated by a tube in a circuit of this type, to an antenna. The tuned plate circuit shown in Fig. 8 is replaced by its equivalent, an antenna circuit of inductance, La, series capacity, Ca, and resistance. This circuit is tuned to the frequency of the grid circuit. The radio-frequency choke coil, Xp, functions as usual, to prevent the short-circuiting of the output circuit by the plate source. The blocking condenser functions conversely, to prevent the short-circuiting of the plate source by the output circuit.

COLPITTS CIRCUIT

The Colpitts circuit is shown fundamentally in Fig. 10 and is named after its inventor, Mr. E. H. Colpitts, of the Western Electric Company. The frequency of the generated oscillations depends upon the inductance, L, and the two capacities, Cp, and Cg, in series. These elements, together with the resistance, R, constitute the load circuit. The grid excitation is determined by the voltage drop across the condenser, Cg, the smaller the condenser, the greater the voltage drop and the greater the grid excitation. The grid excitation varies with the power capacity of different tubes. If a 1 k.w. tube were

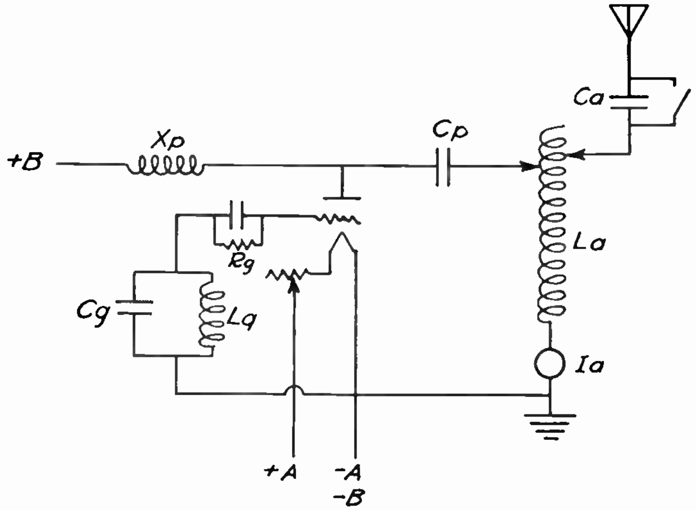

Fig. 9—The Armstrong tuned plate circuit showing its connection to the antenna.

used in this circuit, the values of inductance and capacity should be so chosen that, with 1 k.w. dissipated in the circuit, the total reactive voltage (that between the points x and y) would be 7,500 volts. The proper grid excitation for this tube is 1,000 volts, so the proper values for the condensers Cp and Cg are determined by the relation, Cg/Cp equals 6,500/1,000; then, Cg equals 6.5 Cp. Thus when the grid condenser, Cg, is 6.5 times as large as the plate condenser, Cp, the voltage drop across the grid condenser, Cg, will be 1/6.5 of the voltage drop across the plate condenser, Cp, giving 1,000 volts across the grid condenser and 6,500 volts across the plate condenser and 7,500 volts across the two.

Figure 11 shows the application of the Colpitts circuit to an antenna, with the addition of grid choke, Xg, grid leak, Rg,

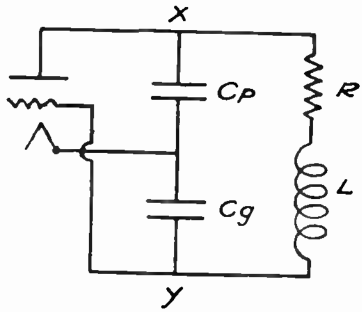

Fig. 10—Fundamental diagram for the Colpitts circuit.

grid blocking condenser, Cg, and plate choke, Xp, which function as previously described. This circuit is the same as the fundamental circuit shown in Fig. 10 with the exception that the plate capacity, Cp, has been replaced by the antenna which functions as a capacity. No plate blocking condenser is

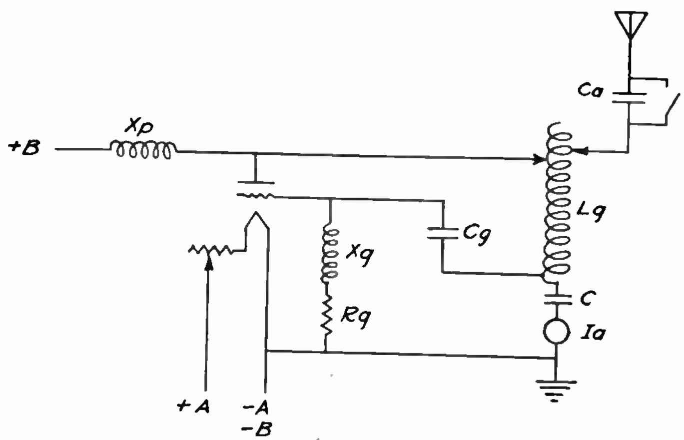

Fig. 11—Diagram of Colpitts circuit showing antenna connection.

necessary in this circuit, since, due to the load circuit arrangement, there is no possibility of the plate supply being short-circuited by the output circuit.

HARTLEY CIRCUIT

The Hartley circuit is named after its inventor, Mr. R. V.

L. Hartley, of the Western Electric Company and is shown in Fig. 12. The frequency of the oscillations generated depend upon the constants of the load circuit. The grid excitation is obtained by means of the voltage drop between x and y. As is the case in the Colpitts circuit, the grid excitation depends upon the voltage drop across a reactance in the load circuit, but in the Hartley circuit the reactive drop is across a coil, whereas in the Colpitts circuit the reactive drop is across a condenser. The greater the number of turns between x and y, the greater the voltage drop and the greater the grid excitation. As in the previous case, if a 1 k.w. tube, type UV-206 were used in this circuit, the total drop from x to z should be 7,500 volts and the drop from x to y 1,000 volts, thus leaving 6,500 volts from y to z. Figure 13 shows the application of this circuit to an antenna system. The fundamental change between the circuit shown in this figure and the one in Fig. 12

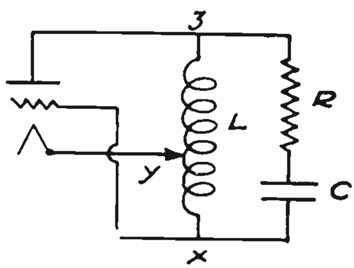

Fig. 12.—Fundamental diagram of the Hartley circuit.

is the replacing of the load circuit lumped capacity and resistance by the antenna circuit which has distributed capacity and resistance. This circuit, although not considered the best for direct application to an antenna system, has many useful applications both in transmitting and receiving, notably as a master-oscillator circuit for transmitting and as a local oscillator for heterodyne reception.

In the Hartley circuit, the voltage fed back by means of variations in the plate current, which excite the grid and cause it to vary, depends upon the reacting drop across the coil. This is an inductive effect and is the result of the current passing through an inductance; whereas, in the Colpitts circuit, the grid voltage or excitation depends upon the voltage drop or potential across a condenser.

From the preceding paragraphs, you have learned that it is necessary to cause the grid to have a varying voltage applied to it and in the case of the Hartley type of transmitting circuit, this voltage is obtained by means of an inductance, whereas in the Colpitts type, the voltage is obtained from the potential of a condenser.

COUPLING OSCILLATING CIRCUITS

U. S. Government regulations require the inductive type of coupling between the closed oscillatory system and the antenna system of a transmitter.

The oscillation transformer consists of the primary and secondary coils, which are mutually related and are mounted as one unit. Sometimes, in some installations, it is desirable to place the complete antenna system with coils outside of the building. In such installations it is necessary to connect the closed oscillatory circuit to the antenna system with a link circuit or feeder line as it is somtimes called, this coupling between the two circuits is effected either by inductive or capacitative coupling.

Whenever either of these two arrangements are used, the antenna inductance, antenna ammeter and ground connections are all in series; therefore, no part of the radiating system enters the building where the transmitter is located, only the feed wires connecting from the transmitter to the antenna.

This type of coupling is very often used to good advantage for short wave transmission because it reduces to some extent the length of the lead-in wires from the antenna to the set. It is also used advantageously in many high-power broadcasting stations.

THE MASTER-OSCILLATOR CIRCUIT

All of the foregoing types of oscillatory circuits described have been of the self-excited type; that is, they were of the type that supplied their own grid excitation. Now we come to the master-oscillator system which is the separately excited type of circuit. From an electrical viewpoint, this type of circuit is superior to any of the self-excited type. It is far more flexible than the latter and is less susceptible to frequency changes. This last feature is of special importance. The fundamental circuit shown in Fig. 11 is composed of two tubes. One is the "master-oscillator" used for generating the desired radio-frequency output and the energy thus obtained is used to excite the grid of another tube which is termed the "power amplifier" tube. The power amplifier tube in turn can feed into the antenna system, or, if there are several power tubes in the transmitting assembly, they can

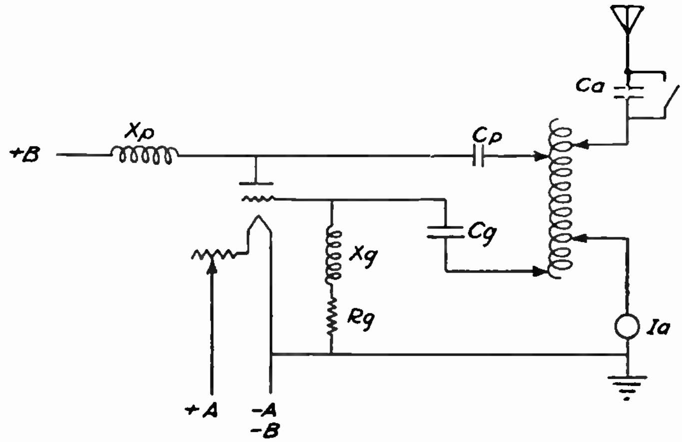

Fig. 13—Diagram of Hartley circuit showing antenna connection.

all be used in successive stages of amplification. The constants of the master-oscillator circuit determine the frequency of the energy to be radiated from the antenna. Due to the fact that the master-oscillator is not directly coupled to the

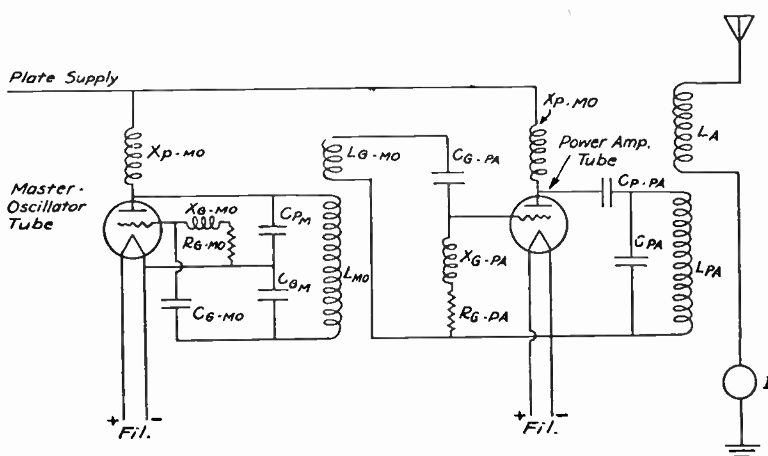

Fig. 14—Diagram of the Master-Oscillator circuit.

antenna system, this arrangement is free from frequency changes, in the course of transmission caused by a swinging antenna, etc. The master-oscillator tube simply has to be of sufficient size to supply the losses in its own oscillatory circuit and the losses in the grid circuit of the power amplifier tube. The losses in the grid circuit of the power tube would probably be between 2 per cent. and 10 per cent. of the total capacity of the tube, hardly ever over 10 per cent. The oscillatory circuit for the master-oscillator is of the Colpitts type and has already been described. The grid circuit of the power amplifier tube instead of being coupled to its own output circuit as in the case of the self-excited types, is inductively coupled to the master-oscillator oscillatory circuit inductance, Lmo. The grid of the power amplifier tube is supplied with the proper amount of grid excitation by varying the coupling to the master oscillator. The grid-blocking condenser, Cg-mo, grid choke, Xg-mo, and grid biasing resistance, Rg-mo, function as previously described. The plate circuit of the power-amplifier tube is tuned by means of the inductance, Lp-pa, and the condenser, Cp-pa, to the frequency of the oscillations generated by the master-oscillator. The antenna circuit is inductively coupled to the plate circuit of the power amplifier by means of the coupling coil, La. The adjustment of this system is simple. The master-oscillator is first set at the frequency desired. The power amplifier plate circuit is then tuned to resonance with the frequency of the master oscillator. The grid excitation of the power amplifier is adjusted for maximum efficiency. The antenna circuit is then tuned to the same frequency and its coupling to the power amplifier varied until maximum efficiency is obtained. On ships at sea, during heavy storms, the ship rolls and the antenna swings from side to side and is constantly changing in capacity. If a type of circuit were used in which the antenna circuit were directly associated with that part of the circuit whose constants determined the frequency of the radiated energy, the frequency would change, due to the change in antenna capacity, and the frequency of the radiated signals would vary in synchronism with the swinging of the antenna. This condition is unfavorable because signals of this type are difficult to understand at the receiving station. They would be strong one minute and the next minute would be weak due to the change in wave-length. Obviously, it would be impossible to vary the tuning of the receiver in synchronism with the variations in the frequency of the incoming signals. This condition is not only true of ship antennas but might likewise be true of shore-station antennas which are subjected to a strong wind. The master-oscillator system eliminates this condition due to a swinging antenna. In the case of the master-oscillator, the frequency is fixed by the constants of the master-oscillator circuit and there is no reaction from the antenna. The only thing that changes as the antenna capacity changes is the efficiency. As the antenna swings out of tune, the current in that circuit will decrease.

MODULATION SYSTEMS

Now that we have a source of radio-frequency energy, we must have a system of modulation. The function of the modulating system is to vary the radio-frequency output current in accordance with the low-frequency variations of the sounds to

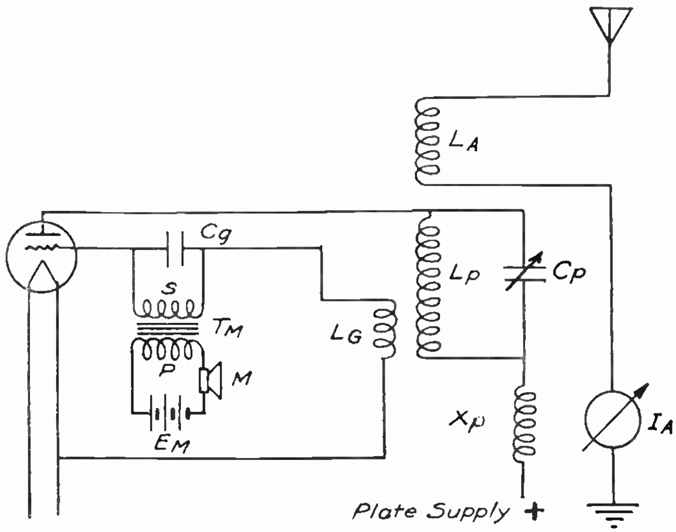

Fig. 15—Diagram showing method of modulation by the variation of grid voltage.

be transmitted. The different schemes of modulation operate principally by three fundamental methods, namely:

1. Variation of the resistance of the antenna circuit.
2. Variation of the grid voltage of the oscillator tube.
3. Variation of the plate supply to the oscillator tube.

The *first* of these methods has already been touched on and is shown in Figs. 1 and 4. This method shows very clearly the fundamental operation of a radiotelephone transmitter, but as far as its practical application is concerned, it is almost obsolete. In fact it is obsolete where any power over 5 watts is used. Fair results can be obtained with this method when the output of the transmitter is 5 watts or less. However, the method is inherently a poor one both as to quality and efficiency.

The *second* method listed above depends upon the variation of the average grid voltage (biasing voltage) of the oscillator tube. Figure 15 shows the application of this method of modulation using a typical oscillatory circuit. The functioning of this type of oscillatory circuit has already been described so the method of modulation only will be considered at this time. The microphone circuit is composed of the microphone, M, a 6 volt storage battery, Em, or any 6 volt battery capable of supplying 200 or 300 milliamperes, and the primary of the microphone transformer, Tm. The secondary of the microphone transformer takes the place of the grid biasing resistance and is connected across the grid condenser, Cg. When the microphone is spoken into, the resultant action that takes place is the varying of the grid biasing voltage, in accordance with the variation in the microphone displacement. As mentioned before, the result desired is to have the amplitude of the antenna current vary exactly in accordance with the microphone displacement. This desired result is not entirely obtained with this system of modulation due to the following facts: the relation between the grid biasing voltage and the antenna current is not linear (and it should be for good modulation) that is, a certain percentage variation in grid biasing voltage does not produce a relative percentage variation in antenna current. In fact, if a circuit condition has been obtained at which point the oscillations are stable, the antenna current is only slightly effectual throughout a relatively wide range of variation in the grid biasing voltage. Obviously, these conditions are not favorable for good modulation and by "good modulation" is meant the faithful reproduction of speech vibrations in the varying of the amplitude of the output radio-frequency current. By very careful adjustment, however, fairly satisfactory operation is possible.

The *third* method of modulation, which depends upon the variation of the plate supply to the oscillator tube, is far more efficient than either of the other two methods mentioned above. By variation in plate supply is meant, either the variation of the plate voltage, the plate current, or the plate power. This method excels the first due to the fact that there is no waste in the oscillatory power (as there is in the first), which might logically be called the "absorption" method. It excels the second method due to the fact that the relation between plate supply and antenna current is fairly linear over a wide range. In this method a voice voltage (one which varies in accordance with the frequency and amplitude of the sound waves due to speech which actuate the microphone diaphragm) is superimposed upon the D. C. voltage in the plate circuit of the oscillator tube, thus causing the plate current, and subsequently the plate power, to vary at speech frequencies. A complete variation from zero current to double the normal current of the oscillator tube entails an amount approximately equal to that supplied to the oscillator during normal operation. By normal operation is meant the functioning of the oscillator tube as a generator of radio-frequency currents with a constant plate supply, hence with no superimposed variations due to speech. The modulating device must be capable of supplying this power to the

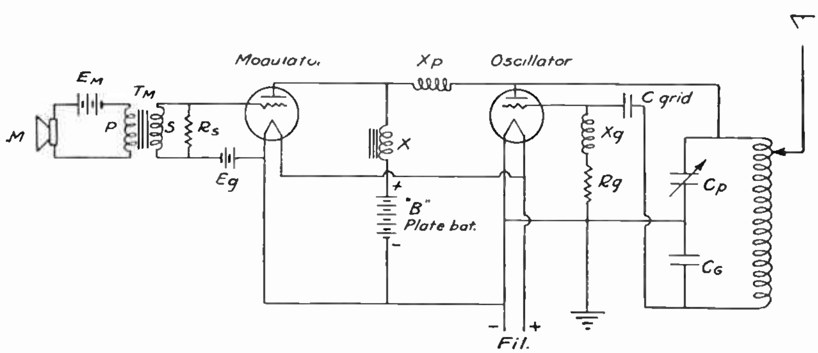

Fig. 16—This diagram illustrates the Heising system of modulation.

oscillator tube or of controlling its supply from the plate source. The microphone, due to its low capacity rating (100 milliamperes) is incapable of controlling the plate supply to the oscillator tube directly, but must effect its control indirectly and it does this through the medium of an auxiliary tube called the "modulator" tube.

The practical application of the plate modulation system which is called the *Heising method of modulation* after Mr. R. A. Heising, is shown in Fig. 16. The oscillatory circuit shown here is of the Colpitts type. When the microphone, M, is idle there is a constant plate supply, both to the oscillator and the modulator tubes. It follows then that the radio-frequency currents in the antenna circuit are of constant amplitude (C. W.) and the output is "unmodulated." When the microphone is spoken into, its diaphragm follows the speech frequency variations and subsequently its resistance varies accordingly. The direct current in the microphone circuit goes through similar variations and we now have a pulsating direct current flowing in this circuit. Alternating emfs. are set up in the secondary winding of the microphone transformer, Tm, due to the pulsating currents flowing in the primary winding, and are applied to the grid of the modulator tube. This causes the plate current of this tube to vary accordingly. There is an iron-core choke coil, X, in the common plate supply to the modulator and oscillator tubes, which is of very high inductance. It is the inherent property of an inductance to oppose any change in the current flowing through it, therefore, the choke coil in the plate circuit tends to keep the value of the current flowing through constant. If, at any instant the grid of the modulator tube goes positive, the plate current of this tube increases and since the choke coil tends to keep the total flow of current to both tubes constant, the modulator draws current away from the oscillator tube and the current to the oscillator tube decreases. Conversely, when the modulator grid goes negative, the modulator plate current decreases and the oscillator plate current increases due to the fact that the total supply of current to both tubes is maintained constant by the choke coil. The average plate current to the oscillator tube is varied at an audio-frequency rate (speech frequency) and the amplitude of the radio-frequency antenna current is correspondingly varied.

This explanation may seem a little hard to understand at first reading, but looking at Fig. 16 again, you will see that the Heising system of modulation employs two vacuum tubes. One is used to generate radio-frequency power to apply to the antenna. This is connected as an oscillator; the other tube is employed as a modulator tube. Both tubes are fed from a common plate supply source through a large iron-core coil. The reactance of the choke coil X is so great that the current through it is practically constant and cannot vary at speech frequencies or higher frequencies. When the transmitter is working, the current from the source is constant. For this reason, the Heising system is sometimes known as the constant current modulating system.

The oscillator works steadily and the radio-frequency is coupled into the antenna circuit. A radio-frequency choke coil Xp keeps the high-frequency current from leaking back into the modulator and supply circuit. The load which the modulator tube takes varies. As the grid voltage of the modulator tube is changed at speech frequencies, the plate current is made larger and smaller accordingly. We have a high-frequency carrier-wave completely modulated with a speech envelope.

With the aid of Figure 17, this action can be made clearer. Here the modulator plate filament circuit has been represented by a variable resistance, Rm, due to the fact that its average grid voltage varies at a speech frequency rate. The oscillator tube plate filament circuit has been represented as a constant resistance, Ro, since its average grid voltage remains constant. The plate source is shown at B and the iron-core choke at X.

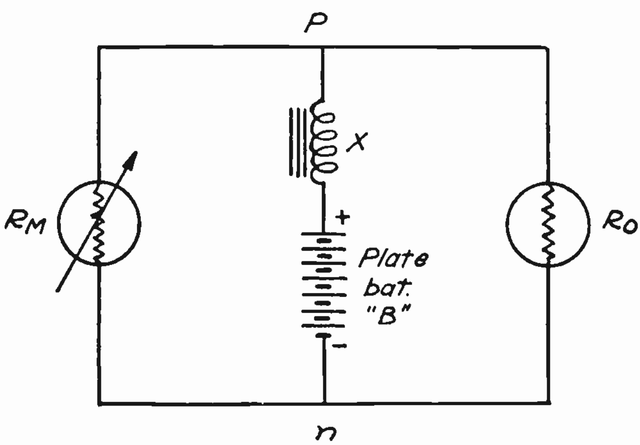

Fig. 17—Theoretical diagram of the Heising system of modulation.

For the sake of simplicity in the discussion, let us assume that a 1,000 cycle tuning fork is set vibrating in front of the microphone, producing a sine wave of sound. The modulator grid voltage and consequently, plate current, will go through similar variations of the same frequency as the tuning fork. This will make the plate circuit of the modulator tube function as a variable resistance connected across the plate supply. If we assume that the modulator plate current changes from zero to twice its normal value and by normal value is meant the value of the plate current flowing when the microphone is idle, then it follows that the oscillator plate current must increase and decrease about its normal value to the same extent, since the choke coil functions to maintain the total plate current approximately constant.

Obviously, if the value of the oscillator plate current is varied at the rate of 1,000 cycles per second, the amplitude of the radio-freqeuncy antenna current will be varied at the same rate. Since the resistance of the oscillator plate current is varied at the rate of 1,000 cycles per second, the amplitude of the radio-frequency antenna current will be varied at the same rate. The resistance of the oscillator plate filament circuit is considered constant. The current through this resistance is changing from zero to twice the normal value. The power expended in this resistance must change from zero to four times the resistance. The power is equal

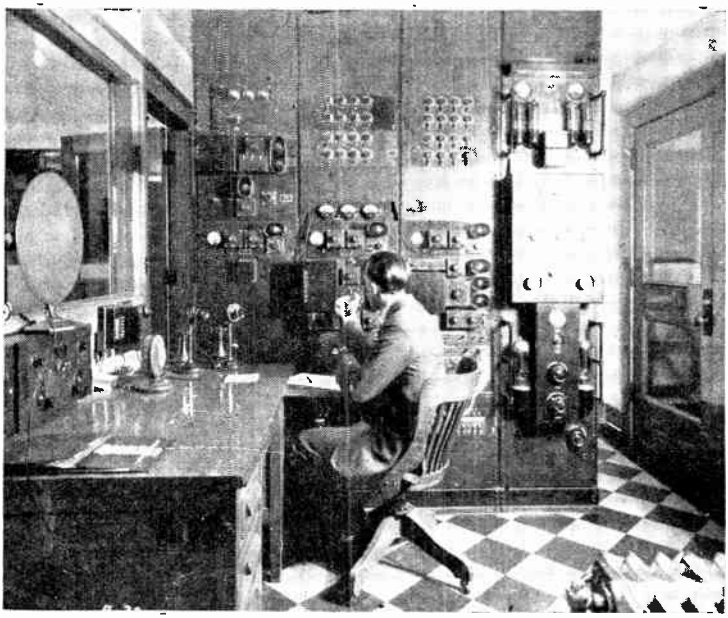

Fig. 18.—This is an inside view of a Broadcasting Station, showing the operator adjusting the proper control units.

to the voltage across the resistance times the current through it and since the power changes as the current, the voltage across the oscillator resistance and hence the voltage across the points, n and p, in Fig. 17 must change to twice its normal value. It has been mentioned that the choke coil in the plate feed circuit tended to maintain the total plate current approximately constant. If it held the plate current absolutely constant, it would be untrue that there was any change in voltage across the points, n and p. However, the inductance of the choke coil is so high and the current flowing through it is varying at an audio-frequency rate (1,000 cycles per second in this case) only a slight change in the value of the current flowing through the coil would cause a large change in the voltage across it. The following are some actual figures from Radiophone sets using this type of modulation:

Average value of total plate current	.08	amperes
Inductance of choke coil, X	2.	henries
Plate voltage	300	volts

In this case, if there was a maximum variation of 20 per cent. in the current through the choke coils, at a modulating frequency of 1,000, the maximum voltage drop across X would be equal to 2πfLI, where f is the frequency in cycles and L the inductance and I the change in current. Writing this out mathematically we would have:

2x3.1416x1000x2.x(20 per cent of .08)=200 volts. The voltage across the points, n and p, would vary from 300-200=100 to 300+200=500. It can be said that the oscillator plate voltage and the amplitude of the antenna current varies in accordance with the microphone diaphragm displacement. This is due to the sounds impinged upon it.

GENERAL RELATIONS IN RADIOTELEPHONE TRANSMITTER CIRCUITS USING PLATE MODULATION

A Radiotelephone set using plate modulation is a more or less complicated network in which three classes of currents coexist—radio-frequency, audio-frequency, and direct. In Figure 19 is shown schematically a typical Radiotelephone transmitter set, analyzed for purposes of discussion into four distinct units. At the extreme right is the radiator unit, which joins up the transmitter with the distant receiving station. The signal depends upon the nature of the wave form of current in this radiator unit. It is independent of the process by which that current is produced. The useful currents in this circuit are of radio-frequency. The modulating mechanism may cause slight audio currents to flow in the radiator unit. These produce practically no effect except at near-by stations. Such audio currents result from the audio current flowing in the lead to the tube, O, which is inductively coupled to the antenna or radiator circuit. During speech the radio-frequency current is of variable amplitude, and is known as modulated radio-frequency. For the purpose of explaining the general operation of the transmitter, it is not necessary to analyze completely the wave form of this current.

The Radio generator unit is to the left of the radiator unit. This contains electron tubes which, from the functions performed by them, are known as oscillator tubes. They also contain the other electrical equipment essential to the production of radio-frequency power from whatever power is supplied at the input b+ and b— terminals of this unit. An important part of any generating unit in Radiotelephony is a device such that the radio-frequency voltage across the input terminals is small compared with other voltages of lower orders of frequency. In the present case, this device is a condenser Cb, the reactance of which for radio-frequencies is low compared with the ratio of average plate voltage of the oscillator tubes to the average plate current. In any continuous wave transmitter, a device of this nature is required in case the radio impedance of the system supplying the plate power is so high that otherwise considerable radio voltage variations would occur across the input terminals, limiting the useful power output. In the present case, the condenser Cb may be thought of as an electrical valve which prevents radio-frequency power working back into the part of the network to the left, but which does not interfere with the lower frequency power entering the generating system. This particular type of generating circuit is known as the Meissner circuit. It is classified electrically as one with plate and grid both inductively coupled to the radio-frequency circuit. Series power supply is used with the same radio-frequency current flowing through the plate coupling coil as through the tube. In place of such a circuit, any of a large number of other types might be used. In the generator unit all three types of electrical currents exist. The power entering the unit during operation is direct power and audio power. The output through the antenna and ground terminals, A and G, is modulated radio-frequency. While a tube in continuous wave telegraphy may be thought of as a converter of power from direct to radio-frequency. In a radiotelephone set, the generator tube converts power from direct and audio to modulated radio-frequency.

To the left of the generator unit is the modulator unit. Its function is to supply audio and direct power to the generator unit, the audio power being controlled by the operator speaking into the microphone. In the case shown, an electron tube is shunted across the input terminals of the generator unit, the two in parallel being supplied with direct power from a direct current source through the iron-core choke coil, Lb. The tube in this case is a speech-controlled resistance in which the instantaneous resistance, or ratio of plate voltage to plate current, is determined largely by the instantaneous grid voltage. On account of the functions it performs, it is known as a modulator tube. Mechanically, it is usually the same as the oscillator tube.

When tubes are paralleled, approximately as many modulator tubes are used as oscillator tubes. The modulator tube is a converter of power from direct to audio-frequency and the audio current and voltage output of the modulator tube is a more or less faithful reproduction of the audio voltage impressed upon the grid of the modulator tube by the use of a microphone and transformer. The modulator tube, therefore,

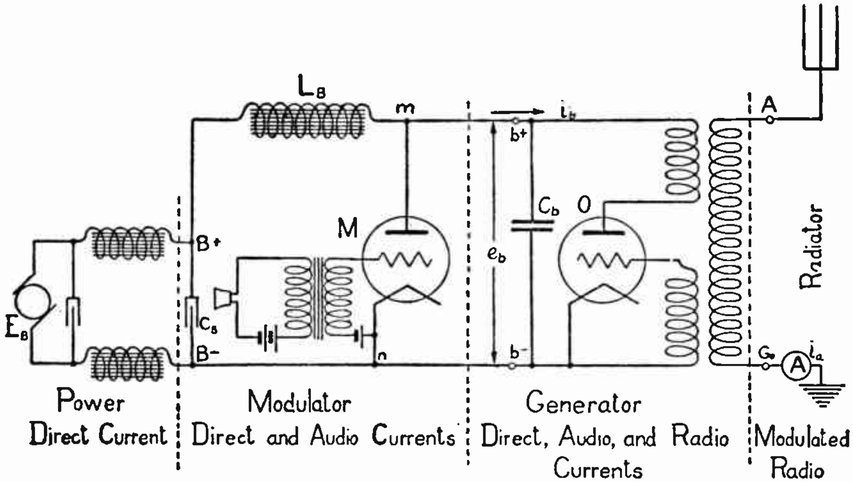

Fig. 19—Analysis of a radiotelephone transmitter set.

functions as an aperiodic power amplifier. The audio power output may be tested, for example, by connecting a suitable resistance and stopping condenser in series across m and n of Fig. 19, instead of the generating circuit. The power which is manifested by the heating effect upon the resistance, during speech, is entirely audio power, converted from direct power from source Eb through the agency of the modulator unit. Tubes for modulating are usually designed to operate with a negative average voltage on the grid, which in the case shown is obtained by the use of a battery in the grid lead. The choke coil, Lb of the modulator circuit partially performs the same function for the modulator unit as does the condenser Cb for the generator unit. It prevents audio currents produced by the unit from working back through the input terminals B+ and B—, and in this it is aided by the condenser, Cb. It performs, however, another important function.

If a fixed impedance and a variable impedance be connected in parallel and placed across a direct power source of zero internal impedance, then variations of one impedance will not disturb the current to the other unless the two in parallel are supplied with power through a common line impedance. The generator unit may be thought of as the fixed impedance and the modulator tube as the variable impedance in parallel, both being supplied with power through the common impedance Lb.

Fig. 20.—This shows the picture of an N. R. I. graduate making changes in the tube transmitter which he operates.

Without this impedance, practically no variations in the audio-frequency voltage across the b+ and b— terminals could occur. The impedance of Lb is usually high for the average speech frequency of 800 cycles per second in comparison with the impedance given by the ratio of the direct voltage across the B+ and B— terminals to the direct current constituent flowing through the choke coil. Choke coils for this purpose are usually built with an air-gap in the magnetic circuit and with a large number of direct current ampere-turns per unit length of the magnetic circuit.

To the left of the modulator unit is the direct power supply unit. In this case it consists of a direct current generator provided with filter circuits to prevent voltage due to commutation from existing across the terminals B+ and B—. The condenser Cb functions doubly as a part of the filter network and as a device which by-passes any audio-frequency current which may flow through the choke coil.

To summarize, tracing from left to right, the primary power supply to the set is direct current delivered to the B+ and B— terminals of the modulator unit. By an audio-frequency variation of the modulator tube impedance, audio power is produced and, together with direct power, is supplied to the b+ and b—input terminals of the generator unit. As a result, the amplitude of the radio-frequency output current of the generator unit is varied at speech frequencies and a wave form emitted, which upon reception gives rise again to speech currents.

TEST QUESTIONS

Number your answer sheet 34 and add your Student Number

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Illustrate by drawing a modulated carrier-wave.
2. Explain the difference between the carrier frequency and the modulating frequency for a 400 meter Broadcasting Station.
3. What two factors determine the R. F. generated by the tube in the Meissner circuit shown in Fig. 5?
4. State the reason for using the coil Xg in the grid leak circuit of Fig. 6.
5. What is the one important advantage of the Armstrong circuit shown in Fig. 9?
6. Why can the plate blocking condenser be eliminated in the Colpitts circuit Fig. 11?
7. Make a diagram of the Master Oscillator circuit.
8. What is the essential difference between the Hartley and the Colpitts circuits?
9. Draw a diagram showing control of modulation by varying grid voltage.
10. Explain briefly by aid of a diagram the Heising system of modulation.

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A COMMERCIAL RADIOTELEPHONE TRANSMITTER

Having discussed the fundamentals of radiotelephone transmitter circuits, we are now going to consider a standard installation in detail. The schematic diagram of a commercial transmitter is shown in Figure 1.

Power is derived from the motor-generator set shown in Fig. 2. The 6¼ horse power driving motor is located in the center of the unit and requires either A. C. or D. C. supply according to local conditions. If the supply is D. C., 115 volts are required. If A. C. is available, a repulsion induction motor that will run on either 110 or 220 volts, 50 or 60 cycle single phase supply is used.

The plate voltage generator furnishes 1. ampere at 2,000 volts and has a mid tap for the 1,000 volt supply. It is a flat compounded machine and is excited from the double current generator located at the right of the motor. Plate voltage is controlled by means of the plate rheostat in series with the main field of the high voltage generator, which is energized by the 125 volt D. C. supply from the double current generator. The handle of this rheostat is mounted on the middle panel, lower center, as shown in Figure 3.

The power control resistance is in series with this circuit, the resistance being short-circuited when the "power" switch on the front of the transmitter panel is set at "high power." When this switch is set at "low power," the short-circuit is removed and the resistance is in series with the field and field-rheostat, thus lowering the plate voltage. The plate voltage is shown by the voltmeter at the left-hand side of the top panel which is connected between the 2,000 volt lead and ground. (See Fig. 1.) There are two protective condensers in series across the high voltage leads, the mid-point of these condensers being connected to ground, their purpose being to safeguard against high voltage surges.

The filter condensers between the plate supply leads and ground are used to smooth out the generator ripple. The double current generator will deliver 4. amperes at 125 volts D. C.

and 10 amperes at 88 volts A. C. It is a flat compounded type of machine and is self-excited. The motor is directly connected to the two generators. The 2,000 volt plate supply is connected to the 250-watt oscillator tubes and the two 250-watt modulator tubes through the common iron-core reactance coil O. P. This reactance is necessary for the application of the Heising system of modulation. Small choke coils are placed in the plate leads of both oscillator and modulator tubes to prevent the production of ultra high-frequencies. These are generally known as parasitic oscillations which are likely to be generated when operating tubes in parallel. The 50-watt speech amplifier tube receives its plate voltage from the 1,000 volt tap on the plate supply generator. The 125 volt D. C. from the double current generator is not only used for energizing the field of the plate supply generator, but it also supplies the negative bias for the grids of the speech amplifier and modulator tubes.

The 88 volt A. C. is applied to a step-down transformer, the secondary of which is connected to the filaments of the tubes. The filaments of the tubes are all in parallel and the voltage applied to them is controlled by means of the filament rheostat on the primary side of the filament transformer. This rheostat and the filament voltmeter is usually located at the operator's desk enabling him to check and adjust the filament voltage.

Eleven volts are required to heat the filaments of the 250-watt tubes, but since only 10 volts are required for the 50-watt speech amplifier tube, a fixed resistance is mounted in series with the filament leads to this tube, of such a value, that with 11 volts at the terminals of the 250-watt tubes there will be 10 volts at the terminals of the 50-watt tube. Two by-pass condensers are connected in series across the secondary of the filament transformer and their midpoint is grounded. These condensers form a low resistance path for the radio-frequency in this part of the circuit and make it unnecessary for the radio-frequency currents to pass through the high reactance of the secondary winding of the filament transformer in order to get to ground as would be true if these by-pass condensers were not in the circuit.

The type of oscillatory circuit used is the "tickler" coil circuit with inductive plate coupling, the fundamentals of which have been previously discussed. The oscillator plates are connected to the positive high voltage through the plate coup-

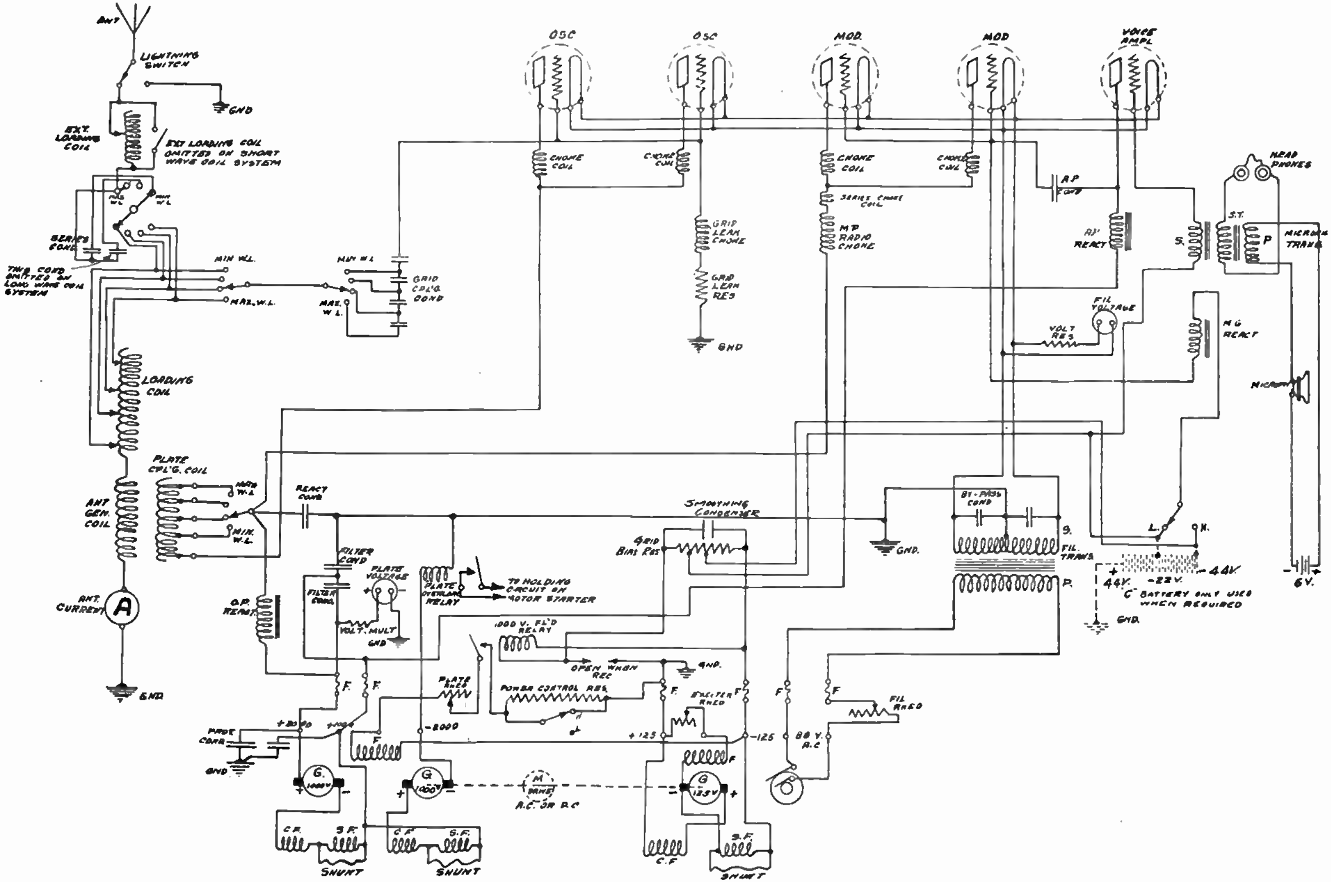


Fig. 1—Schematic Diagram of a Vacuum Tube Transmitter with Telephone Attachment (ET-3608).

ling coil and the iron-core reactance O. P. The grid excitation is supplied by means of the capacity coupling to the antenna circuit through the grid coupling condenser shown in the schematic diagram. The grid leak circuit is composed of the grid leak choke and grid leak resistance. The choke coil isolates the radio-frequency from this part of the circuit to reduce losses and the resistance, together with the D. C. flowing through it, determines the amount of negative bias on the oscillator grids. When a filament switch is closed the filaments are heated to their normal degrees, the application of the plate voltage causes an instantaneous surge in the plate circuit with the result that the antenna is forced into feeble oscillations, the frequency of which depends upon the constants of the antenna circuit. The grid circuit due to its capacitive coupling to the antenna circuit, withdraws some of this oscillating energy with the result that a radio-frequency potential is applied between the grid and the filament. This produces a

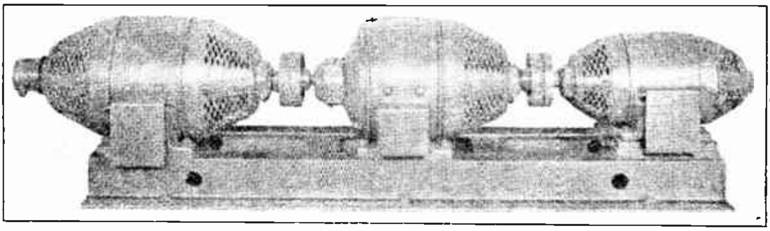


Fig. 2—Motor Generator Set

corresponding change in the plate circuit, which, if the circuits are properly arranged, adds to the effect of the original surge. This cycle of operations is then repeated with the antenna current continually increasing until limited by the antenna and tube characteristics.

MODULATOR CIRCUIT

The Heising system of modulation is used in this set, modulation being accomplished by means of the two 250-watt modulator tubes shown in the schematic diagram and their associated circuits. In addition to the two modulator tubes, a third tube is employed which functions as a speech amplifier. The plates of the two modulator tubes are connected to the positive high voltage terminal through the modulator radio-frequency choke and the iron-core reactance O. P. The filaments of the modulator and oscillator tubes being in parallel, the plate circuit is completed through the space between the plate and filament within the tubes and thence to the negative side of the high voltage generator.

The grids of the modulator tubes are connected through a biasing resistance to the negative filament lead and are also connected to the plate circuit of the speech amplifier tube by a condenser. The plate of the speech amplifier tube is connected to the high voltage source through an iron-core reactor. The

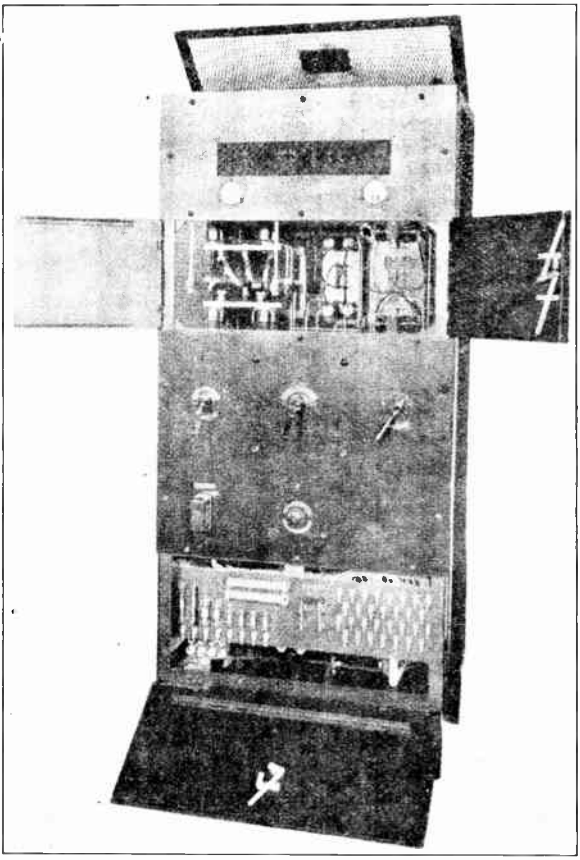


Fig. 3—Transmitter Panel

grid of the speech amplifier tube is connected through the secondary of the microphone transformer and the biasing resistance to the negative filament lead. The primary circuit consists fundamentally of a microphone in series with a 6 volt battery and the primary winding of the microphone transformer. The action that takes place is as follows:

ACTION THAT TAKES PLACE IN A TRANSMITTER

The current passing through the primary winding of the microphone transformer is varied at speech frequency due to the operator talking into the microphone, the secondary of the microphone transformer being connected between the grid and filament of the speech-amplifier tube, impresses upon the grid an alternating potential, the variations of which are in accordance with the sound waves spoken into the microphone. This variation of the speech amplifier grid potential results in a similar variation in the plate circuit. In other words, the output of the microphone is amplified to an extent determined by the circuit and tube characteristics of the speech-amplifier tube. These amplified variations are in turn impressed upon the modulator grid by means of the capacity coupling. The variation of the modulator grid potential produces a corresponding change in the plate current and tube impedance. These variations in the modulator plate circuit result in a corresponding increase or decrease of power available for the plate circuit of the oscillator tube, due to the fact that there is practically a constant current supply for both the plate circuit of the oscillator and modulator tubes which is due to the iron-core reactor in the positive side of the plate generator.

Therefore, if there is a constant supply of plate current for the combined oscillator and modulator tubes and the supply to the modulator tubes is decreased by negative grid, then the supply to the oscillator tubes must be increased and *vice versa*. Thus, the radio-frequency output of the set is modulated. It might be well to note here that the transmitter is supplied with a resistance connected across the 125 volt D. C. supply from the double current generator, this resistance being shunted with a smoothing condenser so that the generator ripple will not be applied to the grids. By means of suitable taps taken from this resistance the correct biasing voltage is maintained on the speech amplifier and modulator grids.

If for any reason, the commutation of the 125 volt generator becomes poor and causes interference, "C" batteries may be used for grid biasing, connected in the circuit as shown by the dotted lines in the diagram, Fig. 1. If this is done, the grid biasing resistance should be removed from the circuit. The speech amplifier grid is maintained at the same negative potential, both when the power switch is set for "high power" and when it is set for "low power," but the negative bias on the modulator tubes is doubled automatically when the power switch is thrown from "low power" to "high power."

The control unit on the operator's desk is shown in Fig. 4. When the operator presses the "start" button on the control unit on his desk, the automatic starter for the motor of the motor-generator set, functions, and the motor is brought up to full speed automatically. Then the "send-receive button is

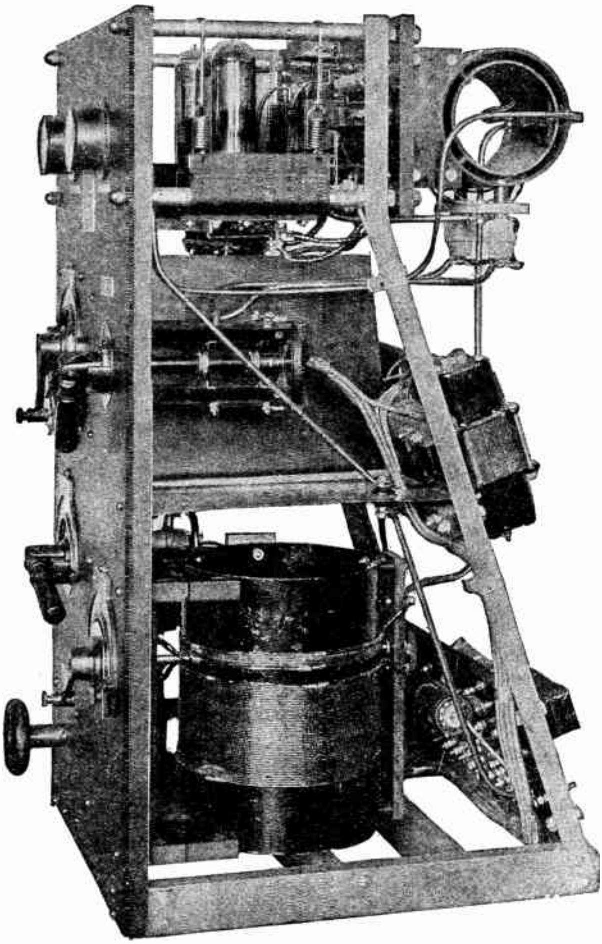
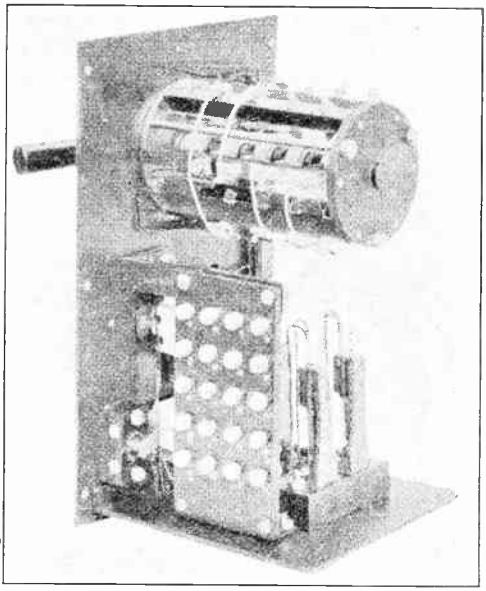
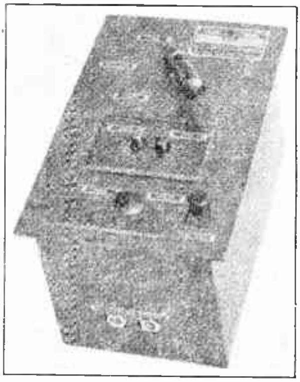


Fig. 3-A—Marine Type of Tube Transmitter

pressed to the "send" position, thereby applying plate and filament voltage to the tubes. The filament voltage is adjusted to 11 volts by means of the filament rheostat and the plate voltage to 2,000 volts by means of the plate rheostat. The transmitter is now ready for operation and if the operator plugs his microphone into the "microphone" jack of the control unit, with the signal switch on the "local" position, he can modulate the set by talking into the microphone. If there is another microphone located at a distance from the transmitter, the local operator presses the "ring" button which rings a bell at the distant position and with the signal switch on "interphone" the local operator can converse with the distant operator without modulating the set. Then if the remote control operator is ready, the local operator sets the signal switch at the "remote" position and the remote control operator can modulate the set. When the conversation has been completed and it is desired to shut down the set, the send-receive switch is pressed



Operator's Control Unit.
(Interior View).



Operator's Control Unit.
(Exterior View).

Fig. 4

to the "receive" position and the "stop" button also pressed, thus opening the circuit to the motor and the motor-generator set comes to a stop.

SIMULTANEOUS TRANSMISSION AND RECEPTION

So far we have considered the radiotelephone transmitter by itself now we are going to discuss the circuit arrangement and apparatus necessary to carry on simultaneous transmission and reception. By simultaneous transmission and reception is meant the same thing as talking over the wire telephone, where it is possible to talk and listen at the same time, except of course that in radio transmission of this type, the air takes the place of the wires between stations. This method of operation is sometimes referred to as duplex radio communication. Figure 5 shows the ideal arrangement for duplex communication. The transmitting and receiving stations at point (A) are located five miles apart with all the controls installed in the receiving station. The microphone and transmitter controls are wired over to the receiving station making

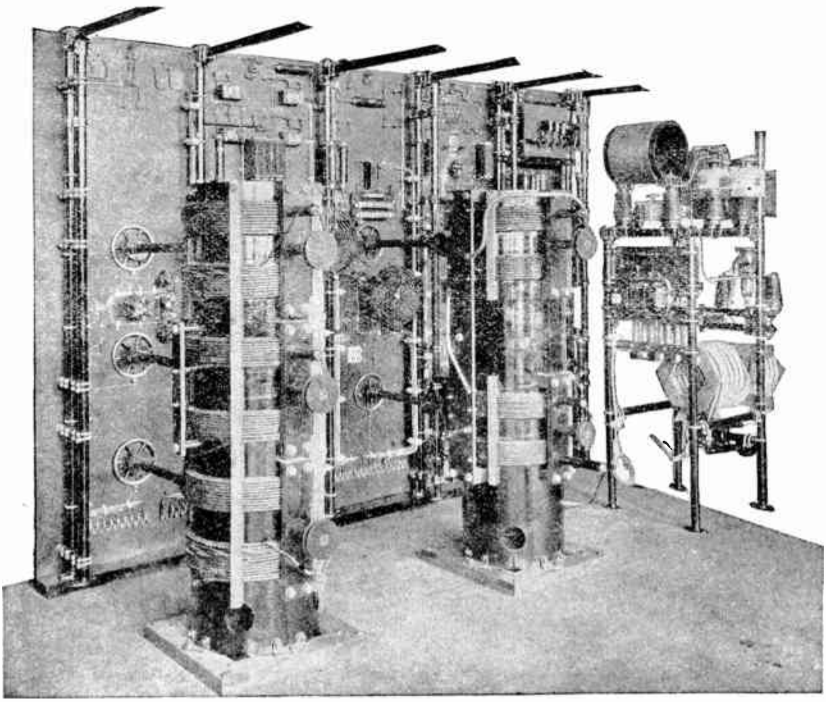


Fig. 4-A—Commercial Trans-Atlantic Tube Transmitter

it possible to start the transmitter and control or modulate its output from the receiving station.

Let us assume that the transmitter at station (A) is tuned to 400 meters and the receiver to 350 meters. The receiver must be of a selective type, either a Super-Heterodyne or a tuned radio-frequency receiver. Station (B) is 100 miles from station (A) and the transmitter and receiver here are also located five miles apart. At this point, however, the transmitter is tuned to 350 meters and the receiver to 400 meters. When the operator at station (A) talks into the microphone, a 400 meter voice-modulated wave is radiated from his transmitting antenna. His receiver being tuned to 350 meters does not pick up the 400 meter wave, but the operator at station (B) who has tuned his receiver to this wave-length hears the voice from the distant station and answers, speaking into the microphone at station (B). Thus a voice modulated wave is radiated from the transmitting antenna at station (B) but in this case the wave-length of the radiated energy is 350 meters so it does not interfere with the local receiver which is set at 400 meters, but is heard by the operator at station (A) who has his receiver tuned to this wave-length. Thus, the two operators can converse as though they were talking over the land line telephone.

It is possible, although not feasible, to locate the transmitter and the receiver at one of the above stations, five miles

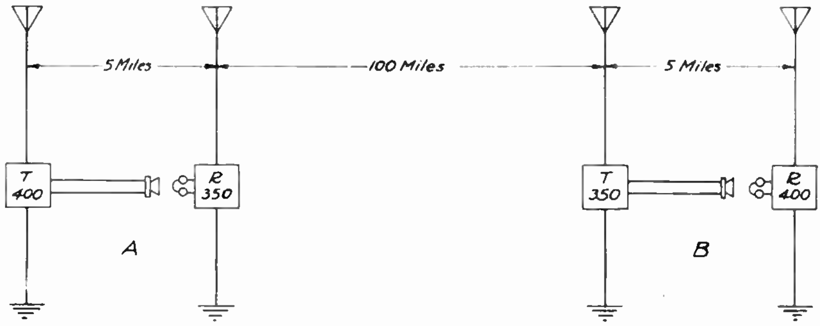


Fig. 5

apart, or they may be located only a mile apart, see Fig. 5-A. In this case it would probably only be necessary to use a loop for reception instead of the overhead antenna to eliminate the interference from the transmitter. In this case it would not be necessary to use any interference elimination circuits in conjunction with the loop, provided of course, a selective type of receiver were used.

The above requirements cannot always be fulfilled. On land it is usually practical and possible to locate the transmitter and the receiver a few miles apart, but on a ship at sea, for instance, this would be impossible. Therefore, if duplex communication is to be carried on from ship to shore it will be necessary, on shipboard, to use some method of eliminating the interference from the local transmitter. Obviously, the best arrangement is to have the transmitting and receiving antennas located as far apart and as loosely coupled as possible. When the transmitting antenna is radiating energy, a considerable amount is picked up by the receiving antenna due to the

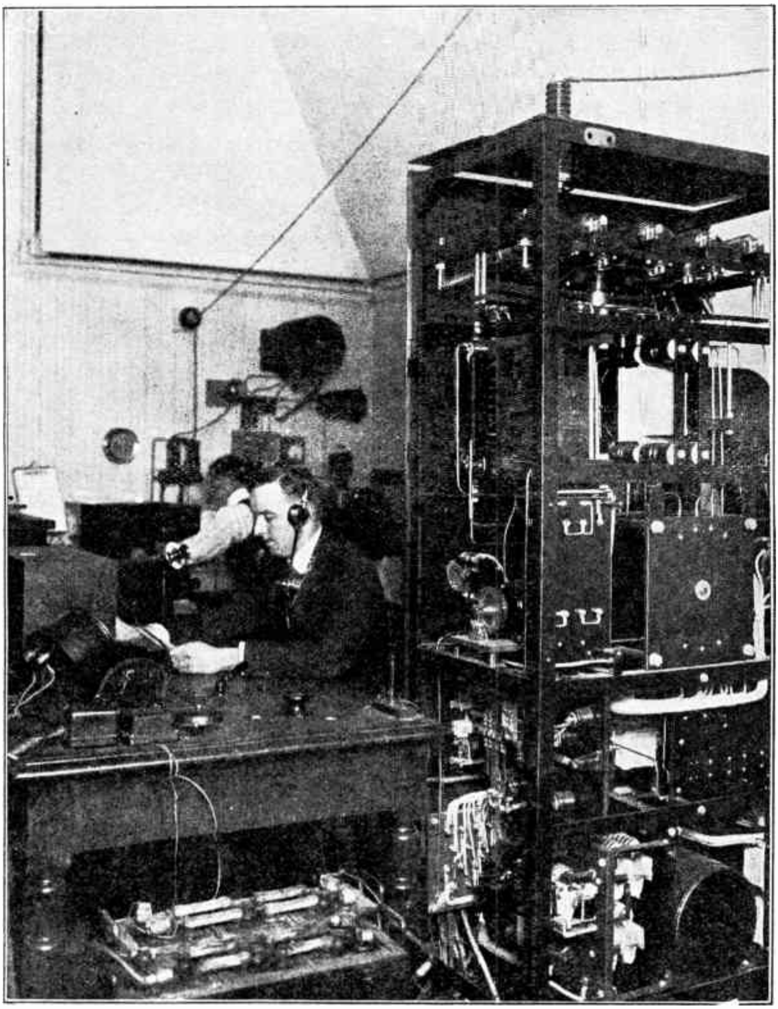


Fig. 5-A—Typical Inside View of a Broadcast Station.

proximity of the two, and even though the receiver is detuned 50 meters from the transmitter wave-length (assuming the same figures as in the previous case) a large amount of interference is experienced due to the strength of the voltage induced in the receiving antenna.

One way of eliminating this local interference and make it possible to work duplex is shown by the schematic diagram in Fig. 6. Here the transmitting and receiving antennas are only 100 feet apart and the interference is eliminated by means of the "anti-resonant" circuit in series with the antenna lead to the receiver. The inductance (L) and the capacity (C) are so chosen that they tune to 400 meters (the wave-length of the transmitter.) An inductance and capacity in parallel, when connected in series in a given circuit, offers extremely high impedance to the flow of any current of the frequency to which the parallel circuit is tuned. The circuit in this case is tuned to 400 meters and the impedance curve is shown in Fig. 7. It can be seen from this figure that the impedance is very high for the wave-length the local transmitter is tuned to, but is very low for the wave-length of the distant transmitter. Thus, the weak signals from the distant transmitter can come through with very little impedance on their path and the answer sent back from the local transmitter without interfering with reception.

Another circuit to eliminate local interference in an installation of this type is shown in Fig. 8. The same values of inductance and capacity as in the previous case are used here, but instead of connecting them in parallel and then in series with the antenna circuit, they are connected in series and the combination in parallel with the antenna circuit. They function just the opposite in this case, due to the fact that when an inductance and a capacity are connected in series and the combination connected in parallel with a given circuit, a very low resistance is offered to the flow of any current of the frequency to which they are tuned. Hence, they tend to shunt the given circuit.

This is called a "series resonant" circuit or a "zero impedance" circuit and in this case is tuned to 400 meters while the receiving circuit is tuned to 350 meters. Thus, the zero impedance circuit will practically short-circuit all 400 meter energy picked up by the receiving antenna, to ground, but will offer a very large impedance at the 350 wave-length. Then, the weak 350 meter energy from the distant station follows the path of least resistance and will flow through the primary coil of the receiver rather than through the high impedance path of the zero-impedance circuit. Fig. 9 shows the impedance curve for the zero-impedance circuit of Fig. 8. The lowest value is reached at the point (x.) Here the inductive reactance and the capacity reactance balance out and the amount of impedance (xy) is due to the ohmic resistance of the circuit. At 350 meters, the impedance of the circuit is very high.

Another type of circuit that can be used in duplex communication under the conditions cited in the previous case is shown in Fig. 10. Here, two or three turns of heavy wire are shunted across the antenna-ground binding posts of the receiving set and this coil is closely coupled to the tuned circuit (C_rLr). The few turns composing the coil (LR) should be wound directly over the coil (Lr). The parallel circuit is so closely coupled to the coil which is shunted across the input to the receiver that if it is tuned to 350 meters it produces the effect of an infinitely high impedance to the flow of all current of that frequency, through the coil (LR.)

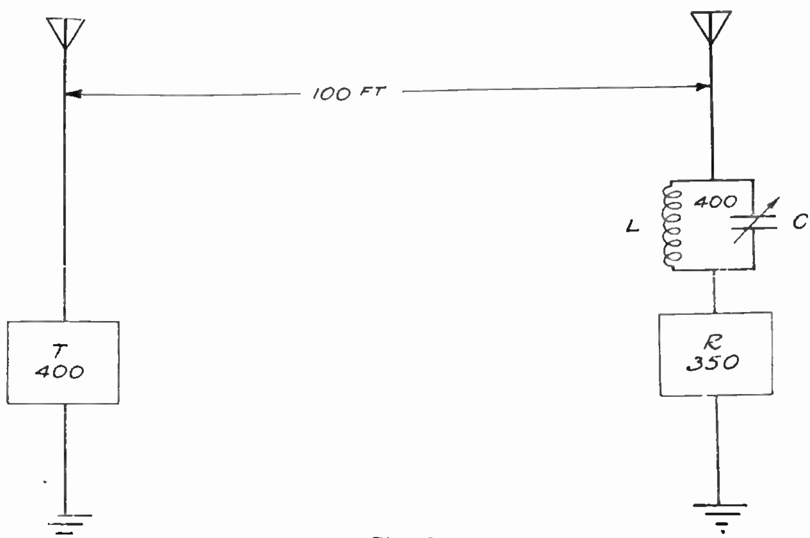


Fig. 6

The impedance of coil (LR) is as shown in Fig. 11. It has a very high impedance at 350 meters, but only practically its own ohmic resistance at all other wave-lengths. Thus, energy picked up by the receiving antenna from the local transmitter is short-circuited to ground while the 350 meter energy from the distant station follows the path of least resistance and passes through the primary coil of the receiver. Any wave-length in the immediate vicinity of 350 meters is received efficiently, but all others are short-circuited to ground. It is important to note here that while the preceding two types of trap circuits eliminated one particular frequency and accepted all others this last type accepts one particular frequency and eliminates all others.

It is often desirable in an installation aboard ship for duplex communication to use the same antenna for transmitting and receiving. This means that it is necessary for the receiver to detect the weak signals picked up from the distant transmitter, amplify them and produce good quality and volume, free from interference, while there are, say 15 amps, of modulated radio-frequency current flowing in the same antenna. These conditions, of course, make duplex communication much more difficult, but it can be done efficiently and practically. The circuit arrangement is shown in Fig. 12. The receiver used in this case is of the Super-Heterodyne type. The transmitter is tuned to 370 meters, say, and the receiver is tuned to receive 400 meter signals from the distant station. The trap circuit used here is of the anti-resonant type and since it is tuned to the same wave-length as the transmitter, offers a very high impedance to the passage of any current of that frequency. However, since there is so much energy in the antenna circuit of that frequency, a little is bound to get through to the primary circuit of the Super-Heterodyne receiver. This energy is used instead of using a separate oscillator to beat with the incoming signal in the receiver circuit. Obviously no local oscillator is necessary in a Super-Heterodyne receiver under these conditions.

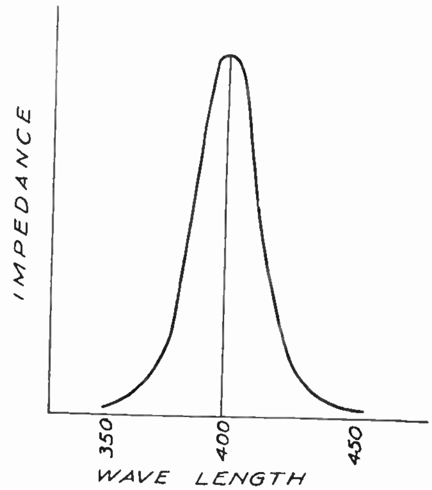


Fig. 7

The frequency of the local transmitter = 300,000,000 ÷ 370 = 811,000 cycles.

The frequency of the distant transmitter = 300,000,000 ÷ 400 = 750,000 cycles.

The beat frequency = 61,000 cycles.

The wave-length of the beat note = 300,000,000 ÷ 61000 = 4,900 meters.

The above calculations are in round figures and not carried out to the last place. The distant 750,000 cycle signals beat with the 811,000 cycles which is the frequency of the local transmitter and form a 61,000 cycle beat note. In terms of wave-length we can say that the distant 400 meter signal has been changed into a 4,900 meter signal at the re-

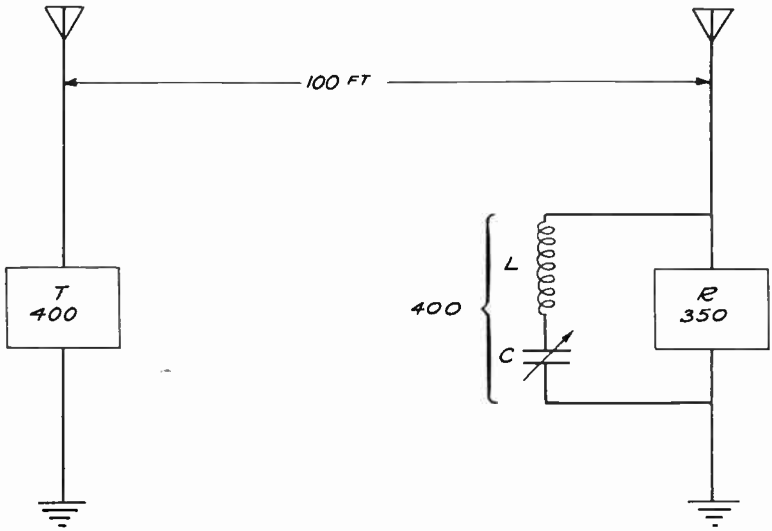


Fig. 8

ceiving station. This 4,900 meter beat note is detected by the high-frequency detector in the receiver and amplified by the intermediate frequency amplifier. The audio-frequency envelope over the 4,900 meter beat note is detected by the low-frequency detector and is amplified in the audio-frequency amplifier circuit. This system has been tried out and proved satisfactory.

BROADCASTING TRANSMITTERS

There is a marked difference between the commercial type of radiotelephone transmitter previously described and the type of transmitter used for broadcasting. The limits for both the mechanical and electrical design of the former are definitely fixed by economic and operating conditions. On the other hand, the economics of the broadcasting station are indefinite at present and the method of operation is determined by factors very different from those governing commercial traffic. The commercial radiotelephone transmitter is designed so that it can be used either for telegraph or telephone communication. Also, in the commercial type of transmitter it is possible, by means of a wave-change switch, to change to any one of half a dozen wave-lengths to which the set is tuned and by a separate gang switch select any one of the following methods of transmission:

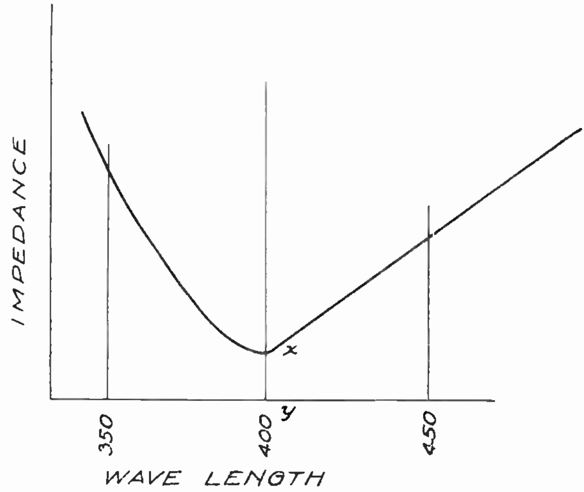


Fig. 9

continuous wave telegraphy (CW), interrupted continuous wave telegraphy (ICW) and telephone.

For transmitting with interrupted continuous waves, use is made of a motor-driven interrupter, which operates similarly to the transmitting key on the continuous wave position except that the oscillations are started and stopped at an audio-frequency.

The broadcasting transmitter, however, is assigned to one particular wave-length. The oscillatory circuits are tuned to that one wave-length and all the associated apparatus is adjusted for maximum efficiency at that particular wave-length. While the commercial transmitter is required to transmit only the band of frequencies necessary to handle commercial telephony, the broadcast transmitter must be capable of transmitting frequencies from the deepest tone of the organ to the highest note of the piccolo flute. In short, the broadcast transmitter has numerous refinements which, due to both economic and operating conditions, could not be incorporated in the commercial type of transmitter. All apparatus in a broadcasting station is in duplicate to insure continuity of service. Summarizing, the general requirements of the broadcasting station are as follows:

1. The station must be ready for operation at all times so that the director may be able to handle a special program.

2. Continuity of service is absolutely necessary. The equipment must be so designed and operated that there will be no interruptions during the program.

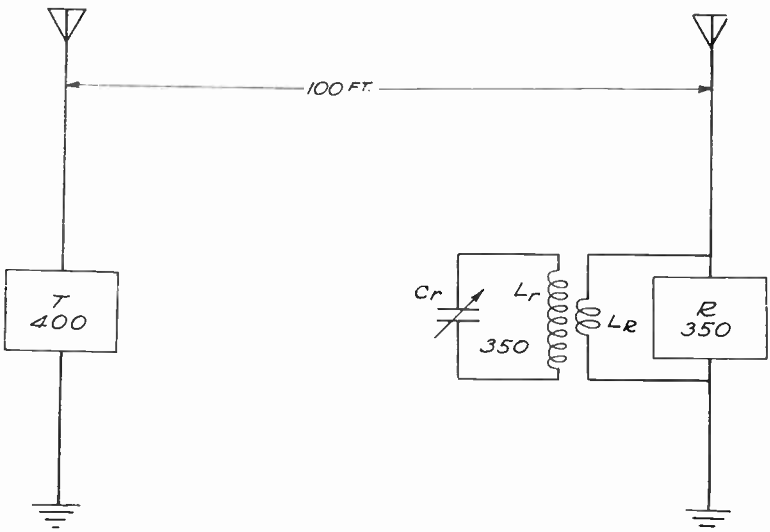


Fig. 10

3. The quality must be of the highest order.

4. The transmitter frequency must remain constant under all operating conditions.

Figure 13 shows a plan view of the layout for a broadcasting station. The power house here is situated 1,000 feet from the studio but this is not a necessity—in many instances the power house is located adjacent to the control room.

The power plant contains all the equipment necessary for the generation, modulation and radiation of radio-frequency power. The apparatus consists of the following, supplied in duplicate to insure continuity of service:

1. Kenotron rectifier unit to supply high voltage D. C.

2. Radio-frequency generator utilizing high power vacuum tubes as oscillators.

3. Modulator unit utilizing high power vacuum tubes as modulators.

The control room contains all amplifying and switching equipment. The main studio consists of a room prepared and furnished especially for broadcasting service. The walls and ceiling are covered with draperies to prevent the reflection of the sound waves. All microphone and control circuits are carried in lead covered cables placed behind the wall draperies. Connection boxes are usually located along the base-

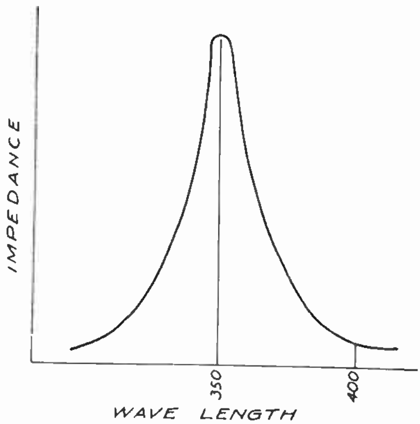


Fig. 11

board near the floor for the microphone outlets. The auxiliary studio is similar to the main studio but is generally much smaller and is used principally for readings and lectures.

The pick-up device or microphone, see Fig. 13-A, is one of the most important units associated with a broadcasting station, its function being to transform the sound vibrations imposed upon it into electrical oscillations that can be handled efficiently by the rest of the apparatus. In the studio, a separate microphone is sometimes used for a particular instrument such as a piano and the soloist also, usually has an individual microphone. A great portion of the success of any broadcasting station depends upon the operation of the studio. The proper placing of the artists and the relation of the various instruments of the orchestra, band or chorus, affect the transmission very materially.

The problem of broadcasting from churches and other places outside of the regular studio has received considerable

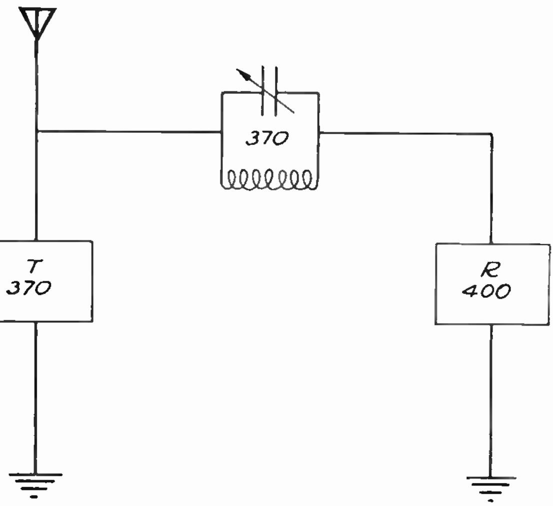


Fig. 12

attention. A typical arrangement of the microphones necessary to broadcast a church service is shown in Fig. 14. Eight microphones are used in this case besides the operator's microphone which is not shown in the figure. By means of a control unit

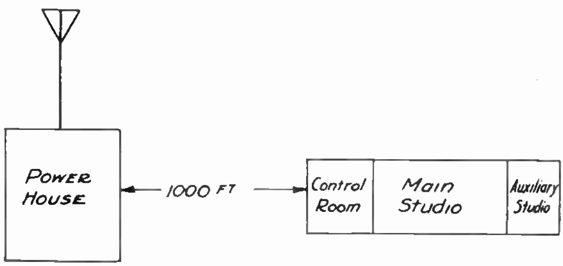


Fig. 13

at the operator's position, any combination of the nine microphones may be switched into service. Figure 15 is a schematic diagram showing an operator's control position with the four incoming microphone circuits and the two outgoing circuits to the control room at the studio. The second circuit to the control room is available for use in case the first circuit becomes noisy or otherwise inoperative.

In the commercial type of radiotelephone transmitter previously described, there was a 50 watt tube which was used as a speech amplifier. In the modern type of the broadcasting transmitter, the speech which actuates the microphone diaphragm passes through an elaborate system of speech amplifiers before it reaches the speech amplifier tube in the transmitter unit, as shown schematically in Fig. 16.

Figure 17 is a plan view showing the layout of the first second and third stage amplifiers with the coupling units and the lines to the power house. In this case, there are 10 first

Fig. 13-A—The Microphone Which Changes the Sound Vibrations Into Electrical Oscillations

stage amplifiers. Numbers 1 and 2 are for the announcer's microphones in the main and the auxiliary studios. Number 3 is for time signals. Numbers 4 and 5 are on church circuits and Nos. 6 to 10, inclusive, are on concert circuits. Four different types of first stage amplifiers are provided and one selected according to the pick-up device used. Certain amplifiers are assigned to certain classes of service. For example, each studio has its own announcer's amplifier which may be of the type shown in Figs. 18 or 19. The former is a first stage amplifier used in conjunction with a single button type of microphone. The latter is the type of circuit used with the double type of pick-up device.

Certain amplifiers are used for broadcasting from the places other than the studio. For example, Fig. 20 shows a circuit arrangement where the condenser type of microphone is used. In this case the output of the microphone circuit is put through two stages of resistance coupled amplification be-

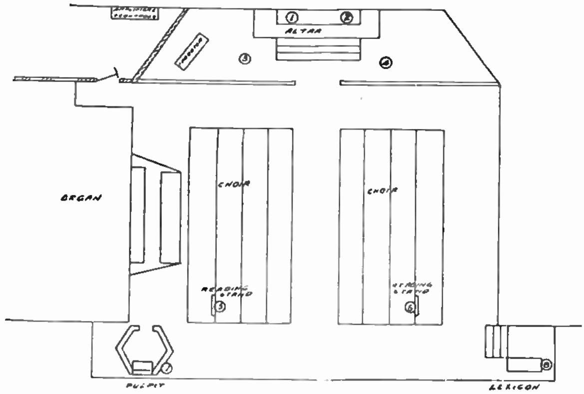


Fig. 14—Typical Arrangement of Microphones in a Church

fore being put on the line to the control room at the studio. When it reaches the studio, this energy passes through another stage of amplification before being passed to the 50 watt second stage amplifier. All the stages ahead of the 50 watt tube or second stage amplifier are referred to as first stage amplifiers. In other words, they are the stages of amplification using the lowest capacity tubes.

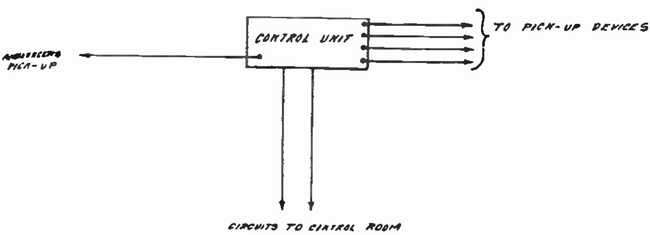


Fig. 15

Another type of amplifier which is used a great deal for broadcasting concerts, etc., is shown in Fig. 21. The push-pull amplifier shown here is located at the concert hall and the output from this amplifier is put on the line to the studio. At the studio, the incoming energy is amplified by a 5 watt tube and the output of this tube is applied to the grid of the second stage amplifier tube.

Each first stage amplifier has its own output control, filament control and listening-in jack. The output circuits of any-

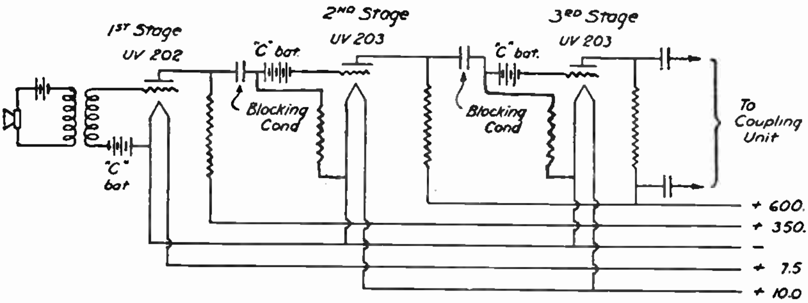


Fig. 16—Circuit diagram of speech amplifier

one of the 10 first stage amplifiers shown in Fig. 17, may be plugged into either one of two second stage amplifiers. The input circuits of the second stage units include several jacks connected in parallel, thus permitting a number of first stage

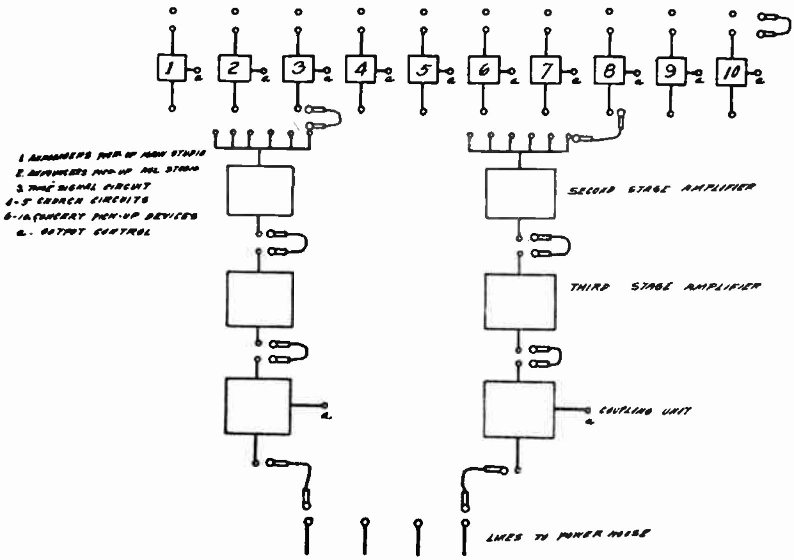


Fig. 17—Layout of Amplifiers, Coupling Units and Lines to Power House

amplifiers to be plugged into one second stage amplifier. For instance, if the first stage amplifiers, Nos. 1, 3 and 6 were all plugged into the second stage amplifier, it would be possible for the local control operator (assuming that a concert was coming in on No. 6) to cut out the concert and cut in the announcer's microphone at the studio by the single throw of a switch. The announcer at the studio might then broadcast the following: "The concert from the Waldorf-Astoria will be in-

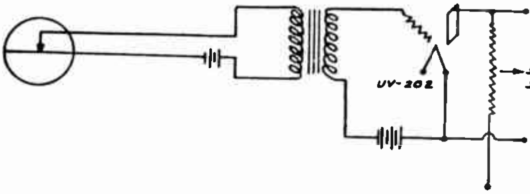


Fig. 18—Schematic Diagram Showing Single Button Microphone Connected to Amplifier

terrupted for a few minutes for the re-transmission of the Arlington time signals." Then with another throw of the control switch, the announcer's microphone at the studio could be cut

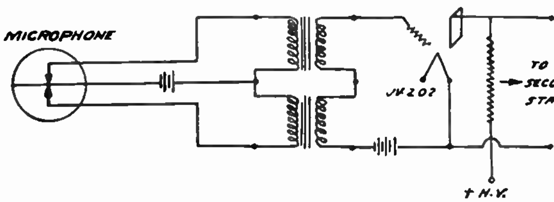


Fig. 19—Schematic Diagram Showing Double Button Microphone Connected to Amplifier

out and the time signals cut in. At the end of the re-transmission of time signals the concert could again be thrown on the air.

The output of the second stage amplifier may be plugged into either of the two third stage amplifiers. Both the second and third stage amplifiers use a 50 watt tube operated at a plate

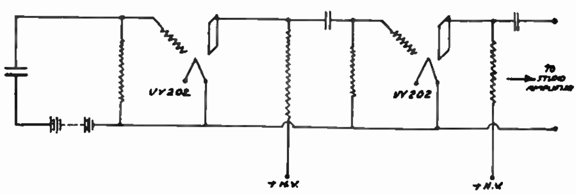


Fig. 20—Schematic Diagram Showing Condenser Microphone Connected to Amplifiers

potential of 600 volts. The output of the third stage amplifier may be plugged into either of two filter units, designated as coupling units in Fig. 17. The output of either filter unit can be plugged into any one of four lines to the power house, where the oscillator and modulator units are located.

The layout of the apparatus in the power house is shown in Fig. 22. This is the transmitter which consists of an oscilla-

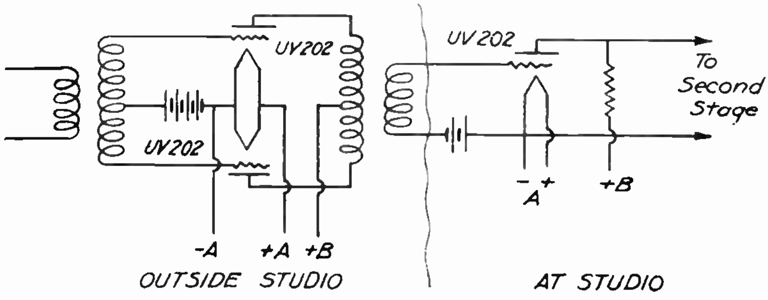


Fig. 21—Push Pull Amplifier

tor, modulator and speech amplifier unit corresponding to the commercial telephone transmitter described previously.

In the commercial transmitter the speech amplifier in the transmitter unit is the first and only stage of amplification, whereas, in this broadcasting layout, the speech-amplifier in the transmitter unit constitutes the fourth stage of amplification.

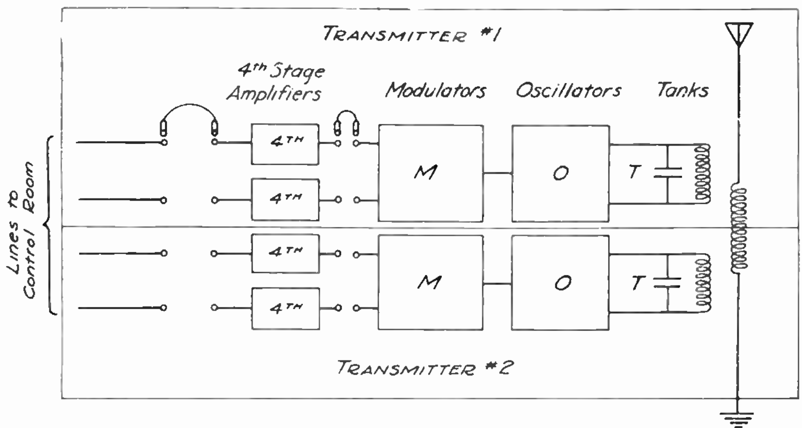


Fig. 22—Layout of Apparatus in the Power House

Any of the lines from the control room may be plugged into any one of the four fourth stage amplifiers. There are two amplifiers for transmitter No. 1 and two for transmitter No. 2. One is a push-pull amplifier and the other a reactance coupled amplifier. Either may be used depending upon operating conditions. Two hundred and fifty watt tubes (UV-204) at a plate

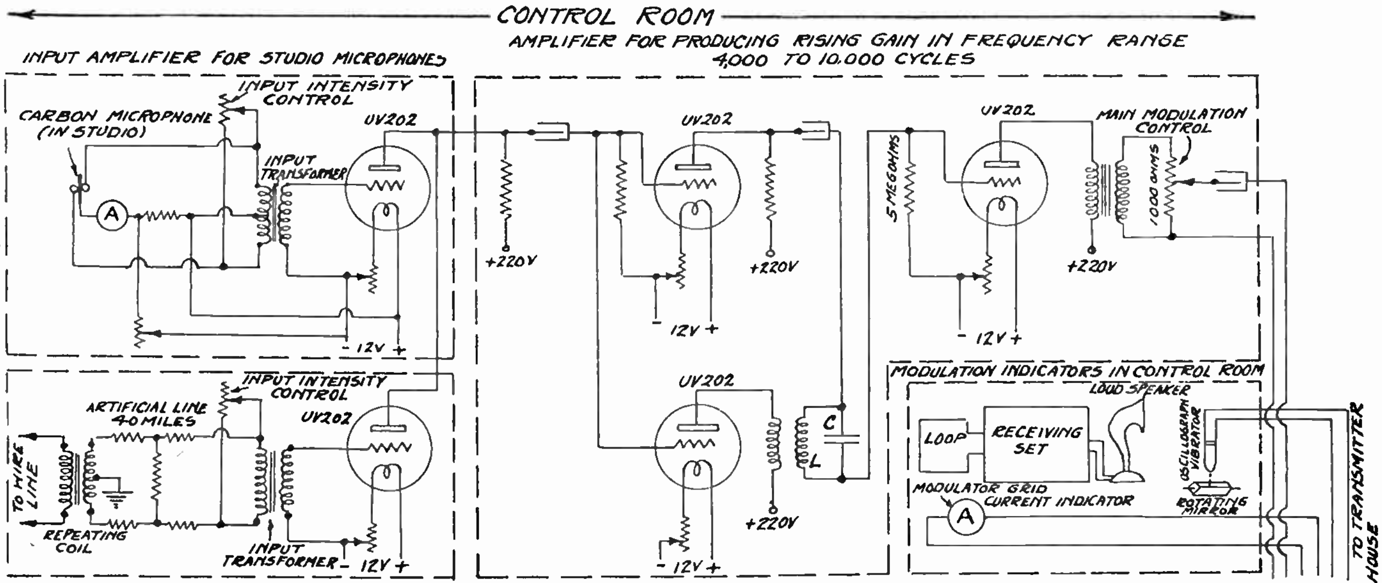


Fig. 23—Wiring Diagram of Control Apparatus

potential of 2,000 volts are used in these amplifiers. The output of the fourth stage amplifier is plugged into the modulator unit which consists of five 1.K.W. tubes (UV-206.) The oscillator utilizes a "tank" circuit, loosely coupled to the antenna circuit to maintain constant frequency. A "tank" circuit is simply a tuned intermediate circuit which transfers the power output of the oscillator to the antenna circuit, the frequency of the radiated energy being determined chiefly by the constants of the tank or dummy circuit.

STATION APPARATUS AND DIAGRAMS OF CONNECTIONS

Schematic wiring diagrams of a station apparatus involved in broadcasting is shown in Figs. 23 and 24. Starting at the upper left-hand corner of Fig. 23, we have a single stage amplifier which is arranged for inputs from a studio microphone or a wire line (in case of broadcasting from points outside the studio.) The microphone is connected directly to the input transformer, while in the case of wire lines a 40-mile resistance artificial line is connected between the line and input transformer to lower the input energy to a level of the same order of magnitude as that obtained from a microphone. The voltage produced by a microphone across the terminals of the input transformer is about two millivolts, while at the end of a line, a signal of about two-tenths of a volt is usually available.

The first stage is resistance coupled to the input side of a special amplifier designed to give uniform amplification over the frequency band from 100 to 4,000 cycles. From 4,000 to 10,000 cycles, it is arranged to produce gradually increasing amplification. The reason for this is that all present loudspeakers, head-telephones, and many audio-frequency transformers (as used in receiving sets) give a decreasing output in this range, and a rising frequency at the transmitting station will tend to compensate for this. As a result, such sounds as the consonant "s," the characteristic frequency of which is of the order of 10,000 cycles, are reproduced very clearly on the average receiving set, while music is also given greater clearness because of the better reproduction of harmonics.

The output of the microphone amplifier is fed to the grids of two tubes, in parallel. The upper tube has a resistance in its plate circuit and the lower one a resonance transformer composed of air-core coils and a condenser with its resonance peak

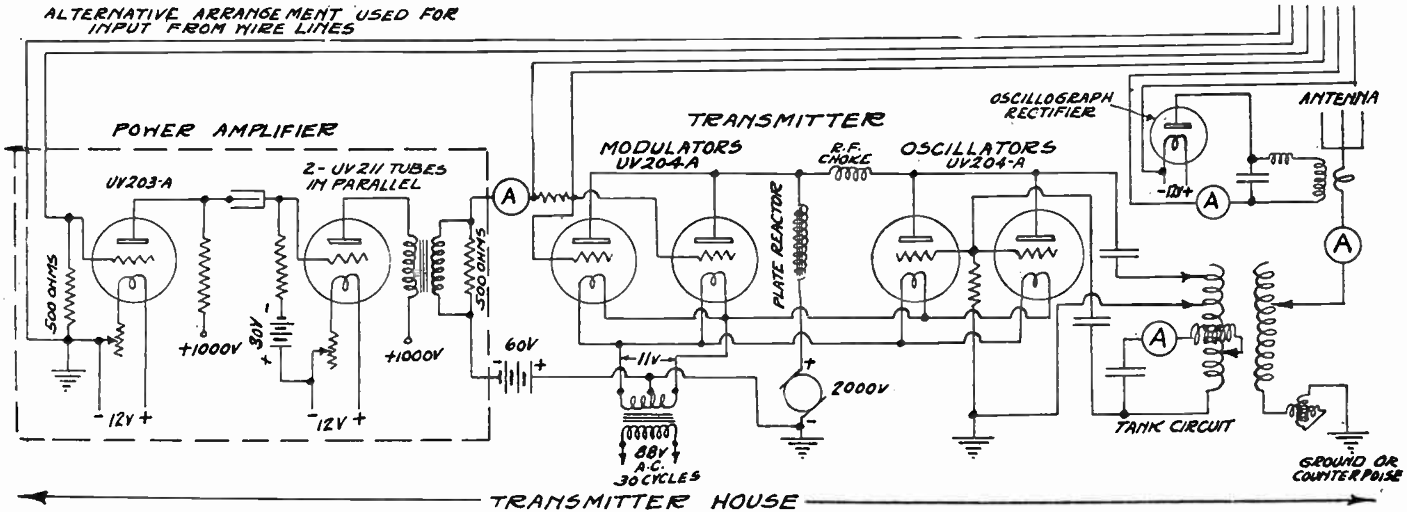


Fig. 24—Wiring Diagram of Transmitting Apparatus

at 10,000 cycles. The voltage delivered by the upper (resistance) coupled tube is uniform with respect to frequency, while that delivered by the lower tube is a resonance curve having a maximum at 10,000 cycles. The voltages delivered by these two tubes are added in series and applied to the grid of a third tube, the magnitudes being so chosen that the sum of the two gives the proper frequency characteristic. The third tube serves as an output tube, and its output is stepped down in order to feed the input side of the power amplifier, Fig. 24, in the transmitter house through a cable which is about 600 feet (185 meters) long. On the low voltage side of the output transformer is placed the main modulation control, a 500-ohm potentiometer, by means of which the voltage supplied to the power amplifier may be regulated. The cable in the transmitter house is terminated by a 500-ohm resistance, from which the grid of the first power amplifier tube is fed. It may appear uneconomical not to place a step-up transformer at this point, but it is preferable to avoid transformers whenever sufficient amplification is already available, since each transformer cuts off transmission of low and high frequencies to some extent.

The power amplifier has two stages, the first being resistance coupled and the second transformer coupled to the grids of the modulator tubes. A step-down transformer with 500 ohms across the secondary is used so that with positive potentials applied to the modulator grids no distortion will occur, due to the grid current drawn. The customary "constant current" modulation system is used. The oscillators work into a local circuit (called the "tank circuit") which is inductively coupled to the antenna. Variometers are provided for wavelength control in both local and antenna circuit. The antenna power, unmodulated, is normally 500 watts, antenna current about 7 amperes on 455 meters and 6 amperes on 405 meters.

TEST QUESTIONS

Number Your Answer Sheet 35 and add Your Student Number

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. How is the high voltage plate current obtained from the 110 volt power lines?
2. Why are the two condensers joined in series (mid-point grounded) and connected across the secondary coil of the filament transformer in Fig. 1?
3. What provision is made to correct interference to the grid bias in case the commutation of the 125 volt generator becomes bad?
4. Represent by a drawing the arrangement of transmitter and receiver (100 feet apart) for simultaneous operation.
5. What is the advantage of the arrangement in Fig. 10 over the other methods?
6. Explain by use of a drawing the method of reception by the transmitting aerial on shipboard for Duplex operation.
7. Illustrate the system of speech amplifiers before it reaches the broadcast transmitter.
8. Show the layout of the apparatus in the power house of a broadcasting station.
9. Draw a wiring diagram for the control room apparatus.
10. Show the method of wiring for the transmitting apparatus.

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AMATEUR SHORT WAVE TRANSMITTERS AND RECEIVERS

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"Everybody likes and respects self-made men. It is a great deal better to be made in that way than not be made at all."—*Oliver Wendell Holmes.*

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

AMATEUR SHORT WAVE TRANSMITTERS AND RECEIVERS

Prior to 1922, very little was known about the so-called "Short Wave-length"—that is, Radio waves of or below 100 meters. Since that time, a great deal has been found out and now the use of short waves is being developed by the commercial companies, and is supplanting some of the high powered long wave-length transmitting stations.

In 1912, the United States Government assigned to the amateurs the wave-length band between 150 and 200 meters, because at that time the amateurs were not considered very important and it was thought that the wave-lengths below 200 meters were of little value for commercial work, and were not satisfactory for long distance communication. About 1922, some of the more energetic amateurs, including Reinartz, decided to explore the short wave-length band below 100 meters, and if possible, determine just what could be accomplished on these short waves.

Experiments during 1922, 1923 and 1924 proved that these short waves were valuable, and that some peculiar conditions existed when transmitting on these waves. It was found possible to cover a much greater distance than when transmitting in the band between 150 and 200 meters, and using the same amount of power, also that on the waves around 20 meters, during the daytime. the signals could be heard several thousand miles, while at night, they could be heard only a very short distance. It was also noticed that these signals could not be heard very easily when the receiving station was located within a distance of 200 to 600 miles from the transmitting station. When transmitting on 40 meters, the signals were practically as strong during the day as they were at night, while on 80 meters, the signals were much stronger at night than they were in the daytime.

Reliable trans-continental communication was established during the daylight hours using only a small amount of power as compared to that used by the commercial stations. When commercial companies learned that reliable daylight transcontinental communication by means of short waves required less power than the longer wave-lengths they began to try out the possibilities of short wave transmitters during the past few years, these commercial companies have spent a great deal of money in developing short wave transmitters.

The result of this development is that there are today commercial stations which are operating on wave-lengths ranging between 15 and 100 meters, and in some cases, they are reliably covering the same distance as the long wave stations and using only a few kilowatts of power, perhaps, from 5 to 20 kilowatts, whereas, the long wave stations use from 100 to 200 kilowatts.

It must be remembered that most of the experiments of Maxwell and Hertz were conducted on very short waves. Therefore, we are today coming back to the short waves employed by Maxwell and Hertz, and we are finding out that we have heretofore overlooked a very valuable asset.

The apparatus used in a short wave transmitter or receiver is fundamentally the same as used in any other type of transmitter or receiver. Figure 1 illustrates the schematic wiring diagram of a Hartley short wave transmitting set including power supply, rectifier, and filter.

Several kits for short wave transmitting sets are now on the market—Fig. 2 illustrates one of these assembled kits. A list of parts necessary for the construction of this set is listed herewith. The numbers refer to the numbers in Figs. 1 and 3.

(1) Radio-frequency choke coil. (Type Radio Engineering Laboratories).

(2) A .001 mfd. receiving grid condenser and grid leak (Sangamo) including one 5,000 ohm Lavite transmitting grid leak.

(3) A .002 mfd. receiving plate condenser. (Sangamo).

(4) A primary inductance. (REL).

(5) A secondary inductance. (REL).

(6) Two brass angle supports for inductance. (Fig. 4).

(7) .0005 mfd. variable condenser. (Cardwell).

(8) .0005 mfd. variable condenser. (Cardwell).

(9) Filament switch.

(10) UX type socket.

Two dials.

One 3½ volt flashlight lamp with miniature base.
Eleven binding posts.
One baseboard of hardwood, ½x8x18 inches.
One panel, hardwood or hard rubber, ¼x7x18 inches.

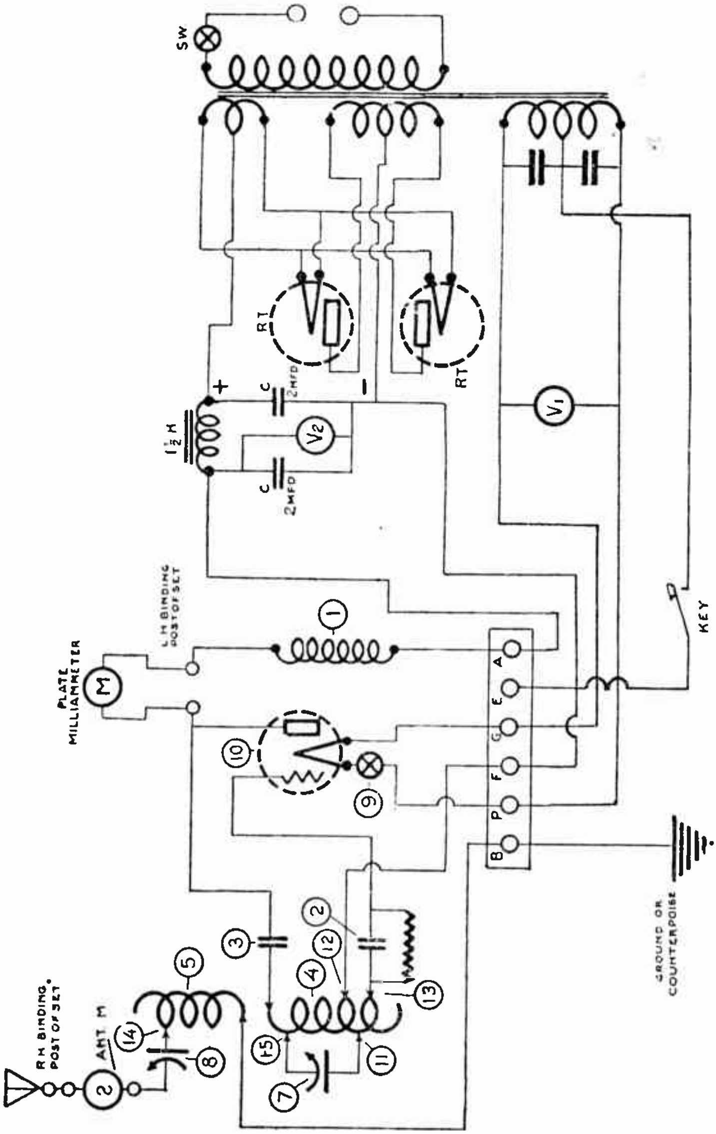


Fig. 1—Schematic wiring diagram of a Hartley Short Wave Transmitter and Power Supply, Rectifier and Filter.

One hard rubber or bakelite terminal strip, ¼x½x6 inches.
Bolts, nuts, screws, and the necessary wire.
Figure 4 is an end view of the transmitter and the right

hand portion of this figure illustrates the inductance clips. The inductances 4 and 5, Fig. 3, may be purchased outright, or they may be built as follows: The winding is 5 inches in diameter and approximately 6 inches long. The primary inductance (4) consists of 8 turns and the secondary inductance (5) consists of 3 2/3 turns. Flat copper strip ¼ inch wide and 1/16 inch thick is used, and this is wound on pyrex glass supports. These pyrex glass supports are approximately 1 inch square and 6 inches long. They are notched so as to space the wiring ¼ inch. Maple or other hardwood strips could be used if boiled in paraffine. Formica or hard-rubber tubing 3 inches in diameter and 1 inch long is used to support the ends of these pyrex glass rods.

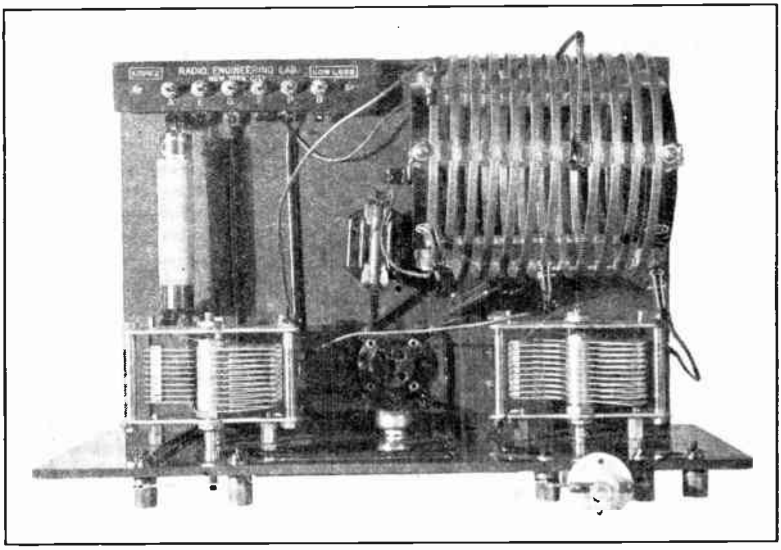


Fig. 2—Assembled Short Wave Transmitting Set.

The radio-frequency choke coil (1) can be constructed by winding 150 turns of No. 28 or No. 30 DCC wire on a cardboard or wooden tube ¾ inch in diameter, and 4 inches long. This choke is also shown in Fig. 5.

This set is so designed that any type of UX base tube may be used. That is a UX-199, UX-201A or a UX-210 may be used. It is necessary to apply the proper A and B voltages for the specific type of tube used. It can be readily seen that a beginner may start in with a UX-201A receiving tube using the conventional 6 volt battery for the filament circuit, and a "B" battery having a voltage from 90 to 180 for the plate circuit.

Thus, when the beginner is acquainted with the rudiments of transmission, he can, without incurring any great expense, insert a UX-210 tube and increase the "A" and "B" battery supply accordingly. However, all the parts furnished in the kit are of such dimensions that they can be used successfully with this larger type, UX-210 tube.

ASSEMBLY AND WIRING DATA

Figures 1, 2, 3 and 4 very plainly illustrate how the parts are mounted. Just a word may be given regarding a few of the pieces which may not show up very clearly. One terminal of the choke coil (1 in Fig. 3) is directly soldered to the soldering lug of binding post A on the binding post strip. This

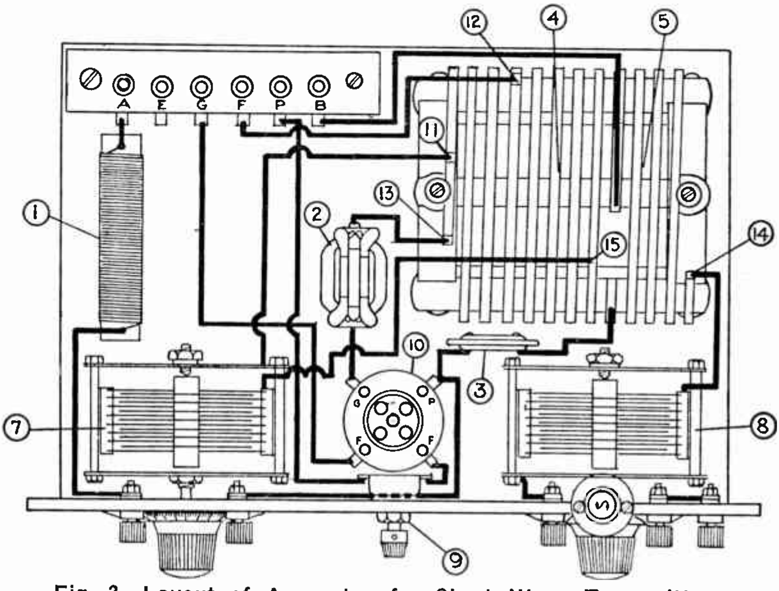


Fig. 3—Layout of Apparatus for Short Wave Transmitter.

will rigidly support this coil. The grid condenser (2) and the plate blocking condenser (3) are elevated from the baseboard by means of the short stiff wires to which they are connected. The inductance coils (4 and 5), are fastened to the baseboard by means of the brass brackets (6). It is necessary for the builder to realize that although the inductance coils are mounted in one piece, they are in reality, two separate coils. The one with the greater number of turns of wire (4) is mounted towards the left. This is shown as the primary or closed circuit coil. The other inductance coil (5) which has a smaller number of turns, is known as the secondary or antenna coil. Connections to these coils are made by means of the clips supplied. The clips are plainly illustrated in Fig. 4. Connections are made to the upper parts of the clips by means of flexible rubber covered wire.

The wire coming from the binding post (B) is permanently soldered to the inside end of the inductance coil (5). In likewise fashion, the wire coming from condenser (3) is soldered to the inside end turn of coil (4). All other connections to the inductance coils are made with flexible wire and clips. This is done so that they may be shifted from turn to turn to correspond to the wave-length required.

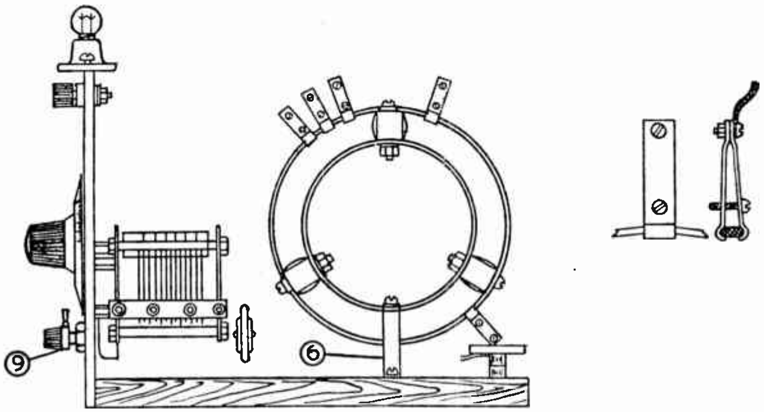


Fig. 4—End View of Short Wave Transmitter.

All other wiring except that going to the inductance clips should be made with bus bar wire of the usual type and covered with black cambric tubing or spaghetti. The builder can follow either the schematic wiring diagram in Fig. 1 or the wiring diagram shown in Fig. 3.

When a transmitter is oscillating we must have some indication as to whether we are putting any energy into the antenna. There are many ways that we can do this. The oldest system of doing this was to put a flashlight lamp or an automobile headlight lamp in series with the antenna circuit. This, however, has proved to be very inefficient and dissipates a great deal of power unnecessarily. We may use this method if a shorting switch is used or a switch connected directly across the bulb so that when a maximum output is obtained we may close the switch and the output will be much greater. The transmitter is first made to oscillate and the antenna tuning device is left in one position while the transmitting tuning condenser is rotated. When the right frequency is reached in the transmitter, to be determined by a wave-meter, the antenna condenser capacity is then varied until the flashlight lights its brightest. We know by this that the antenna coil is absorbing its maximum energy from the transmitting coil. However, meters prove to be much more efficient than any type of lamp even with the shorting switch.

There are radio-frequency ammeters made that have a very low internal resistance of the order of one-tenth of an ohm which indicate very clearly the exact amount of current which is being radiated. This type of meter may be placed directly in any part of the antenna circuit and a direct reading of the amount of current in the antenna circuit obtained. We do not need to short this meter because its resistance is so low that it does not reduce the power output but a very small

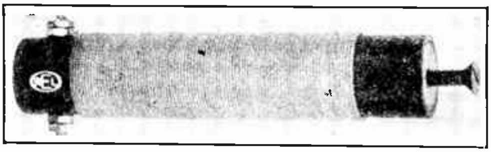


Fig. 5—Radio-frequency Choke Coil.

amount. With the flashlight type of antenna indicator, we cannot tell when the exact full brilliancy of the light has been reached, but with the meter, we can tell exactly when the needle reads highest on its range. Meters of this type, of course, must be radio-frequency ammeters. In some types of these meters thermocouples are used and the voltage produced by the AC causes the meters to read. The thermocouple, as you probably know, has an extremely low resistance and hence may be put directly in the antenna line.

POWER SUPPLY

If the builder contemplates using the UX-210 type of tube, it would be best to use a step-up transformer and some scheme of rectification instead of trying to employ "B" batteries. The UX-210 tube draws approximately 60 milliamperes at 350 volts on the plate and hence, it would be much better to use rectified alternating current for the plate supply instead of "B" batteries, as the "B" batteries will not stand up under this heavy drain for a considerable length of time.

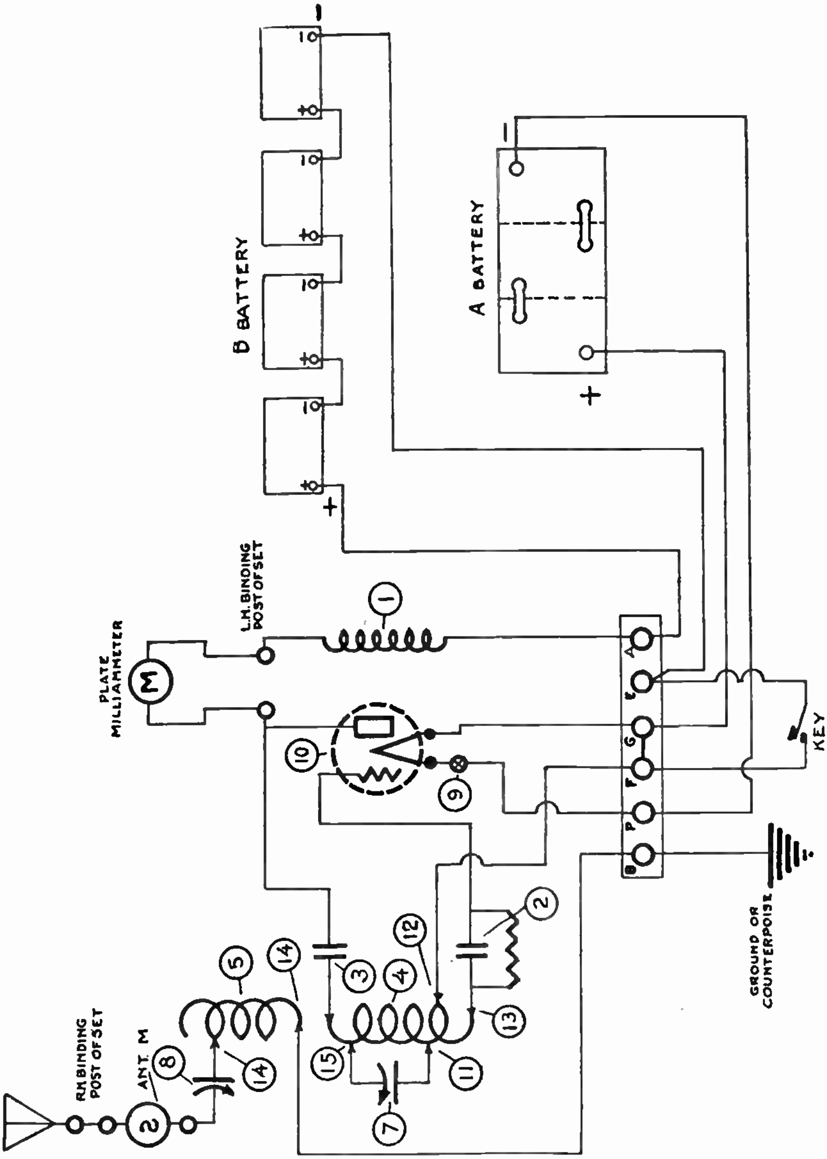


Fig. 6—Schematic wiring diagram of a Hartley Short Wave Transmitter, showing power supply when using batteries.

If it is desired to work the UX-210 tube at full capacity, it will be necessary to have a power transformer with a center tap on the secondary so that 500 volts are supplied on each half of the secondary. The rectifier tubes can be the UX-216B type, or any other type of tubes which will satisfactorily handle this voltage and current. The filament secondary winding is used to supply the current for the filament of the rectifier tubes and the oscillator tube. This winding is tapped in the center as shown in Fig. 1. The voltmeters V1 and V2 are shown in their correct positions. These indicate the A.C. filament voltage and the D.C. plate voltage respectively. These may or may not be used; however, they are a valuable adjunct to the power supply set.

The audio-frequency choke coil shown in Fig. 1 should have an inductance of 1½ henries and be capable of carrying

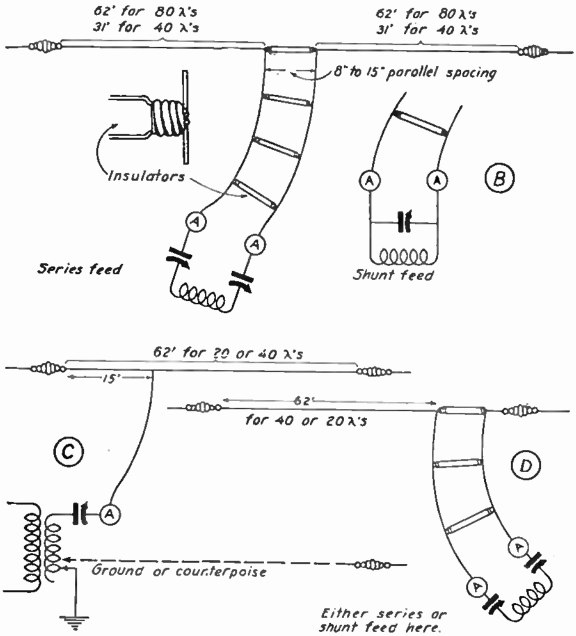


Fig. 7—Current and Voltage Feed Antennas.

150 Milliamperes. The filter condensers (C) may be either 2 or 4 mfd. capacity capable of operating above 500 volts. The whole power supply can be mounted as a separate unit, with the necessary connections to the other unit as shown.

Figure 6 illustrates the connections when using a storage battery for supplying the filament voltage and current and "B" batteries for supplying the plate voltage and current.

ANTENNA AND COUNTERPOISE SYSTEM

The Hertzian type of antenna has gained great favor in the armies of amateur operators, because of its great flexibility and efficiency. It is generally known that a good ground is extremely hard to obtain and the placing of the transmitter the correct distance from the ground is also hard to accomplish. The Hertzian antenna eliminates the necessity for either of these. It is entirely free from any type of ground. There are fundamentally two types of Hertzian antennas. The voltage feed type and the current feed type.

The **voltage feed** type—This type of antenna is fed by placing the lead-in nearest the highest voltage on the antenna, or placing it in any position such that the highest voltage will occur on the antenna at the lead-in, at any given instant. The same thing applies to the current feed antenna and the feeders or double leads from the transmitter are placed in the center of the antenna where the current is always highest. The high voltage on a Hertzian antenna is usually found in one end. So the feeder is attached at this end. This is not always the case, because sometimes the lead-in is placed ¼ of the length from the end. The point on the antenna which has the highest voltage at any given instant is called the voltage anode. And likewise, the point on the antenna which has the highest current is called the current anode. It would be useless to try to feed a current feed antenna at the point of highest voltage because at this point, the current would be zero. The places where the current or voltage are zero on the Hertzian type of antenna are known as the nodes. An antenna cannot be efficiently fed at these points. In Fig. 7-B is shown a current feed type of Hertzian antenna. Investigation of its characteristics would demonstrate that the current is highest right at the middle point between the two extremities and at this point there is no voltage. In Figure 7-C it is either a current or voltage feed antenna, depending on what frequency and the length of the antenna used. Figure 7-D is one of the most common types of voltage fed Hertizian antenna known to the amateur world as the 'Zepplin" type of antenna or "Zepp."

With regard to transmitting antennas, it is necessary to have their lengths very carefully estimated and very exact for good results. It is commonly known that the reception of any signal does not require a special length of antenna. Of course, one length may be better than another, but reasonable reception can be obtained from any antenna varying in length from 50 to 150 feet. On the contrary, transmitting antennas must be the correct length within at least 6 inches of that specified for best results. To obtain the correct lengths to be used for a Hertzian type antenna, multiply the wave-length in meters that you are going to use for transmission by 1.56 and you have the numbers of feet of antenna wire to use.

Its natural frequency will be equal to

$$\frac{300,000 \times 1.56}{\text{length of feet}}$$ the answer being in kilocycles

Thus, suppose we were to transmit on a wave-length of 40 meters and wanted to know how long to make our antenna. 40 times 1.56 equals 62.40 ft. This may be made 62 feet or 63

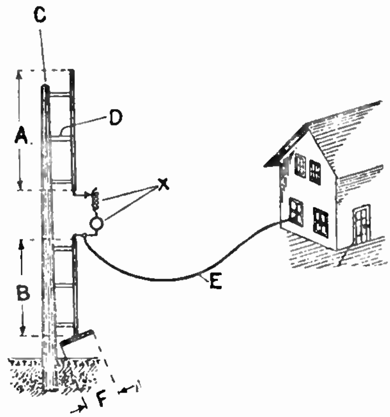


Fig. 8—Hertz Type of Antenna.

feet without serious results, but any greater deviation from this number might cause great loss of power output. Now it must be understood that this is the length in feet of only that part of the antenna which is doing the transmitting or which is radiating energy. With the Hertzian type of antenna the feeder systems are so designed that they do not radiate any energy, so that this number does not include the lead-in or the feeders. The lengths of the feeders which give best results on the current feed type of antenna should be ¼ of the length of the antenna or ¾ of its length. In fact, it is generally known that the length of the feeder system is not at all critical because any length which does not interfere with the natural period of the antenna may be used. In other words, if the feeders are both exactly 62 feet long for operation on 40 meters they would absorb too much energy and not enough would be left for the antenna. However, a half of the length, or 31 feet, would be very desirable for the feeder system. This includes the length of both the wires from the transmitter to the antenna making 62 feet of wire in all.

THE HERTZ ANTENNA SYSTEM

A simple Hertz antenna used for short wave apparatus is shown in Fig. 8. A and B are the antenna and counterpoise conductors. The antenna inductance and radiation ammeter are connected electrically to the inductance in the transmitter itself by the feeder wire E. C is a wooden pole and D the stand-off insulators.

No direct ground is made to the counterpoise B, but as shown in the drawing, the lowest point marked F is located several feet above ground, giving the effect of loading the circuit with additional capacity when necessary.

ADJUSTING AND TUNING THE TRANSMITTER

When all the parts have been assembled, properly wired and the antenna and counterpoise system installed, and all the connections made, the transmitter is then ready to be adjusted and tuned to a certain wave-length. At this point, it is advisable, if possible, to consult either a neighboring amateur or someone who has had experience in tuning a transmitting set. In this way, considerable time may be saved if the builder has not had any experience in adjusting and tuning a transmitting set. However, if no experienced person is available, the following procedure should be carried out. It would simplify matters to have a wave-meter on hand. First connect the power supplies to the plate and filament circuits. Then duplicate the setting of the inductance clips shown in Fig. 3. The connections from condenser (7) are made with clips 15 and 11. The center-tap connection is made with clip 12, and the grid connection with clip 13. The antenna connection is made with clip 14.

If a wave-meter is not available, it will be necessary to have a calibrated short wave receiving set so that it may be determined to what wave-length the transmitter is tuned. Tune the short wave receiver to some amateur station operating within the 80 meter band and leave the receiver oscillating. Disconnect the antenna and counterpoise leads from the transmitter and for the moment disregard the right hand condenser (8) in the transmitter. Then press down the transmitting key, listen in the headphones of the receiving set, at the same time, slowly vary the capacity of condenser (7). If the transmitting tube is oscillating when the variable condenser capacity is varied through the wave-length to which the receiver is tuned, a very loud buzzing noise will be heard in the head-phones. If this noise appears over a wide range of the condenser dial (7), move the receiver further away from the transmitter. If, on the other hand, you do not hear any buzzing at all, the tube in the transmitter is not oscillating. Move clip 12 a turn or two towards the right, again varying the capacity of the condenser (7) listening for the buzzing noise in the receiver. When it is heard, it should be at only one sharp definite point and should be very loud. After these adjustments have been made, connect the antenna and counterpoise to the proper terminals on the transmitter.

Now press down the key again and slowly vary the capacity of condenser (8), at the same time watch the lamp in the antenna circuit. When resonance between primary and secondary has been secured, the lamp will light and as soon as the lamp shows signs of becoming very bright and there is danger of it burning out, it is advisable to open the key circuit of the transmitter and short circuit the lamp or else use a larger lamp.

If, during any of these adjustments, the plate of the tube becomes more than a very dim cherry red, move clip 12 towards clip 13, then vary the capacity of condenser (7) and after the lamp has been made to burn as brightly as possible, it will then be necessary to vary the capacity of condenser (8). After this has been accomplished, it is advisable to slightly detune this condenser, otherwise the tube may stop oscillating when the set is keyed. Usually, it is not possible to key the set when the antenna condenser is so adjusted that the greatest amount of antenna current is present. It is necessary to vary slightly the capacity of this condenser (8) so that the keying may be accomplished without causing the tube to stop oscillating. After the set has been tuned, try varying clip 12 back and forth a turn at a time until the proper adjustment has been found when the lamp will burn brightest and the plate of the tube hardly shows any color at all. It will be necessary to retune the antenna every time the clip is changed.

For 40 meter operation, it is advisable to erect another antenna and counterpoise. These antenna systems should be at least 30 feet apart. When adjusting the transmitter to operate on 40 meters, the above procedure should be followed. First adjust the receiver to a station within the 40 meter band;

then using less turns in the plate and grid portion of the coil (4) of the transmitter, follow the previous instructions.

Bear in mind that all of the adjustments are more or less dependent upon each other. A change in any of the clip positions or the slightest variation of the condenser capacity will require readjustment of the other clips. One can always stop and start over from the beginning, and with a little time and patience, the transmitter can be adjusted so as to put more power into the antenna system.

METHOD OF KEYING

Keying may be accomplished in a variety of ways. With powers not exceeding 7½ watts or when using the UX-210 type of tube, the keying may be done directly in the plate circuit. Either the positive or the negative side will be equally as effective for this purpose. However, when higher powers than this are used, the keying must be accomplished in a different manner. It is more preferable to key even a low power transmitter such as shown in Fig. 1 by the center-tap method. You will notice that the high negative voltage of the power supply is applied constantly to the center-tap or the main coil and one part of the key and the entire filament circuit are isolated from the transmitter when the key is up. The key simply allows the current to pass into the filament when it is pressed. Much less arcing and key trouble will be encountered with this method. If the key does arc too much or if it continues to spark across when it is raised, a condenser of large capacity say .2 to .5 mfd. may be placed across the key contacts. This condenser should be constructed to stand the high plate voltage directly. Even better, this condenser and small series resistance on the order of 200 to 1,000 ohms may be placed in series and the combination shunted across the key contacts (as shown in Fig. 9). However, when using power up to 50 watts and above, an entirely different system must be used. In some cases, a relay is used which is operated by the key. With this method the key circuit is simply a very low potential circuit having a "C" battery or small battery, the key and an electromagnet in series. This system has many advantages. It prevents any damage to the operator due to high voltage, because the voltage at the key is not much greater than that of a dry cell. The relay may be made as large as necessary and the contacts open as much as ¼ or ½ an inch so that no arcing can take place. The relay has to be timed so that no dots are missed.

When powers of the order of 50 watts are used, the high voltage transformers usually do not have the filament windings wound on them. In this case, the key may be placed in the primary of the high voltage transformer. You can readily appreciate the reason why the key could not be put in the primary if the filaments of the tubes were operated from the same transformer. Each time the key was lifted, the tubes would go out, and could not heat up quickly enough to start up oscillating instantly as

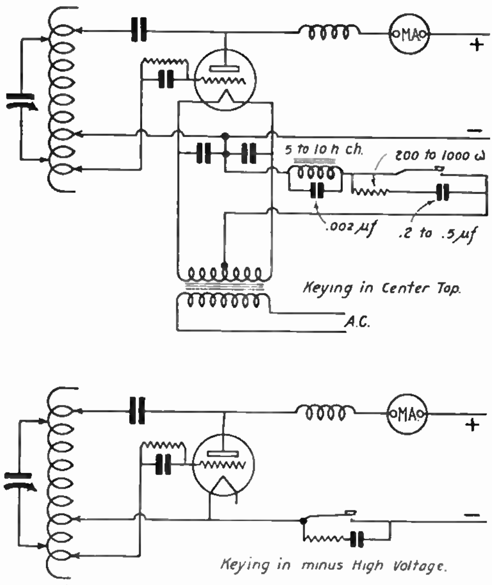


Fig. 9—Keying Circuits.

the key is pressed. In this case, the voltage is much lower then in the secondary and less trouble is encountered in keying.

In some cases, it is necessary to use a key filter of some type to prevent the peak voltage from changing the frequency of the transmitter at the instant it is pressed. In other words, a device for making the key current constant. Chokes for this purpose are of the order of 5 to 10 henries, wound with very large turns of wire on a heavy iron core. This system prevents what is known as chirping. If you have ever listened to short wave reception, sometimes a station will sound chirpy or in other words, its frequency will change slightly between the time the key contact is made and when the dash is ended. This is very undesirable as it is hard to copy and is very annoying.

When the filament leads are made rather long from the filament transformer to the transmitter, it is very desirable and often absolutely necessary to put two condensers across the outside of the filament and connect them together with the center-tap of the transformer. This provides a low resistance grid-return without having to go through the high inductance filament windings which in some cases, will ruin the transformer and in other cases prevent the transmitter from oscillating.

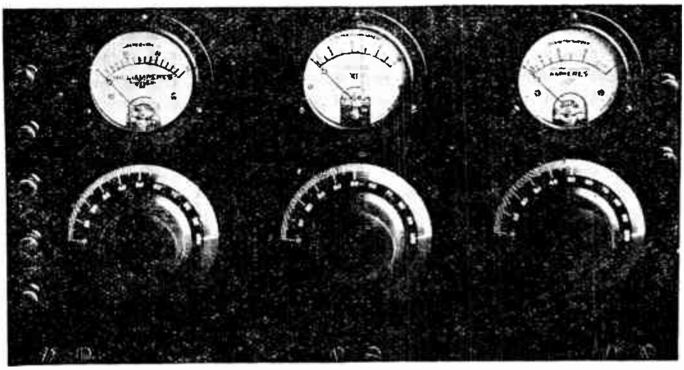


Fig. 10—Panel Arrangement of Tuned Plate Tuned Grid Transmitter.

RADIOTELEPHONE TRANSMISSION WITH THIS SET

If so desired, this set can be used for speech transmission. This can be accomplished by winding 1 turn of large, well insulated, copper wire around the left end of inductance (4). Across the two ends of this wire, connect any type of standard carbon microphone. This is known as the "absorption loop" method of modulation. Although it is not the most efficient, it is very satisfactory for low power and is capable of transmitting as far as 5 or 10 miles according to the type of tube being used in the transmitter.

TUNED PLATE-TUNED GRID TYPE OF TRANSMITTER

Another type of short wave transmitter which is very popular among the amateurs is known as the "Tuned Plate-Tuned Grid" circuit. Owing to the flexibility of this circuit and the ease with which it may be tuned and shifted from one waveband to another, it is very popular among amateurs. Since the short wave-length bands, 20, 40 and 80 meters vary in their effectiveness at different times of the day and different seasons of the year, it is highly desirable to be able to change the operating wave-length easily. In order to be able to change from one wave-band to another quickly, it is necessary to employ plug-in inductances which do not have taps, and make use of some circuits which can be tuned entirely by the use of variable condensers. Figure 10 shows a front panel view of a tuned plate-tuned grid circuit transmitter. Figure 11 shows the rear view of this set and Fig. 12, the schematic wiring diagram. A list of apparatus used in constructing this set is as follows:

List of Parts:

1—Aero interchangeable transmitter kit 2040 or 4080; including two mounting bases and two choke coils.
3—.0005 mfd. receiving variable condensers. (Karas or Cardwell).
3—Dials.
1—4,000, 5,000 or 10,000 ohm grid leak, wire wound. (Center-tapped.)
2—.0001 or .00025 mfd. fixed mica receiving condensers.
2—.001 mfd. or larger, fixed mica receiving condensers. (Paper dielectric cannot be used).
1—UX type tube socket.
7—Binding Posts.
1—Rubber, micarta, or bakelite panel, 10x18, or 7x18, depending upon whether meters are used.
1—Rubber, micarta, or bakelite sub-panel, 10x18.
2—Sub-panel brackets.
Hook-up wire, mounting screws, etc.

Optional Equipment:

1—0-100 D.C. milliameter.
1—0-10 A.C.-D.C. voltmeter.
1—0-1 thermocoupled radio-frequency antenna ammeter.

Other Equipment Needed:

One key.
Filament supply.
Plate supply.
Antenna and Counterpoise.

By carefully following these diagrams and photos, and the constructional data, the builder should be able to construct a very successful type of transmitter. As can be seen by the schematic wiring diagram, Fig. 12, the grid and plate circuits are tuned by their respective variable condensers, and the output or antenna circuit is coupled inductively to the plate circuit, in which most of the radio-frequency energy flows. This circuit is extremely flexible and is easy to adjust, therefore, it is suitable for both the experienced amateur and the novice. The antenna circuit is coupled through the variable coupling coil and is tuned by means of the variable condenser in series with the antenna and counterpoise.

The wave-length range of this transmitter complete with five coils is from 16.5 to 90 meters inclusive. The plate and grid coils are interchangeable and may be removed from their bases, as they are of the plug-in type. The two smaller coils have three turns each, and cover, when using the .0005 mfd. variable condenser, from 16.5 to 52 meters. The larger coils have 8 turns each. These cover, with the same condensers, 36 to 90 meters. Figure 12-A shows plug-in transmitter coils and bases.

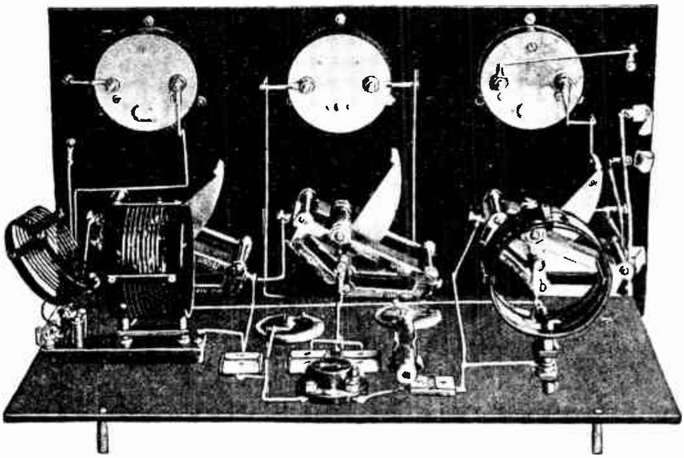


Fig. 11—Rear View of Transmitter.

The coils and condensers are primarily adapted for low power transmitters using up to about 100 watts input. This means that anything from a 199 type of tube up to a 50 watt tube, working at the rated input, can be used. Operation is possible with one UX-210 type tube or two in parallel. While ordinary amplifier tubes, such as the UX-171, 112, or 201-A may be used with good results; greater range, of course, will be obtained with higher power. When using any of these receiving tubes, "B" batteries may be used for the plate supply. However, it is best to use rectified alternating current for the plate supply when using a UX-210 type of tube.

The tuning condensers used are the ordinary single spaced receiving condensers, as the power is low and no flash-over troubles will be encountered. When using high power, double spaced condensers will be necessary. The plate and grid blocking condensers are .0001 mfd. fixed mica receiving condensers. Better operation might be secured by using .00025 mfd. fixed condensers instead. The filament by-pass condensers are also mica fixed receiving condensers, .001 mfd. or larger may be used. The grid leak is a small size 4,000 ohm wire wound resistance, known by the trade name of Crescent Lavite. A 10,000 ohm resistance, center-tapped, so that either 10,000, 5,000 or 2,500 ohms may be used to an advantage, gives better output under certain circumstances. The choke coils are small honeycomb inductances of at least 200 turns which serve to keep the radio-frequency component out of the direct current leads. In some cases it may be necessary to use slightly larger honeycomb coils.

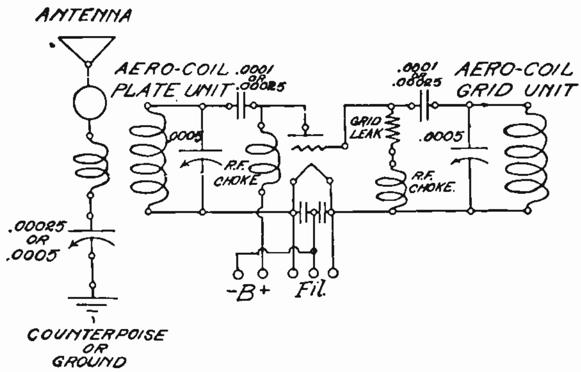


Fig. 12—Circuit Diagram of a Tuned Plate Tuned Grid Transmitter.

The meters shown are optional, but are of great assistance in tuning the set. A plate milliammeter having a scale reading of 0-100 D.C. milliamperes should be used with one 210 type tube. When using any of the receiving tubes mentioned, a smaller reading meter may be used, and when using a 50 watt tube, a higher reading meter will be required. The filament voltmeter is merely used to indicate the filament voltage, and when using the 210 type of tube, it should read 7½ volts. It will be found that in some cases, the filament voltage can be reduced without lowering the antenna current, and this is, of course, advisable, as it will prolong the life of the filament. The antenna ammeter is used to indicate the antenna current and when using a 210 type of tube should be a 0 to 1 ampere thermocoupled radio-frequency meter. When using a 201A or 199 type of tube, the antenna ammeter can be a 0-500 or even a 0-250 milliampere meter, while for a 50 watt tube, a 3 ampere meter should be used.

By referring to Fig. 11, it will be noted that the grid and plate coils are placed at right angles to one another and some distance apart. This reduces coupling between them and makes for better control. In assembling the set, the coils should not be placed too near metallic bodies, such as the condensers, frame, etc. The lay-out as shown in the sketch should be followed for best results.

OPERATION

Unless the operator is experienced in tuning a transmitter, extreme care should be used. If inexperienced methods of tuning are used, the tube may be injured.

Let us presume that the set is completed, power supply connected to the transmitter, but not turned on, and the antenna coil is connected to the antenna and counterpoise. The antenna tuning condenser is the one shown to the right in Fig. 10, the plate tuning condenser is the center one; and the grid tuning

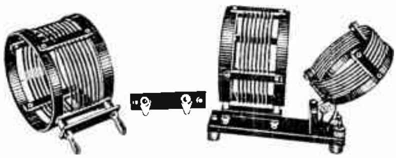


Fig. 12-A—Transmitting Plug-in-Coils.

condenser is the one on the left hand side of the panel. Set the plate tuning condenser at some convenient point such as 20 on the dial. Set the grid condenser at the same point. Turn on the filament current. Then turn on the plate current and quickly vary the grid tuning condenser until the plate milliammeter shows a minimum reading. When this is obtained, the grid and plate circuits are in resonance and the set will oscillate, but if the two circuits are not tuned to resonance, a large plate current will be indicated with the key open. If the current is not turned off quickly, the tube may be ruined. **Be sure to switch off the plate supply immediately if the plate of the tube begins to heat with key open.** When this has been done, the antenna and counterpoise may be brought to resonance by varying the position of the antenna series condenser while the key is closed. Resonance will be indicated by a maximum reading both in the plate milliammeter and the antenna ammeter. This adjustment of the antenna may tend to throw the plate and grid circuits out of resonance, and a slight re-adjustment of the grid tuning condenser capacity may be necessary. At first, the antenna coupling coil should be tightly coupled to the plate coil. By listening in on a short wave receiving set located near-by, the tone of the note may be determined. If it is found that the wave is unsteady when in this condition, the antenna circuit should be slightly detuned or the coupling loosened.

Now press down on the key of the transmitter, and by means of a wave-meter or calibrated receiving set determine on what frequency the transmitter is operating. Then vary the capacity of the tuning condensers until you attain the desired wave-length as indicated by the wave-meter or calibrated

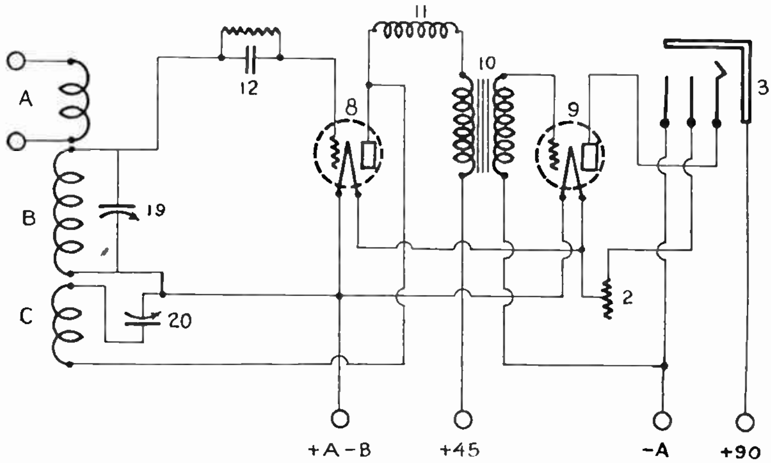


Fig. 13—Schematic Diagram of Short Wave Receiver.

receiver. **Be sure to vary both grid and plate tuning condensers together.** Otherwise, the set may get out of resonance and you will damage the tube. Be sure to switch off the plate voltage every time you see the plate beginning to get too hot, or when the plate milliammeter reads too high when the key is open. The secret of successful operation of this set is to keep the plate and grid circuits in resonance.

The matter of coupling between the antenna and plate coils is one which can be worked out to best advantage by the operator. Too tight a coupling will produce a bad note and unstable operation; too loose a coupling will not put the maximum amount of energy into the antenna.

While any type of antenna system may be used with this circuit, however, better results may be expected with the Hertz type of antenna described in the early part of this lesson. For best results on any particular wave-band, it is found that the antenna should really be constructed to operate on that particular wave-band, although a single wire, from 40 to 100 feet long, and a single wire counterpoise of the same length may give good results on any wave to which the set can be tuned. It is very important that the antenna system be as high and as free from obstructions as possible.

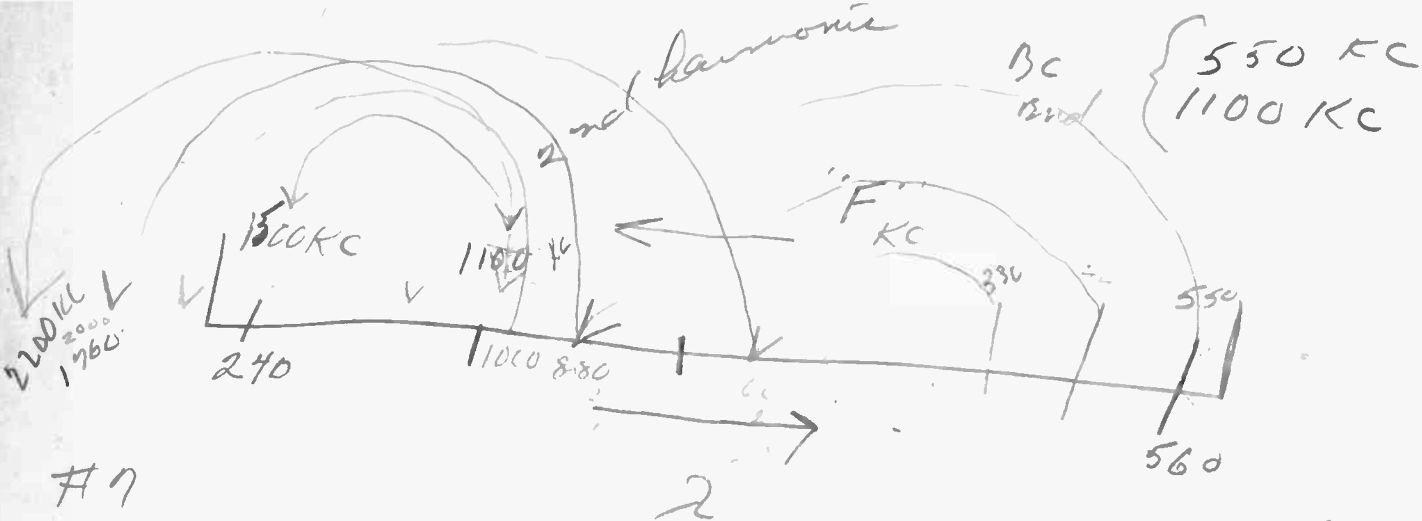
THE SHORT WAVE RECEIVER

There are various types of short wave receiving sets now in use and their owners have reasons for their preferences "or selections." However, to successfully receive signals on the short wave-length (high frequencies), certain principles of design must be more closely followed than for reception on the higher or broadcast wave-band. In general, when receiving short wave signals, the strength of the signal is far less than when receiving broadcast signals. This is especially true when the signals come from a great distance.

Tests by the U. S. Bureau of Standards on various forms of inductances used in receiving sets have proved that the loose basket-weave wound coil is superior to other types for short wave receivers. The advantage is that the loose basket-weave coil is slightly more efficient; has a lower distributed capacity due to its form of winding; low dielectric loss, because no forms of any kind are used to support the coils; they are mechanically rugged because of the heavy gauge wire used; and in general, are more easily constructed than the space wound solenoid type of coils.

Short wave receivers must have interchangeable coils in order to cover all the amateur wave-bands. It is desirable that each coil cover only a small wave-band (for example, 30 to 50 meters). Reception on short waves being very critical, a number of coils must, therefore, be used to cover and spread out all wave-lengths between 10 and 200 meters, also the tuning variable condensers must be of low maximum capacity so as to efficiently operate in conjunction with these coils.

The type of circuit shown in Fig. 13 is very well adapted to the reception of short wave signals. Figure 14 shows a picture diagram of how the apparatus is mounted and wired. A list of parts required for building this receiver is as follows:



#7

Broadcast stations [illegible] ~~between~~ lower than 1100 KC will not be affected by harmonics from other stations in the band as the second harmonic of 550 KC will manifest itself at 1100 KC, the 3rd harmonic will be at 2200 KC, or below the Broadcast Band. also any harmonic of a frequency between 550 and 11:00, will (not) fall between ~~[illegible]~~ 1100 KC & 1500 KC.

1—Tuning or wave-length control condenser 19. (Radio Engineering Laboratories).

1—Oscillation control variable condenser 20, .0001 to .00025 mfd. (Type REL).

1—Grid condenser 12, .00025 mfd.

1—Grid leak, 1 to 10 megohms.

1—Filament rheostat 2, 10 to 20 ohms, according to type of tubes used.

1—Radio-frequency choke coil 11. (Type REL., No. 132).

2—UX tube sockets.

1—Audio-frequency amplifying transformer 10, ratio 10 to 1.

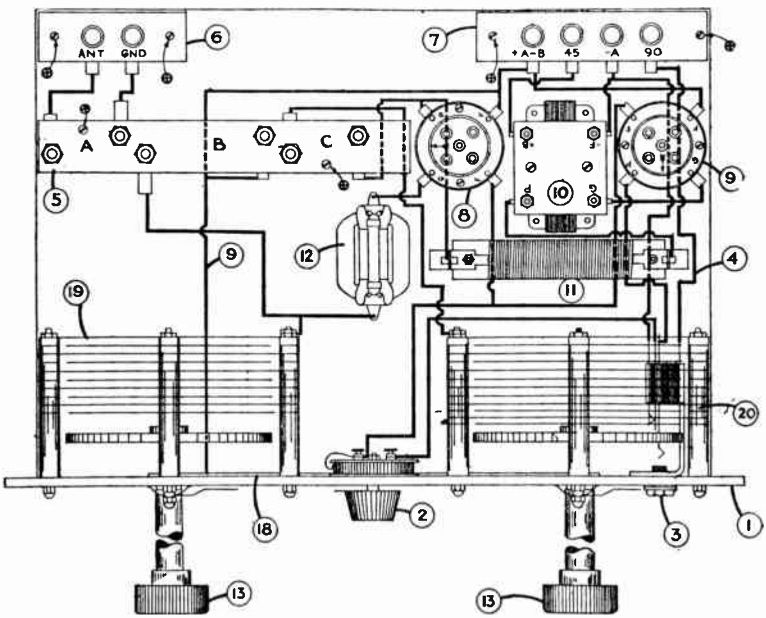


Fig. 14—Picture Diagram Showing Apparatus Mounted and Wired.

1—Filament control jack 3.

6—Binding posts.

1—Set of REL short wave coils with plug-in arrangement and bases.

1—Panel 14x7, rubber, micarta, or bakelite.

1—Baseboard, 13x8¾ inches.

Necessary wire, bolts, screws, nuts, etc.

Figure 15 shows a view of the unassembled parts. The circuit employed is the well-known capacity control feed-back with separate coils for antenna, secondary and tickler circuits. The variable condensers are expressly designed for short waves. Double spacing eliminates any chance of leakage due to dirt and moisture. These condensers are so constructed that a few stationary and a few rotor plates may be removed so that the capacity may be reduced. Vernier control is obtained by means of soft and hard rubber discs mounted behind the panel. This eliminates any metallic friction noises as well as all back lash. The vernier control knobs of these condensers are mounted on half-inch round rubber shafts extending 4 inches from the front of the panel. This arrangement eliminates body capacity without sacrificing efficiency on short wave reception.

ASSEMBLY

The panel (number 1 referring to Fig. 14) is supplied separately and is partially assembled with the variable conden-

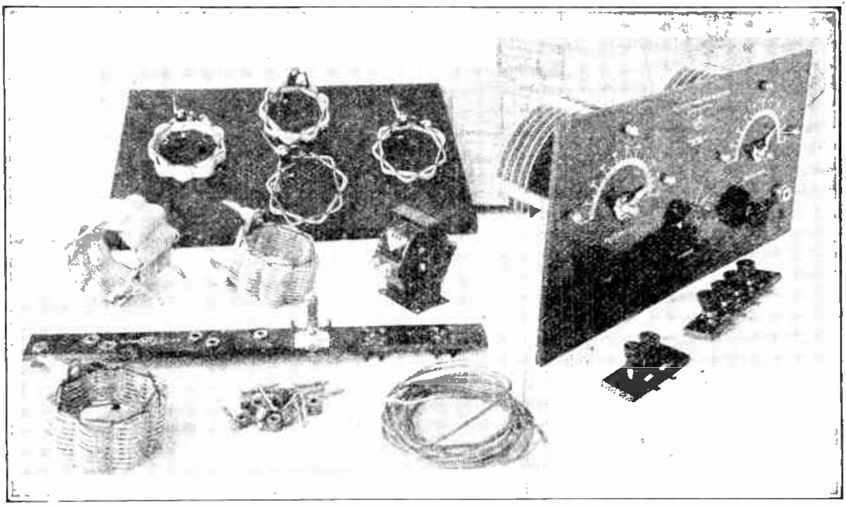


Fig. 15—View of Unassembled Parts for Short Wave Receiver.

sers and the vernier controls. To complete the panel assembly, it is necessary to mount the rheostat (2) and the jack (3). The panel is then fastened to the baseboard (4) by means of the three small wood screws. A blue-print is supplied with the kit; it is of actual size, and may be used as a template for mounting the other parts on the baseboard.

By closely following the blue-print, the coil base (5), antenna binding post strip (6), battery binding post strip (7), detector tube and audio amplifier sockets (8 and 9), audio transformer (10), radio-frequency choke coil (11), and the grid condenser and grid leak (12), should all be located and mounted on the baseboard. The vernier knobs (13) are fastened to the shafts by means of small set screws. The shafts have the holes drilled to take these set screws. Proper friction must be maintained at all times between the soft rubber ring and the hard rubber disc. Should the soft rubber ring become worn, it can easily be replaced. The bakelite strips (5, 6, and 7) are raised from the baseboard by means of the small bushings underneath. The antenna coil (A), the secondary coil (B), and the tickler coil (C) plug in at their respective positions marked A, B and C on strip (5).

WIRING

It will be noted that the rotor plates of both variable condensers are connected by a strip of brass (18). All positive "A" and minus "B" connections should be made to this strip by means of the wire (9).

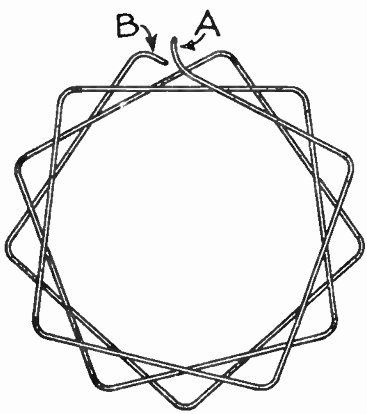


Fig. 16—Illustration Showing How Inductance Coils are Wound.

It is advisable to fasten the two wires to the rheostat before the choke coil is mounted, otherwise, it will be hard to get at this device. By carefully following the above instructions and the schematic wiring diagram as shown in Fig. 13, it will be found a simple matter to build this receiver. If a soldering paste is used for flux in soldering the joints, it will be necessary to wipe all joints with alcohol afterwards, otherwise, corrosion will occur. The best policy is to use rosin core solder and thus eliminate this kind of trouble.

If so desired, all filament and high voltage "B" leads may be cabled together. Make sure that the plate and grid leads are short, direct and free from other objects.

TUNING

Any type of tubes may be used with this receiver. It will, however, be necessary to apply the correct plate and filament voltages as required for the tubes used. If every connection is properly made, the filament will light when the phone plug is inserted in the filament control jack (3). The rheostat knob should then be turned until the tubes indicate proper brilliancy.

By setting the tuning condenser (19) at some arbitrary position and rotating the oscillation control condenser (20), a point on the dial will be reached where the detector tube oscillates; this will be indicated by a click in the head-phones. Keeping this condenser (20) so that the detector is in an oscillating condition and varying the capacity of the wave-length condenser (19), signals should be heard. If it is desired to receive modulated signals, it will be necessary to tune condenser (20)

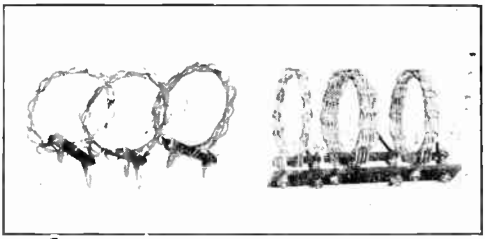


Fig. 17—R. E. L. Short Wave Coils.

to a point just below oscillation. Oscillation may be more easily controlled by using less filament current and keeping the oscillation control condenser (20) nearer maximum capacity.

There may be a possibility that "dead" spots or points will be noticed on the condenser dial (19) where oscillation does not take place. In such cases, a very small variable condenser with a maximum capacity of .00001 to .0001 mfd. should be inserted in series with the antenna.

The following table shows the correct coils to be used to cover various wave-lengths:

Wave-length Range in Meters	Primary Coil A	Secondary Coil B	Tickler Coil C
12 to 29	7 turns	3 turns	5 turns
29 to 58	5 turns	7 turns	7 turns
52 to 107	7 turns	14 turns	12 turns
100 to 212	12 turns	32 turns	18 turns

The primary and tickler coils are interchangeable and have the same number of turns and same width of base mounting.

For those who desire to construct their own coils, Fig. 16 will give them a clearer idea of how these coils should be constructed. Thirteen wooden or metal pegs ¼ inch in diameter are equally spaced on the circumference of a circle 3 inches in diameter. As noted in this figure, the consecutive turns are not parallel to each other, the winding starts at point "A" and makes three complete revolutions before coming back to the point "B". This gives practically a space-wound, air dielectric coil of exceedingly low distributed capacity. Figure 17 shows the plug-in coils and mounting.

ANOTHER TYPE OF SHORT WAVE RECEIVER KIT

The short wave, interchangeable coil system was invented primarily for amateur and experimental use, but it is suitable also for reception of broadcast programs on the short wave-

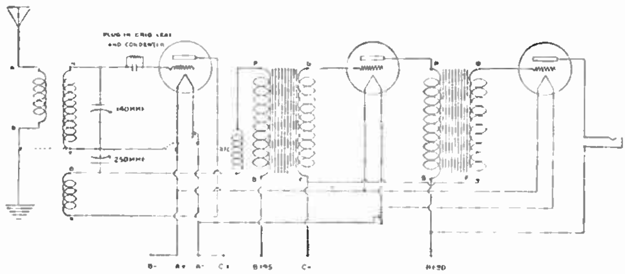


Fig. 18—Short Wave Circuit with Two Stages of Audio-frequency Amplification.

lengths. This receiver consists briefly of three interchangeable coils, each unit comprising a grid and plate inductance. A suitable base is provided, on which is mounted an adjustable primary coil, whose coupling may be set for best results with a long or short antenna. The circuit of this receiver is shown in Fig. 18. It uses the familiar fixed tickler, capacity control circuit, which has been found suitable for short wave receivers. It is recommended that if you use this circuit in a low wave set, make it so you can use interchangeable coils. This receiver uses two controls, tuning and feed-back, and since the feed-back is quite constant over a fairly wide band, operation is very simple. Two variable condensers are used. To obtain satisfactory results, the grid tuning condenser must be a 7 plate 140 mmf. (.00014 mfd.) straight line frequency condenser, while the feed-back control may be any 250 mmf. (.00025 mfd., usually 11 to 13 plates) condenser of good construction. The shape of the plates of this condenser does not matter very much, as it only controls regeneration. One stage of audio-frequency amplification is usually ample for ordinary head-phone reception, although two stages are used for broadcast music, or code signals from foreign countries.

The following is a list of apparatus to be used in building this receiver:

These parts or their equivalent will give satisfactory results.

1—7x18x3/16 inch drilled and Engraved Formica Panel.
1—5/8x2½x3/16 inch Formica Terminal Strip.
1—5/8x5x3/16 inch Formica Terminal Strip.
1—8½x17x½ inch Wooden Baseboard.
2—Karas Harmonik Audio Transformers.
1—Karas .00014 mfd. SLF Variable Condenser.
1—Karas .00025 mfd. SLF Variable Condenser.
3—Benjamin Type 9040 Cleartone Sockets.
2—Yaxley 4 ohm Fixed Resistances.
1—Yaxley Type 2-A Jack.
1—Yaxley Type 3 Jack.
1—Yaxley Filament Switch.
1—Daven No. 51 Mounting.
1—Daven 8 Megohm Grid Leak.
1—Dubilier .0001 mfd. Fixed Condenser.
1—25 Ohm E.E.E. Rheostat.
1—Set of Aero Interchangeable Coils—Range from 15 to 133 Meters.
1—Piece Bakelite Tubing ¾ inch, 3½ inches long.
1—Foot Insulated Flexible Wire. (For finding grid-return, grounding filaments, etc.)
Miscellaneous Screws, Wire, Lugs, etc.
1—Package Kester Rosin Core Solder.
1—Blackburn Ground Clamp.
40 feet or more of No. 28 DCC Copper Wire.
25 feet No. 12 Belden Copper Tinned Wire.

The detector tube socket should be either of some cushion or spring construction or be supplied with a sponge rubber base. The four leads going to the socket should be very light flexible leads, so as to allow the socket to vibrate. This eliminates microphonic noises which are so troublesome on the shorter waves.

The grid condenser and leak should be mounted in a removable fashion, so that various values of either may be tried in combination. Change the grid-return from positive to negative filament and vice versa until the best point is found. If a choke coil is needed, it may be home-made or purchased, and any very small coil, wound with fine wire (No. 28 or smaller, insulated) and having 200 turns or more, may be used, 200 turns on a ¾ inch tube or wound lorenz (basket-weave) fashion will be ample. In some cases, this coil may not be necessary, as the primary of the audio transformer may have sufficient impedance to act as a radio-frequency choke, but this effect varies and it is always best to include the choke coil.

Various broadcasting stations are now transmitting on short wave-lengths. These stations furnish considerable entertainment for those who are interested in receiving broadcast programs, and for those interested in code reception.

TEST QUESTIONS

Number your Answer Sheet 36—2 and add your **Student Number**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What wave-lengths are included in the short wave-length band?
2. Draw a diagram of a Hartley short wave transmitter showing power supply, rectifier and filter.
3. Describe the construction of the inductances used in the transmitter illustrated on page 3.
4. What kind of tubes may be used with this transmitter?
5. When using a UX-210 tube, what kind of power supply should be used?
6. How is it possible to eliminate arcing at the key points?
7. What change is necessary to make the set illustrated in Fig. 3 into a transmitter suitable for speech transmission?
8. Draw a diagram of a tuned plate—tuned grid transmitter.
9. What is the best form of inductance for use in a short wave receiver?
10. Draw a wiring diagram of a two tube short wave receiver.

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DESIGN AND INSTALLATION OF SHORT WAVE TUBE TRANSMITTERS

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DESIGN OF SHORT WAVE TRANSMITTERS
250 WATT TRANSMITTER: 20 TO 60 METERS
(15,000 Kcs. to 5,000 Kcs.)

Figure 1 shows the schematic wiring diagram of a short wave transmitting circuit that is capable of coverng the wave-length band between 20 and 60 meters. One UV-204-A is used in this circuit (250 watt tube).

This is a "Split Hartley" circuit, also called a "Series Hartley" circuit and differs from the similar type of circuit shown

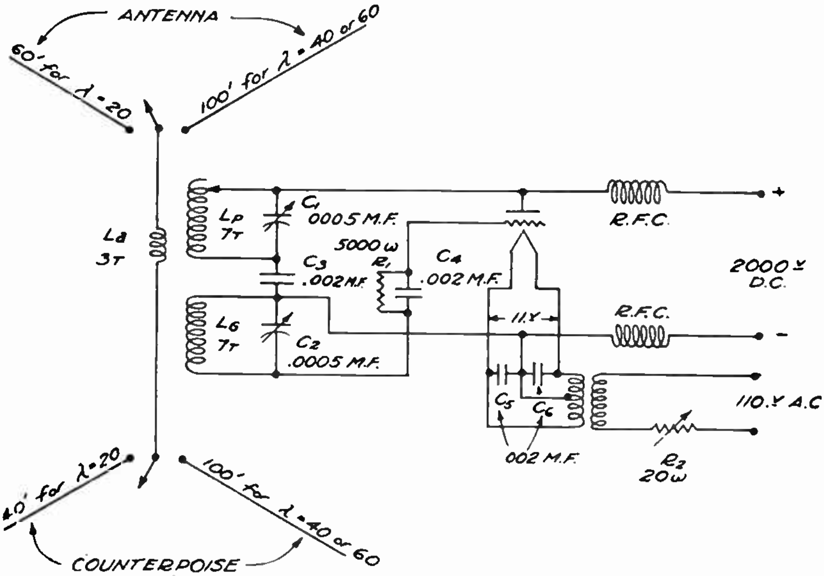

Fig. 1.—250 Watt Transmitter.

in a previous text-book in that it has tuning condensers, C_1 and C_2 across the plate and grid coils, respectively, to increase the flexibility of the transmitter. By increasing the "flexibility," we mean that the introduction of the tuning condensers increases the band of waves that it is possible to cover.

First of all, in this unit, we must have a power source, capable of supplying 2,000 volts D. C. and 110 volts A. C. One way of obtaining the 2,000 volts is by means of a motor-generator set and another is by means of a source of high potential A. C. and a suitable rectifier unit.

The positive lead from the high voltage D. C. source is connected to the plate of the UV-204-A through a radio-frequency choke coil. The plate is also connected to one end of the plate coil L_p which is shunted by the condenser C_1. C_3 is a radio-frequency by-pass condenser and also is a blocking condenser for the plate voltage.

The grid of the tube is connected to one end of the grid coil L_g through a grid biasing resistance R_1, the latter being shunted by a radio-frequency by-pass condenser C_4. The grid coil is shunted by the tuning condenser C_2.

The 110 volt A. C. supply for the filament of the tube is applied to the primary winding of a step-down transformer. The secondary winding should have a potential of 11 volts across its extremities. The mid-point of this secondary filament winding is common to the grid-return and the negative lead from the high voltage plate source. The negative lead from the 2,000 volt supply has a radio-frequency choke coil between the source and the mid-point of the filament secondary winding.

The antenna coupling coil consists of 3 turns which are wound around the plate coil of the closed oscillatory circuit. The antenna system has a 60 foot wire for an antenna and a 40 foot wire for a counterpoise when transmitting on 20 meters. For 40 and 60 meters, a 100 foot antenna and a 100 foot counterpoise are used.

There is a 0 to 5. thermo-coupled ammeter in series with the antenna lead to read the radio-frequency current and there is a 0 to 500 D. C. milliammeter in series with the negative plate supply lead to read the value of plate current.

It seems worth while to give you a list of the apparatus that was used in the construction of this transmitter because there may be some of you who will find it within your power to build this unit. Here are the parts that were used.

1—UV-204-A (250 watt tube).

1—Each, plate and grid sockets for above.

2—Radio-frequency choke coils; 100 turns of No. 22 double cotton covered wire, 3 inches in diameter.

1—7 turn plate coil (L_p); ½ inch copper ribbon self-supporting coil, 3 inches in diameter.

1—7 turn grid coil (L_g); same as the plate coil.

1—3 turn antenna coil (L_a); ½ inch copper ribbon self-supporting coil, 4½ inches in diameter.

2—.002 Mfd. fixed condensers (C_3 and C_4) rated at 6,000 volts.
1—Electrad 5,000 ohm resistor (R_1).
2—.0005 Mfd. variable transmitting condensers (C_1 and C_2).
1—General Radio type 214-A rheostat (20 ohms—.75 amp.) R_2.
2—Electrad .002 Mfd. fixed condensers (C_5 and C_6).
1—Weston Thermo-coupled Ammeter (Model 425) (0 to 5. amps.)
1—Weston Model 301 milliammeter (0 to 500.).

Figure 2 gives you an idea of the general appearance of the transmitter in question. The power tube is mounted in the foreground with the plate milliammeter at the left and the antenna ammeter at the right. The grid biasing resistance is shown at the right, shunted by the .002 Mfd. grid condenser

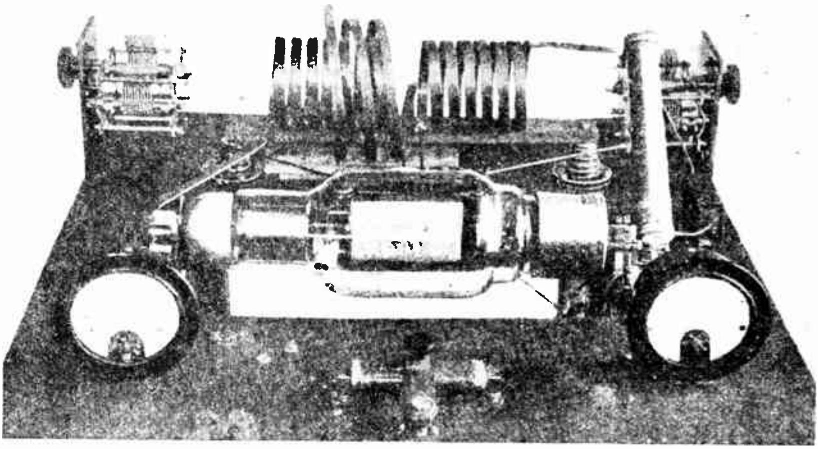

Fig. 2.—General Appearance of Transmitter.

C_4. The plate coil is shown in the coil assembly at the rear, left, with the antenna coil L_a wound around it. The grid coil L_g is just to the right of the antenna and plate coils. The plate tuning condenser C_1 is mounted at the rear of the baseboard to the left and the grid tuning condenser C_2 is on the extreme right.

HISTORIC SHORT WAVE TRANSMITTER, 15 to 85 METERS

Figure 3 is a view of one of the first short wave transmitters ever built for handling commercial radiotelegraph traffic. This ¼ Kw. transmitter was built by the Zenith Radio Corporation for the 1925 McMillan Arctic Expedition. It was capable of transmitting on either phone or C. W., on wave-lengths ranging from 15 to 85 meters and was heard over extremely great distances.

First, we have the power supply panel at the extreme right. Then in the middle we have the modulator panel which includes a 50 watt speech amplifier and a 250 watt modulator. The 250 watt tube is shown mounted in a horizontal position. It is a type UV-204-A.

At the extreme left of the picture is the oscillator panel which includes a 250 watt oscillator tube with its associate circuit. The oscillator tube can also be seen, in a horizontal position, and this, too, is a UV-204-A.

Now, we have considered several different low power transmitters, which are by no means of commercial status, simply to help you grasp the fundamentals of short wave transmission and to get accustomed to the constants used on these short wavelengths. The foregoing transmitters described embody the fundamentals of short wave transmission and give the layman an opportunity to construct them and become accustomed to the intricacies in the operation of them. The discussion of the foregoing circuits gives you an insight into the field of short wave transmission and now we are going to tackle the real thing. We will go into the discussion of real commercial equipment and will show you the vast difference there is in the details of a high power short wave installation.

First of all, in commercial short wave transmitters, and by this we mean, transmitters that are used for the transmission of regular radiotelegraph traffic, a generator of high-frequency energy, other than the vacuum tube, is used, because of its inherent ability to maintain a very constant frequency. This unit is the "Crystal Oscillator" and the next part of this text will describe the fundamental principles underlying the operation of the "Oscillating Crystal."

CRYSTAL CONTROL

When certain crystals are subjected to stress or are heated or cooled, electrical charges are produced in certain sections. When these electrical charges are produced by stress, the effect is called "Piezo-electric." When these charges are produced by heat, the effect is called "Pyro-electric." It is with the piezo-electric effect that we are concerned at this time.

Many years ago, the discovery was made that a piece of Rochelle salt changes its shape when it is placed between two metal plates which are connected to a source of potential. The action that takes place is similar to that manifested when you squeeze a rubber sponge. For instance, say you have a square piece of rubber sponge and simultaneously apply a compressive force with your hands to the top and bottom surfaces. As you apply pressure to the sponge, the length of the surfaces which are perpendicular to your hands, becomes smaller, and the length of the surfaces which are parallel to your hands, becomes greater. This analogy gives you an idea as to how the crystal of Rochelle salt acts when it is placed between two charged plates.

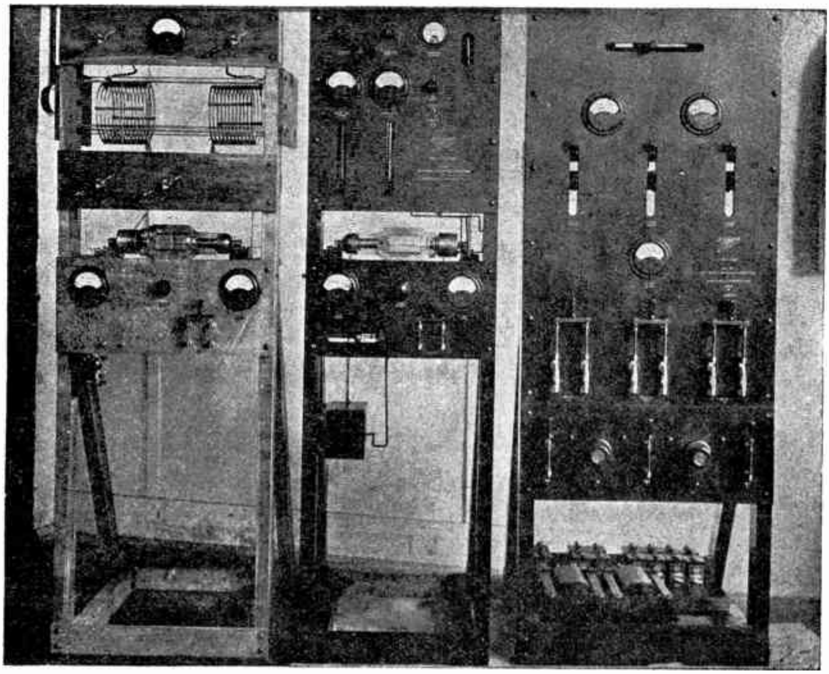

Fig. 3.—View of First Short Wave Transmitter.

It has also been found that this action can be reversed. For instance, if the crystal is subjected to a mechanical strain, its surfaces become charged electrically.

It follows, then, from the foregoing, that a crystal may be distorted by means of mechanical or electrical pressure. When this occurs, the crystal immediately tries to return to its original shape and in so doing it swings past the normal state and actually contracts. Then it tends to swing back the other way and, in so doing, it again passes the starting point and becomes larger along the particular dimension we are considering. In other words, the crystal oscillates, just the same as a metal disc oscillates when you hit it with a hammer.

In the case of the metal plate, hit with the hammer, the oscillations are of audio-frequency and you can hear them, but in the case of the crystal, the oscillations are of radio-frequency and you cannot hear them. Also, in the case of the metal plate, the magnitude of the vibrations becomes smaller and smaller and finally dies out, so with the crystal, the magnitude of the oscillations would diminish to zero if some means were not employed to maintain it in an oscillating condition.

Summarizing, to get at the fundamentals, we see that the crystal can be set into oscillation by either mechanical or electrical pressure, these oscillations being of radio-frequency. When the crystal is connected in the proper circuit the oscillations can be maintained.

Rochelle salt has the greatest piezo-electric effect and quartz has a comparatively small one, but due to the mechanical characteristics of the latter, it is much more suitable for use as a constant source of radio-frequency energy in a transmitting unit.

Thus, quartz crystals are the type that are used in commercial practice. These crystals are cut in a particular manner and they each have three fundamental frequencies, regardless of whether the cut is bounded by a rectangle, square, ellipse or circle, as long as the thickness is small in comparison with the other dimensions.

The following is a short list of the three fundamental frequencies of each of several crystals and the corresponding wavelengths in meters, to give you a general idea of the comparative values of these frequencies in kilo-cycles.

Crystal	f_1 K-C	f_2 K-C	f_3 K-C	λ_1	λ_2	λ_3
No. 1	74.95	105.5	452.5	4000.	2842.	663.
No. 2	75.05	105.91	454.2	3995.	2831.	659.8
No. 3	74.9	105.15	454.25	4003.	2853.	660.0
No. 4	75.4	106.0	457.0	3976.	2828.	656.0
No. 5	74.75	105.35	454.5	4011.	2847.	659.5

The thickness of the crystal is a function of the frequency. A thick plate is required for low-frequencies and a thin plate for high-frequencies. Of course, it is not logical to try and produce crystals with fundamental frequencies so high that the thinness of the quartz plate is such as to make it difficult to handle without fear of breaking. The logical limits at the present time are between 100,000 cycles and 7,500,000 cycles. Higher and lower frequencies are readily obtainable from these fundamentals, as the crystal oscillator output is rich in harmonics.

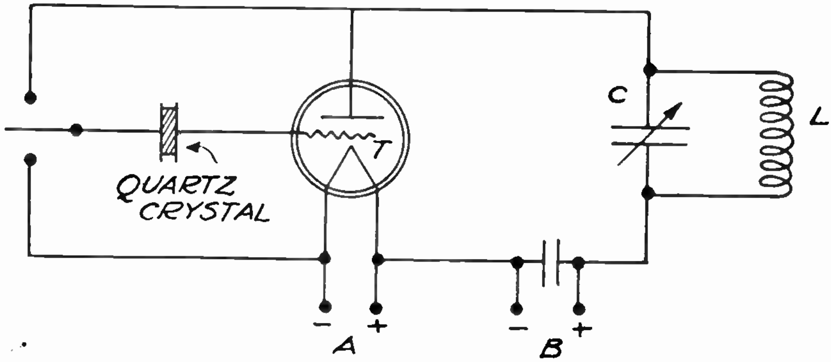

Fig. 4.—Circuit for Crystal Oscillator.

Figure 4 is a schematic diagram of the circuit connections for a Piezo-electric Oscillator. The crystal may be connected between the grid and the plate or the grid and the filament of the tube, in this particular circuit. The plate circuit is tuned to one of the fundamental frequencies of the crystal oscillator by means of the inductance (L) and the capacity (C).

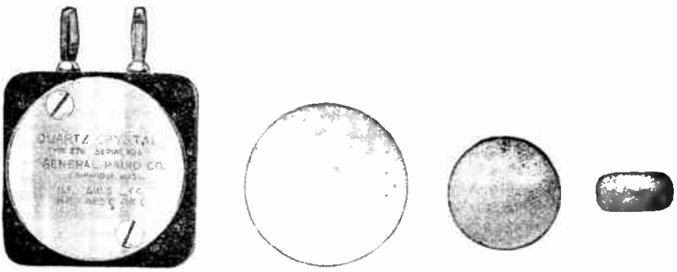

Fig. 5.—Quartz Plates.

The action that takes place is, in general, as follows: When the vacuum tube in the circuit in Figure 4 is put into operation by applying filament heating and plate potential, there is a difference of potential between the plates, between which the crystal is located. This distorts the crystal, which immediately tries to swing back to its normal state and in so doing, swings past normal, etc., thus a transient oscillation is produced which would die out before being noticed, if it weren't for the regeneration effected by means of the tuned plate and the capacity between the electrodes within the tube.

The oscillations that are set up in the grid circuit, appear in the plate circuit in magnified form due to the inherent characteristic of the vacuum tube to amplify voltages applied to its grid. These amplified variations are applied back to the grid of the tube, supplying the proper grid excitation, by virtue of the grid plate and grid filament capacity. If the crystal is connected between the grid and the filament of the tube, the grid

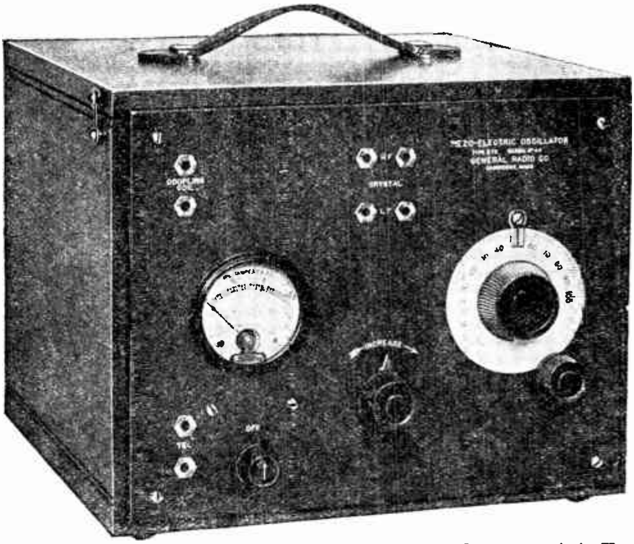

Fig. 6.—View of General Radio Company's Commercial Type of Piezo-electric Oscillator.

plate capacity functions to effect regeneration and if the crystal is connected between the grid and plate of the tube. the grid filament capacity functions to effect regeneration and maintain the crystal and the tube in the oscillatory state.

Figure 5 is a picture of a commercial type of quartz crystal assembly that is put out by the General Radio Company. You notice on the left, the neat little case that is used to enclose the crystal. You will note that the two highest fundamental frequencies are marked on the outside of the case.

To the right of the case are several views of crystals of different shapes. These are the quartz plates that are enclosed in the case shown at the left. This assembly is known as the General Radio type 276 quartz plate.

Figure 6 is a view of the General Radio Company's commercial type of piezo-electric oscillator, type 275, which uses the type 276 quartz plate described above. Figure 7 shows the schematic wiring diagram for this particular oscillator and you can see that this diagram is fundamentally the same as that shown in Figure 4.

Crystals for frequencies above 500 kilocycles are plugged in the jacks marked "H. F." (between plate and grid), while crystals for frequencies below 500 kc. are plugged in the jacks marked "L. F." (between grid and filament). You may ques-

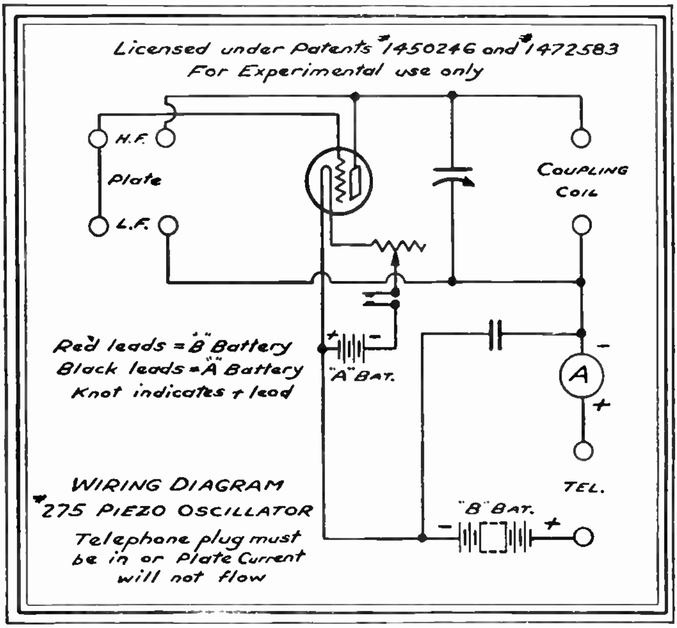

Fig. 7.

tion this last statement due to the fact that there is no metallic circuit between one side of the crystal and the filament terminal when it is plugged in the "L. F." jacks, but on closer examination you will notice that there is a radio-frequency by-pass condenser between one side of the crystal and the positive "A" battery terminal which has the same effect, for radio-frequency, as tying the side of the crystal in question directly to the positive "A" battery lead.

The coupling coil is applied externally and is a function of the frequency of the crystal, since the coil and the condenser C_1 are tuned to the crystal frequency. The milliammeter (A) and the telephones are used to indicate when the circuit is oscillating. This will be manifested by a decrease in the value of the current as shown by the milliammeter, and by a click in the phones.

COMMERCIAL 50. METER, 5. KW. TELEPHONE TRANSMITTER

We are now going to take up the description of a commercial radiotelephone transmitter that is operated on a wave-length of 50 meters with an antenna output around 5. kilowatts.

This transmitter is located at Belfast, Maine, and can be operated on either 70 or 50 meters. The fundamental details are similar in either case.

Figure 8 is a schematic wiring diagram of this transmitter. To start with we have a 100 meter crystal which is the constant source of our radio-frequency energy. As has been stated before, crystals that are thin enough to have a fundamental frequency of the order of 100 meters are quite delicate, mechanically, and must be handled with extreme care.

It is more difficult to make a crystal oscillate below 200 meters than it is above, and due to this fact as well as the fact that we have, to start with, a 100 meter crystal, it is necessary to use an auxiliary battery (E_1), about 8 volts, in the crystal circuit to insure dependable operation of the crystal oscillator. A radio-frequency choke (X_1) is used in series with the crystal battery to prevent any loss of energy in this circuit.

In this case, the crystal is applied between the grid and the filament of a 5. watt tube T_1, a UX-210. The plate circuit of this first tube is tuned to 100 meters and the thermo-ammeter (A_1) is connected in series with the tuning condenser C_{p1} so that radio-frequency current only passes through it, the D. C. plate current passing through the plate coil L_{p1}. The ammeter A_1 is a Weston thermo-ammeter having a range of from zero to 1.0 ampere.

The plate tuning coil in the crystal amplifier tube plate circuit is coupled to the grid coil (L_{g2}) which is in the input circuit of another 5. watt tube. This tube is a "frequency doubler" or "harmonic amplifier," either term being used to denote the function of the tube in question. What we want to do in this second tube circuit is to cut the wave-length in half, or, in other words, double the frequency.

We know that the output of the crystal amplifier tube T_1

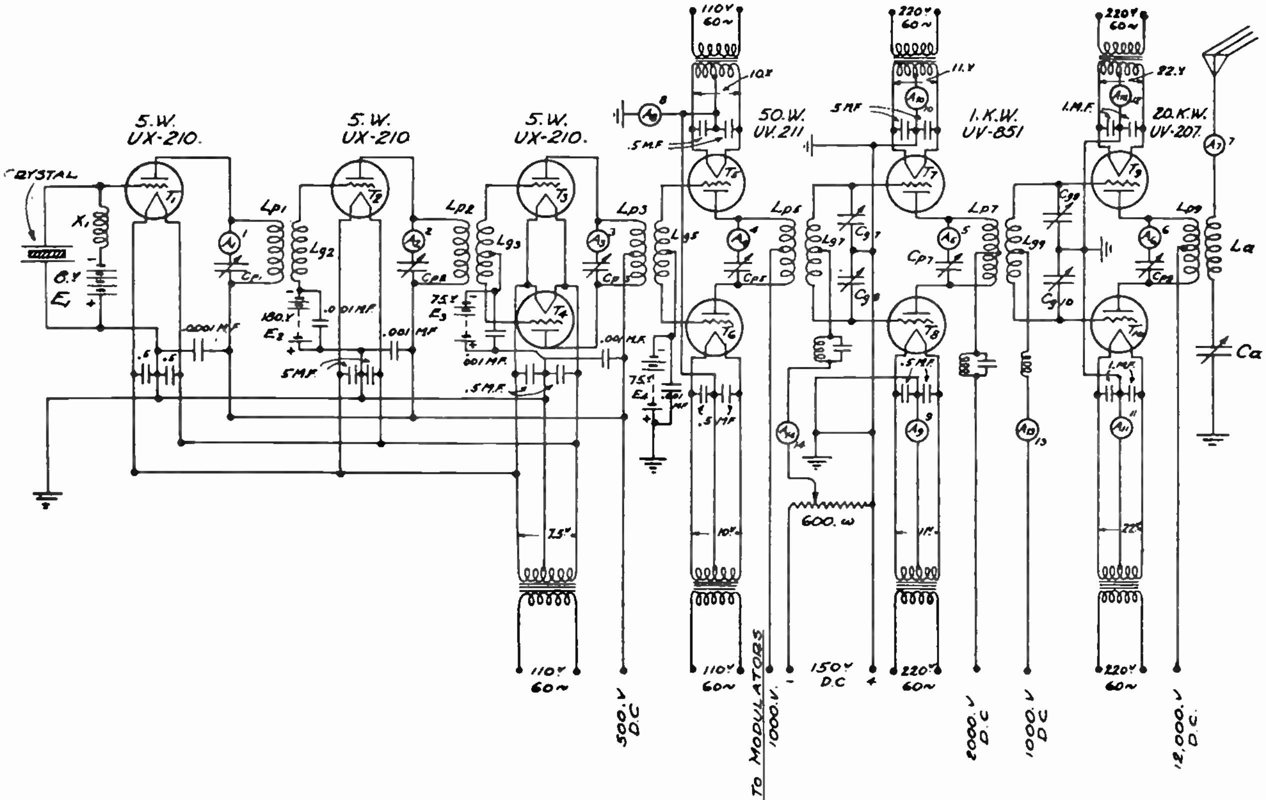

Fig. 8.—Commercial 50 Meter Telephone Transmitter.

is full of harmonics, from previous discussion in this text, and we apply a high bias to the grid of the harmonic amplifier tube T_2 to cause its output to be rich in harmonics. This bias, E_2, is 180 volts and is shunted by a radio-frequency by-pass condenser having a capacity of .001 Mfd.

The plate circuit of T_2 is tuned to 50 meters, the first harmonic of the fundamental frequency of the crystal. It follows that the voltage on the grid T_2 at the first harmonic frequency will be of far smaller amplitude than that of the fundamental frequency and it also follows that we will have a correspondingly small amount of energy in the output circuit of T_2, so it is only necessary to have a zero to 250 mils. thermo-milliammeter (A_2) in the plate circuit of this tube to denote the point of maximum radio-frequency current in the tuned circuit.

If the plate circuit of T_2 were tuned to the fundamental frequency of the crystal, we would, of course, have a greater amount of radio-frequency current in the plate circuit of T_2 than in the plate circuit of T_1, but we must bear in mind the fact that we are amplifying the first harmonic of the crystal in the output circuit of T_2 and, therefore, do not expect as great a value of radio-frequency current as we had in the output circuit of T_1.

The inductance L_{p2} and the capacity C_{p2} in the plate circuit of T_2, then, tune to 50 meters. L_{p2} is coupled to the coil L_{g3}, the latter being the input coil to a push-pull amplifier consisting of two 5. watt tubes T_3 and T_4, with their associate circuits. From this point in the transmitter circuit, on, we want to have linear amplification. We want to amplify only one frequency, 6,000,000 cycles per second (50 meters), and we don't want any harmonics. Push-pull amplifiers are used because they are conducive to this effect; they eliminate the odd harmonics.

A 75. volt bias battery E_3 is used in the common grid-return circuit of the tubes T_3 and T_4. This battery is shunted by a radio-frequency by-pass condenser having a capacity of .001 Mfd. The inductance and capacity L_{p3} and C_{p3}, respectively, in the plate circuit of this 5. watt push-pull amplifier, tune to 50 meters and a Weston (0 to 1.5 amp.) thermo-ammeter (A_3) is used to denote the value of the radio-frequency current in the output circuit of this stage of amplification.

So far we have taken into account the functioning of the four 5. watt tubes, T_1, T_2, T_3 and T_4. The filaments of these tubes are all supplied with a potential of 7.5 volts, at their respective terminals, by means of a step-down transformer. The secondary winding of this transformer is tapped at its mid-point and this point is grounded. When alternating current is used for the filaments, instead of direct current, the grid-return lead is brought to the mid-point of the filament supply winding of the transformer used, rather than to one or the other of the filament terminals, as in the case of D. C. filament supply.

To keep all the radio-frequency leads as short as possible, an artificial neutral point between the two filament supply leads is effected right at the filament terminals of each of the four tubes in question, by means of two .5 Mfd. condensers, connected in series, and their mid-point grounded. The grid-return, in each case, is brought to the grounded point between the two condensers and the direct current in the grid circuit passes around through the tube, from grid to filament, through the winding of the filament supply transformer and back to the neutral point between the two series condensers right at the filament terminals. The radio-frequency current is by-passed by these series condensers.

There is also a .001 Mfd. radio-frequency by-pass condenser connected directly from the low side of the plate tuning coil, in each circuit, to the neutral point between the filament by-pass condensers. The plates of these four 5. watt tubes are supplied with a potential of 500 volts from a direct current source.

We now pass from the 5. watt push-pull amplifier to a 50. watt push-pull amplifier having two UV-211, 50. watt tubes, T_5 and T_6. The output coil (L_{p3}) in the 5. watt stage is coupled to the input coil (L_{g5}) in the 50. watt stage. There is a 75. volt bias battery E_4 in the common grid-return lead of these two 50. watt tubes. This bias battery is shunted by a radio-frequency by-pass condenser having a capacity of .001 Mfd.

The inductance and capacity L_{p5} and C_{p5}, respectively, are used to tune the output circuit in this stage of amplification to 50 meters. A closed oscillatory circuit of this type, functioning in this manner, is often called a "tank circuit." A Weston (0 to 10. amp.) thermo-ammeter, A_4, is used in the tank circuit of this amplifier to show the value of the radio-frequency current. The filaments of these two tubes require a potential of 10 volts which is supplied from two separate filament transformers. Two .5 Mfd. by-pass condensers are connected in series across the filament terminals of each tube and the two neutral points (one at each tube) thus formed, are brought to ground through a Weston (0-400 Mil.) D. C. milliammeter (A_8). This meter shows the value of the plate current flowing to these two tubes.

The radio-frequency output of this stage of amplification is modulated and the method of modulation will be taken up in detail later. It is sufficient to say here that the plates are supplied with potential from a 1,000 volt direct current source.

The output coil L_{p5} of the 50 watt amplifier is coupled to the input coil (L_{g7}) of the 1. kilowatt push-pull amplifier. The mid-point of the input coil (L_{g7}) is connected to a biasing resistance through a (0-300, m. a.) P. C. milliammeter (A_{14}) and a radio-frequency choke composed of an inductance and capacity, in parallel, tuned to 50 meters. 150 volts D. C. is applied across the biasing resistance which has a value of 600 ohms. By means of a movable contact on this resistance, it is possible to apply a negative potential anywhere between zero and 150 volts to the grids of the two UV-851, 1. kilowatt amplifier tubes. The positive terminal of the 150 volt D. C. supply for biasing the tubes in this stage of amplification is grounded. A_{14} shows the value of the grid current.

Two variable condensers C_{g7} and C_{g8} are connected in series across the input coil L_{g7} to effect tuning and thus increase the grid excitation for the two 1. kilowatt tubes T_7 and T_8. The mid-point between these two grid tuning condensers is grounded.

An inductance and a capacity, L_{p7} and C_{p7}, respectively, are used to tune the output of this stage of amplification to 50 meters. A Weston (0 to 20 amp.) thermo-ammeter, (A_5), is connected in the tank circuit to afford a visible indication of resonance and the value of the circulating radio-frequency current at this point in the transmitter circuit.

The mid-point of the tank coil (L_{p7}) is connected to the 2,000 volt D. C. supply through a radio-frequency choke. This choke consists of an inductance and a capacity in parallel, having the proper values to tune this parallel circuit to 50 meters.

Each one of the two 1. Kw. tubes in this amplifier has its separate filament heating transformer which maintains a potential of 11. volts at the filament terminals. The filament terminals, right at the tubes, are shunted, in each case, by two .5 Mfd. condensers connected in series and having their mid-point brought to ground through (0 to 1 amp.) D. C. ammeters (A_9) and (A_{10}). These ammeters show the value of the plate current flowing to each tube and they are placed at this particular point in the circuit because it is the low potential side of the plate circuit.

If it isn't exactly clear to you how the plate current can be shown by a meter in this part of the circuit, let us follow the plate circuit through from the source. Starting from the positive 2,000 volt terminal it passes through the radio-frequency choke to the mid-point of the output coil (L_{p7}). At this point the plate current divides, part of it flowing to one tube and part to the other. It is sufficient if we follow its course through one tube so we note that it passes to the plate of T_7, through the inside of the tube from plate to filament, then

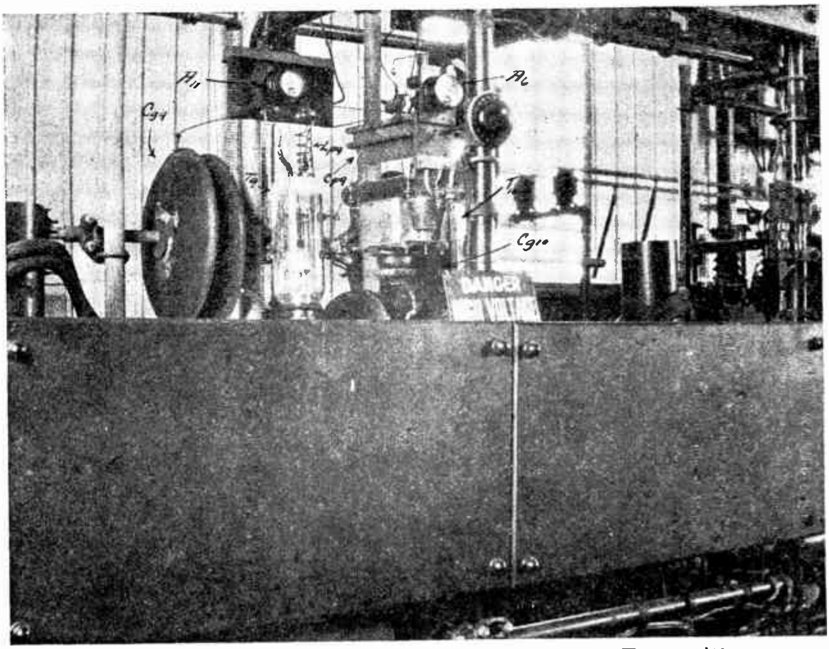

Fig. 9—20 Kw. Push-Pull Amplifier in 50 Meter Transmitter.

the filament supply winding to the mid-point, from whence it flows to ground through the plate current meter, and as the negative terminal of the plate supply is grounded, the circuit is complete.

The output of the 1. Kw. amplifier is coupled to the input of the 20 Kw. amplifier by means of the two coils (L_{p7}) and (L_{g9}). Two UV-207, 20. Kw. tubes are used in this last stage of push-pull amplification. The mid-point of the input coil (L_{g9}) is connected to a bias voltage supply generator through a radio-frequency choke coil and a grid milliammeter (A_{13}).

This bias generator is capable of supplying a biasing potential as high as 1,000 volts and the operating bias is of this order.

The grid milliammeter used in this stage of amplification has 0 at the center of the scale, with a range of 300 milliamps. on either side. The direction in which the meter needle will travel depends upon the polarity of the grid current.

For normal operation, the grid meter needle should indicate that the grid current is flowing from grid to filament, but if the travel of the meter is in the opposite direction, indicating that the flow of current is from filament to grid, we have an unstable condition. This action of the grid current meter would indicate that secondary emission was taking place (electrons given off from the grid) and if it were allowed to continue there would be considerable damage done to the tube. This condition of reverse flow of grid current takes place with the higher power tubes but does not give any trouble with the lower power tubes, those under 1. Kw.

The two condensers (C_{g9}) and (C_{g10}) are used to tune the input circuit of the 20 Kw. push-pull amplifier and thus effect higher grid excitation than could be effected by the coupling be-between (L_{p7}) and (L_{g9}), alone. The tank circuit of this stage of amplification is tuned by means of the condenser (C_{p9}) and the coil (L_{p9}). A Weston (0-40. amp.) thermo-ammeter (A_6) is used to indicate the value of the radio-frequency current in this last closed oscillatory circuit in the transmitter under discussion.

The mid-point of the output coil (L_{p9}) is connected to the 12,000 volt D. C. supply. The filaments of the two tubes in this stage are supplied with filament heating energy by means of a step-down transformer in each case which maintains 22 volts potential across the terminals of each filament. Two 1. Mfd. condensers are connected in series between the filament terminals at each tube. In each case, the mid-point of the filament supply winding is connected to the neutral point between the two series by-pass condensers through a (0 to 5 amp.) D. C. ammeter and thence to ground. These 5. amp. meters (A_{11}) and (A_{12}) show the value of the plate current to each of the 20 Kw. tubes and, the meters, of course, are connected in the low potential side of the plate circuit. See Fig. 9.

The output of the 20 Kw. tank is coupled to the antenna system by means of the coils (L_{p9}) and (L_a). The antenna system is tuned by means of the condenser (C_a) and the coupling coil (L_a). A Weston (0 to 10 amp.) thermo-ammeter (A_7)

is used in the antenna circuit to indicate resonance and also to give the value of the radio-frequency current flowing there.

Figure 10 shows the schematic wiring diagram of the modulator circuit. Four 50 watt tubes, T_1, T_2, T_3 and T_4 are used in this circuit. The filaments of these tubes are supplied with energy from the low potential winding of a step-down transformer. This transformer maintains a potential of 10 volts at the filament terminals of these tubes.

The audio-frequency input to the modulator system, which normally comes from a speech amplifier system, is applied to the primary winding of the input transformer. The high side of the secondary winding of the input transformer is connected to a lead which is brought out as a common audio-frequency supply to the grids of all the modulator tubes. Each grid is connected to this lead through a choke coil and a resistance.

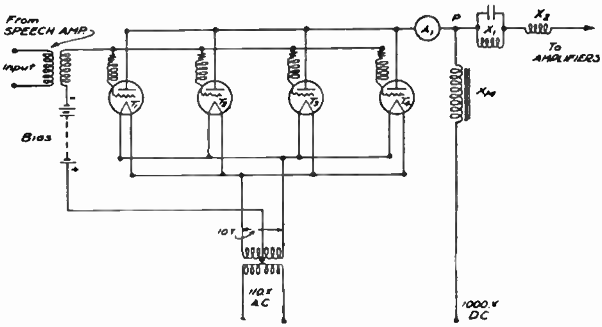

Fig. 10.—Bank of 50 Watt Modulators.

The low side of the secondary winding of the input transformer is connected to the negative terminal of the bias battery and the positive terminal of this battery is connected to the midpoint of the filament supply winding.

The plates of the four modulator tubes are all connected to the 1,000 volt D. C. source through a (0-400 mil.) D. C. milliammeter and an iron-core reactor X_m. The 1,000 volt supply for the two 50 watt push-pull amplifier tubes, T_5 and T_6 (Figure 8), also passes through the iron core reactor X_m, Figure 10, and the two radio-frequency choke coils X_1 and X_2. X_1 is a tuned choke and X_2 is untuned. They keep the radio-frequency from getting into the power supply or the modulator tubes.

The grid potential of the modulator tubes follows the audio-frequency variations of the input from the speech amplifier system and this causes a corresponding variation in the plate current to the modulator tubes. The iron-core reactor X_m is common to the modulator tubes and to the radio-frequency amplifier tubes in the 50. watt push-pull amplifier. Also, its position in the circuit causes it to function to maintain a constant current supply to the point (p), at which point the current divides, part of it flowing to the amplifiers and part to the modulators. If the current supply to the point (p) is constant, then, when the grids of the modulator tubes go positive and there is a greater flow of current to the modulator plates, there will be less current available for the amplifier plates. Therefore, the plate current supply to the amplifier tubes will vary in accordance with the audio-frequency variations that are applied to the grids of the modulator tubes and it is in this way that modulation is effected.

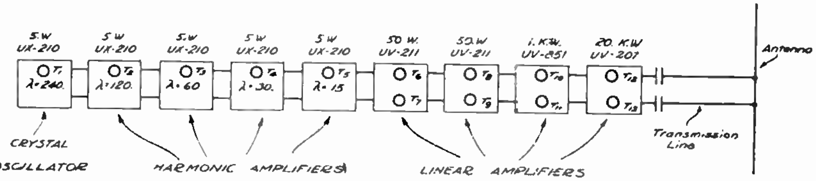

Fig. 11.—Commercial 15 Meter Transmitter.

COMMERCIAL 15 METER, 5 KW. TELEGRAPH TRANSMITTER

The preceding discussion has covered the fundamental details involved in a commercial type of short wave transmitter so, to avoid repetition and thus get as much information into a small space as is possible, we will consider this transmitter generally.

Figure 11 is a sketch of the tube arrangement for this transmitter which carries on commercial radiotelegraph traffic between the United States and South America, on 15 meters. This installation is at Rocky Point, Long Island.

To start with, we have a 210 meter crystal, the radio-frequency oscillations of which are amplified by means of a UX-210, 5 watt tube. The next four tubes are frequency doublers; they are all 5 watt tubes, UX-210's.

T_2 amplifies the first harmonic (120 meters) of the 240 meter crystal amplifier output. Now, we have 120 meters as the fundamental in the output circuit of T_2, since there is more energy at this frequency than at any other in this circuit.

T_3 amplifies the first harmonic of the output from T_2. Since the fundamental output from T_2 is 120 meters, the first harmonic is 60 meters. Hence, the fundamental wave-length in the output circuit of T_3 is 60 meters. T_4 amplifies the first harmonic of this 60 meter frequency which corresponds to 30 meters. This is applied to the input T_5 which again amplifies the first harmonic of the input and we have 15 meters in the output cir-

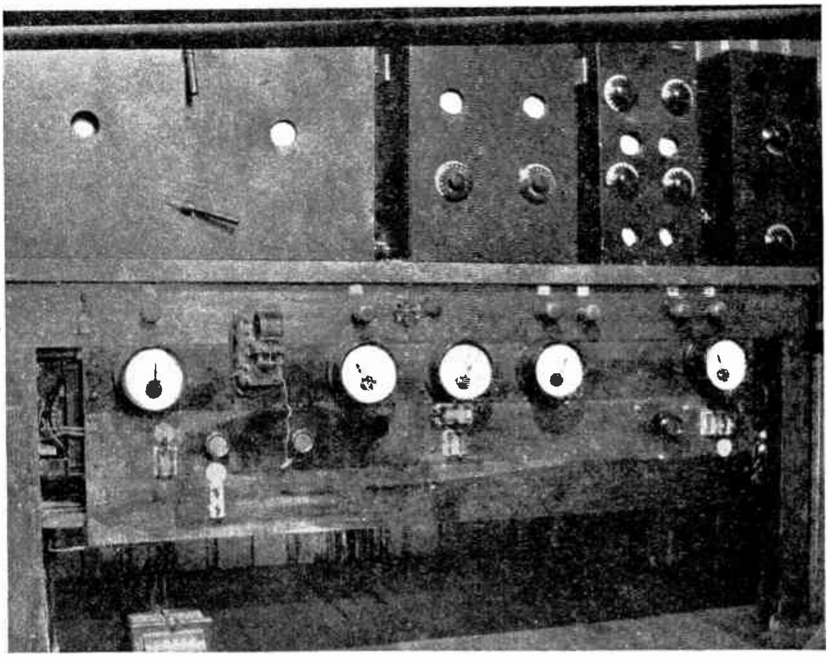

Fig. 12.—Front View of 15 Meter Transmitter Assembly Crystal Amplifier at Extreme Right. Four 5 Watt Frequency Doublers in Second Case From Right. Four 50 Watt Tubes in Third Case From Right, and Two 1 KW Tubes in the Fourth Case.

cuit of T_5. These four tubes, T_2, T_3, T_4 and T_5 can be called harmonic amplifiers, but the term "frequency doubler" seems to explain their function more fully.

From this point in the circuit, on, we simply have linear amplifiers to amplify the output of the last frequency doubler, T_5. This energy is first applied to the input circuit of a push-pull amplifier having two 50 watt tubes. The output of this first 50 watt stage is passed on to a second 50 watt push-pull amplifier which in turn passes the output energy on to a 1. Kw.

push-pull amplifier. The output of the 1 Kw. push-pull amplifier is passed on to a 20. Kw. stage of push-pull amplification.

In this particular transmitter, the keying is accomplished in the grid circuit of the 1 Kw. amplifier stage. The method of keying is quite simple. It simply consists of a scheme whereby the proper operating bias is applied to the grids of the two 1. Kw. push-pull amplifier tubes. When the key is up, there is a negative potential of 450 volts applied to the grids of the tubes from the bias generator through the resistance

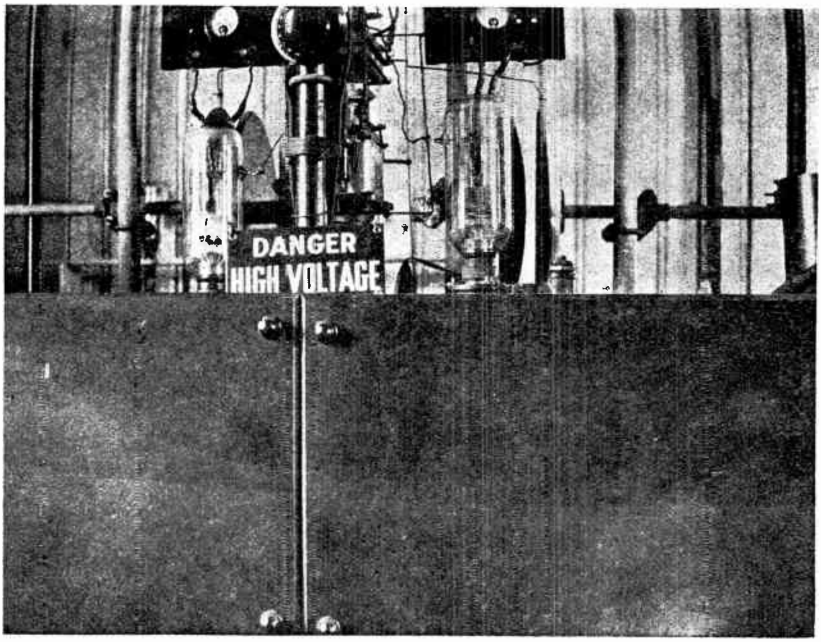

Fig. 13.—20 Kw. Push-Pull Amplifier Stage for 15 Meter Transmitter.

R1. With this amount of negative potential, the tubes will block (their plate current will become zero.)

When the key is pressed down, the negative bias from the generator is shorted through the resistance, R1, and the negative bias from the storage battery is applied, thus causing the tubes to amplify in normal manner, which produces a normal output from the antenna. See Fig. 15.

Another interesting point in the consideration of this particular transmitter is the method of coupling the output circuit of the last stage of amplification to the antenna system. This is done by means of a "transmission line" which carries the

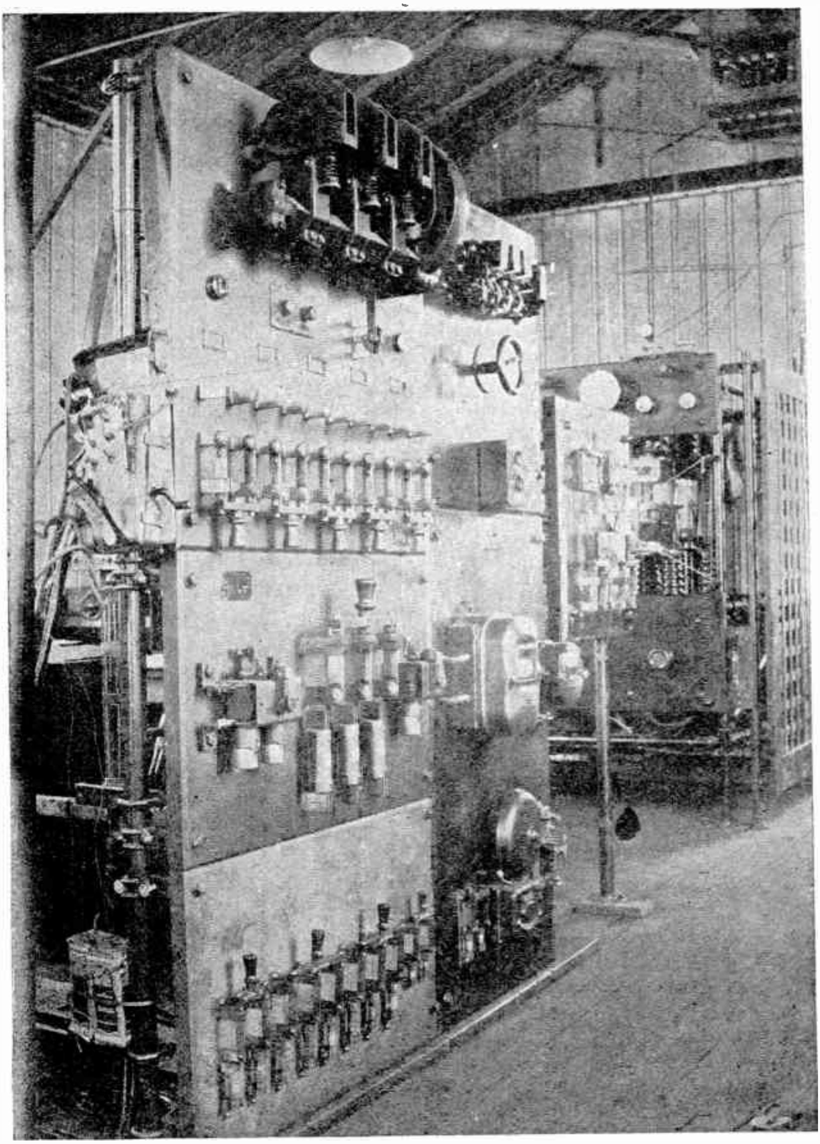

Fig. 14.—Power Panel for 15 Meter Transmitter.

energy from the transmitter to the antenna. Figure 16 is a schematic diagram illustrating this point. The transmission line is directly coupled to the inductance coil in the tank circuit of the last power amplifier. Two .0001 Mfd. blocking condensers are used to keep the high plate potential out of the transmission line and antenna but they, of course, pass the radio-frequency energy.

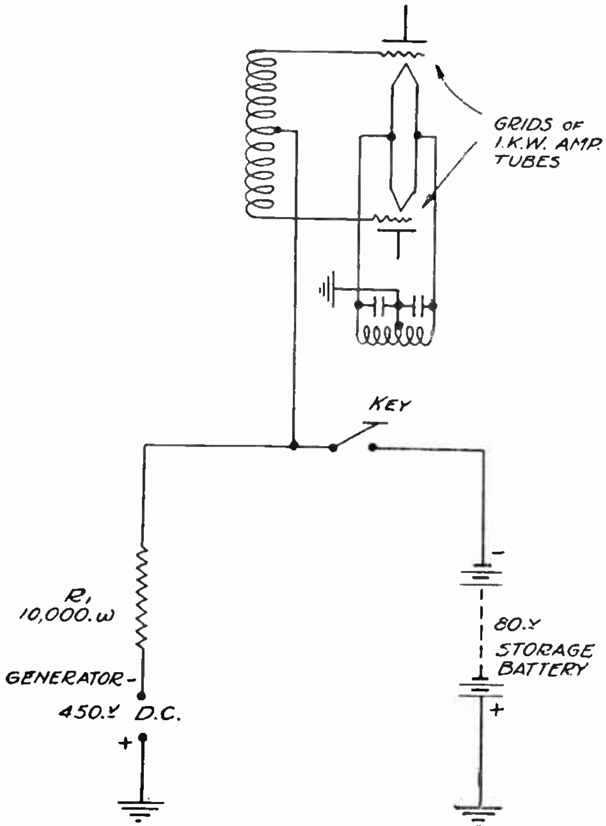

Fig. 15.—Keying Circuit for 5 Kw., 15 Meter Telegraph Transmitter.

The length of the antenna used in this 15 meter transmitting system is just ½ a wave-length, or 7½ meters, or approximately 26½ feet. This 26 foot antenna is suspended between two masts and the transmission line is connected to it at its mid point. (See Figure 16.) The points (a) and (b) where the two leads from the transmission line fasten to the antenna are quite critical and have to be determined very accurately. The impedance of the wire between points (a) and (b) should be such that it would give the effect of a line of infinite length, to the current flowing in the line. This would mean that there would be no reflection at the end of the line, hence the line would not radiate and the antenna would be the only portion of the system that would radiate energy.

Figure 17 is a view of the 15 meter antenna, showing the transmission line and the method of connecting it to the antenna. The system of wires behind the antenna constitutes a reflector which works on the same principle as the reflectors in Marconi's "Beam System" which cause the radiated energy to be most effective in one particular direction. This particular reflector is so constructed with reference to the antenna that it is directive towards South America.

Looking at Fig. 17, it is interesting to compare this little short wave antenna with the large antenna system shown in

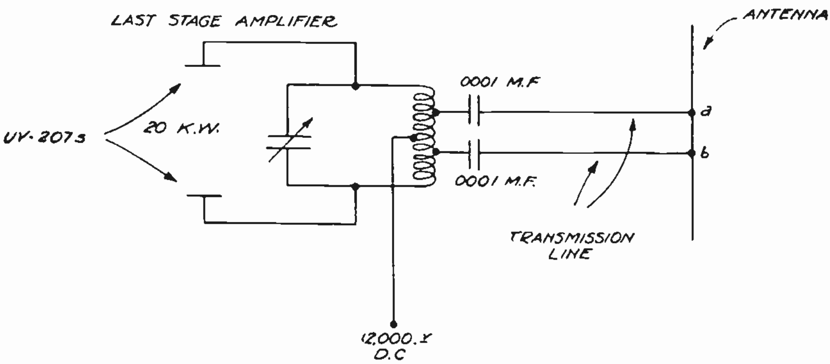

Fig. 16.—Transmission Line Circuit.

the background. The antenna in the background is also for trans-Atlantic radiotelegraphic communication, but it is supplied with 200 Kw. of radio-frequency energy on a wavelength of approximately 12,000 meters. Alexanderson alternators are the source of this radio-frequency energy. The question is, when will these massive antenna systems give way to the miniature systems such as the 15 meter antenna system shown in the foreground, which is supplied with 5 Kw. of radio-frequency energy and which is capable of working with Europe or South America.

Figure 18 is a view of a 15 meter antenna system, without a reflector, and here again the transmission line and method of application is shown quite clearly.

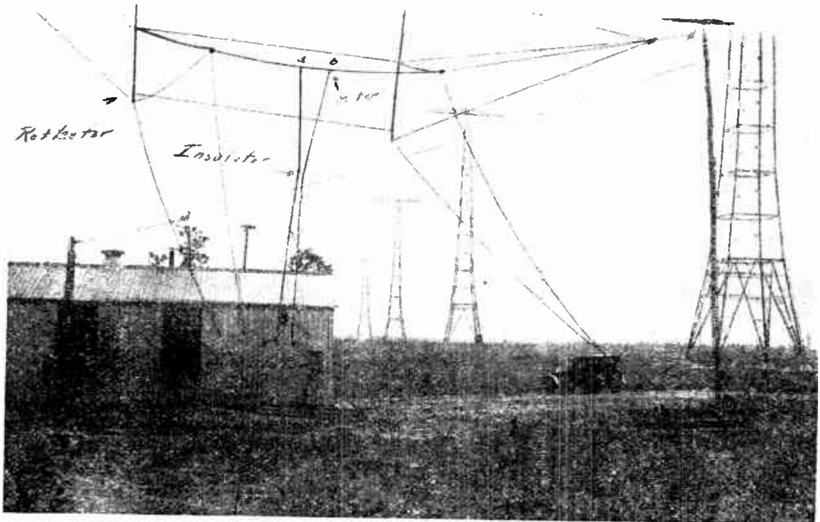

Fig. 17.—View of the 15 Meter Antenna.

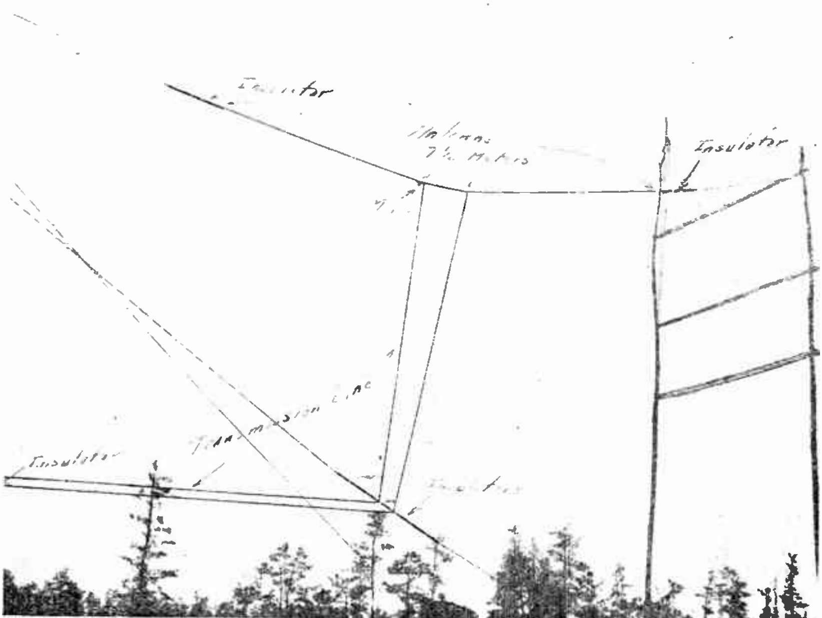

Fig. 18.—15 Meter Antenna System Without Reflector.

AMATEUR'S 150-175 METER C. W. VACUUM TUBE TRANSMITTER

THE MEISSNER TRANSMITTING CIRCUITS

This type of transmitter is used by a number of amateurs. The Meissner circuit employs inductive coupling between the plate and grid circuits and the antenna circuit.

In the circuit shown in Figure 19, the antenna circuit consists of an inductance from which one connection is made to the ground, the other to the antenna. A variable condenser is usually employed in series with the antenna to effect close variation of the wave-length.

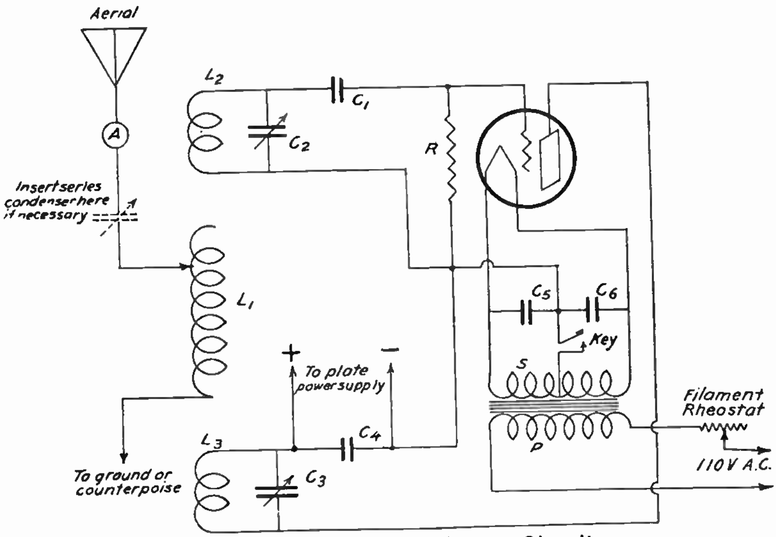

Fig. 19.—Three Coil Meissner Circuit.

The Meissner circuit will work with a ground almost as well as with a counterpoise. The most pleasing thing about the Meissner circuit is that one can change the wave-length from 150 meters to 160, or 175, by simply moving one antenna clip or tuning the antenna series condenser. In addition, the Meissner circuit has the advantage of the inductively coupled circuit in general. Naming the parts in Fig. 19, L_1 is the antenna coil, L_2, the grid coil, L_3, the plate coil. The constructional details of these coils are as follows: L_1, 14 turns heavy wire (such as No. 10 Bare Copper) on 6 inch form; L_2, 15 turns of wire (No. 20 to 30 DCC) on 6 inch tube when using condensers; 18 to 25 turns when working without condensers. L_3, 18 turns of wire (No. 20 DCC) on 6 inch tube when using condensers; 18 to 25 turns when working without condensers. C_1, .00025 to .002

mfd.; C_2 and C_3, good low-loss variable condensers, maximum .0005 mfd., C_4, .002 mfd., C_5 and C_6 1 mfd.; R, 1,250 to 10,000 ohms depending on the tube used.

The plate coil should be coupled closely to the antenna coil. The grid coil should be loosely coupled. Since grid coupling must be adjusted exactly, it is suggested that the grid coil be mounted so as to rotate. A pan-cake grid coil can be used.

To tune the set, put the antenna clip on some convenient point on the antenna coil and then adjust the grid and plate coils, either by means of clips to regulate the number of turns, or by condensers, so that the antenna current reaches its maximum. Then by means of a wave-meter, measure the wave-length radiated. If it is too high, cut out some of the turns of the antenna coil, and adjust the set as before, until the desired wave-length is reached. After the set is once adjusted, the plate and grid circuits need not be varied again, even if the wave-length is changed a great deal, for the antenna current will vary but little over the whole wave-length band between 150 and 175 meters. (The antenna current may be maintained steady by changing the adjustments of the plate and grid condensers. This change is very slight, and for ordinary work, it need not be done.)

The Two Kinds of Meissner Circuits.

There are two main forms of Meissner circuits in use among amateurs today; one form is the 3 coil Meissner as shown in Fig. 19; the second form is the 4 coil Meissner, shown in Fig. 20. In the 4 coil Meissner, two antenna coils are used. They are placed at right angles to each other and as far apart as convenient. With the grid and plate coils placed as they are in the 3 coil circuit, the full benefits of the Meissner arrangement cannot be had. There should be no coupling between the grid and plate coils, excepting through the antenna, but the 3 coil system places the grid and plate coils on the opposite ends of the same antenna coil, which means that there will be coupling between the grid and plate coils. Where the plate and grid coils are coupled directly to each other, oscillations of a different wave-length will be set up which are not the same as those radiated by the antenna. The energy required to do this is lost as far as the working wave-length is concerned. Also, these separate waves may cause correspondence with the Radio Supervisor's office.

The 4 coil Meissner circuit is the best of the two by far, because in the 4 coil set, the coils can easily be placed so that there is little coupling between the plate and grid coils. This is as it should be because it does away with extra waves and puts all the power into the main wave. The result is more miles per watt. The coils L_1 and L_4, in Figure 20, contain 7 turns on a 6 inch form or tube. The rest of the coils and condensers are the same as in Figure 19.

Mount the plate coil next to the lower antenna coil, L_4. The coupling between these two coils must be close, and the number of turns in the antenna coil, L_1, should not be changed.

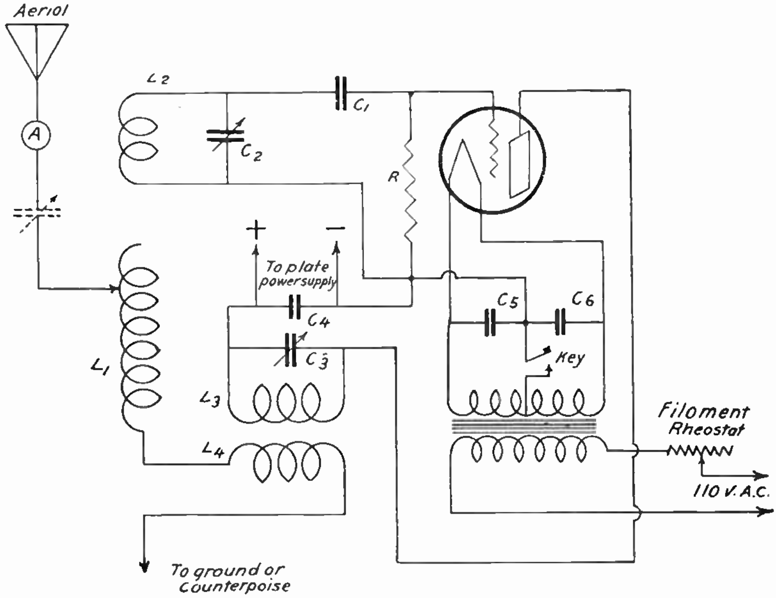

Fig. 20.—Four Coil Meissner Circuit.

Couple the grid coil to the variable antenna coil; place the two sets of coils at right angles so as to prevent setting up local oscillations of an undesired wave-length.

When the coils of the 4 coil set are properly arranged, the set will not oscillate if the antenna is disconnected, and the plate current will drop to almost zero. When adjusting the set, first find a place where the highest antenna current is produced for the least input to the tube. After getting an adjustment where a fair antenna current is produced with a small input, open the antenna switch. Now adjust the grid clip or grid variable condenser until the plate current is lowest. Then close the antenna switch. This grid adjustment should be made with care, but the adjustment of the plate clip (or plate coil condenser) is not critical.

LIST OF A FEW U. S. SHORT WAVE STATIONS

Wavelength	K. C.	Call	Location
14.93	20082	2XS	Rocky Point, New York
16	18738	NKF	Anacostia, D. C.
17.7	16940	KFD	Denver, Colorado
18.3	16380	WBQ	Schenectady, N. Y.
18.62	16100	KEB	Los Angeles, Calif.
19.56	15340	W2XAD	Schenectady, N. Y.
20	14991	NAL	Washington, D. C.
20.8	14414	NKF	Anacostia, D. C.
21.8	13750	KEB	Los Angeles, Calif.
22	13628	WIK	New Brunswick, N. J.
24.3	12340	KFD	Denver, Colorado
25.4	11814	W8XK	East Pittsburgh, Pa.
29.3	10230	KEL	Bolinas, Calif.
30	9994	2XI	Schenectady, N. Y.
30.6	9798	NAL	Washington, D. C.
31.48	9530	W2XAF	Schenectady, N. Y.
35.03	8560	WQO	Rocky Point, N. Y.
37	8130	6XI	Bolinas, Calif.
37.43	8010	WLC	Rogers, Michigan.
40	7496	NAS	Pensacola, Fla.
40	7496	NAJ	Great Lakes, Ill.
40	7496	NPG	San Francisco, Calif.
41.3	7260	NKF	Anacostia, D C.
42	7139	5XH	New Orleans. La.
43.02	6970	WIZ	New Brunswick, N. J.
44	6814	WQO	Rocky Point, New York
44	6814	KZA	Los Angeles. Calif.
44	6814	KZB	Los Angeles, Calif.
49	6119	WHD	Sharon, Penna.
49.02	6120	WABC-W2XE	Cross Hassock Bay, L. I.
49.83	6020	W9XF	Chicago, Ill.
49.9	6040	W2XAL	Coytesville, N. J.
50	5996	WBZ	Springfield, Mass.
51.5	5822	WQN	Rocky Point, New York
54.4	5511	NKF	Anacostia, D. C.
54.5	5501	WQN	Rocky Point, New York
56	5354	KFKX	Hastings. Nebr.
56	5354	1XAO	Belfast. Maine
57	5260	WGN	Rocky Point, New York
58.79	5100	KDKA	East Pittsburgh, Pa.
59	5082	KDC	Casper, Wyo.
62.5	4800	W8XK	East Pittsburgh. Pa.
63	4759	KDKA	East Pittsburgh, Pa.
67	4475	8XS	East Pittsburgh. Pa.
68.4	4383	WRB	Miami, Fla.
68.4	4383	WRP	Miami, Fla.
68.4	4383	WFV	Poinciana. Fla.
70	4283	2XAO	Belfast, Maine
70	4283	KFZP	San Francisco, Calif.
70.5	4253	NQG	San Diego, Calif.
71.3	4205	NKF	Anacostia, D. C.
71.7	4182	NPL	San Diego, Calif.
74	4052	WIR	New Brunswick, N. J.
74.77	4010	WLC	Rogers, Michigan
76	3945	NAJ	Great Lakes, Ill.
77.4	3874	NFV	Quantico, Va.
80	3748	NEL	Lakehurst, N. J.
81	3701	NPQ	San Francisco, Calif.
81.5	3679	NKF	Anacostia, D. C.
84	3569	NKF	Anacostia, D. C.

TEST QUESTIONS

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

Number your answers 37 and add your **Student Number.**

1. Draw a circuit of a 250 watt transmitter for short wave communication, naming each piece of apparatus.

2. Why are crystal oscillators used in transmitters?

3. What type of oscillating crystal is used for commercial practice?

4. Draw a diagram showing how a crystal oscillator is connected in a circuit.

5. Explain why a grid milliammeter is used in the last stage of the push-pull amplifier, Figure 8.

6. How is the antenna system tuned in Figure 8?

7. Draw a circuit showing a bank of four 50 watt modulators.

8. What is the purpose of using the two choke coils X_1 and X_2 in Figure 10?

9. Draw a diagram of a typical keying system in a 5 Kw. 15 meter transmitter.

10. Explain what happens when the key is pressed down in this circuit.

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LESSON TEXT No. 38

HOW TO OPERATE A BROADCASTING STATION

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NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

HOW TO OPERATE A BROADCASTING STATION

In years gone by, the ambitious individual who wished to become a radio engineer or a radio operator and who availed himself of some reputable course in radio, did not find any section devoted to the operation of broadcasting stations.

At the present time, the art in question is expanding and it is difficult to prophesy when the saturation point will be reached. The fact remains that radio broadcasting is now such an important phase of radio that you, who wish to become well informed on the subject in its entirety, would do well to consider the following pages with as much concentration as possible.

There are radiotelephone transmitters on shipboard, at the present time, and it is well for the modern radio operator to understand the maintenance and operation of this type of equipment. It might be pointed out here that this type of telephone transmitter does not require an absolutely distortionless audio-frequency amplifier ahead of the modulator tubes, due to the fact that it has to function chiefly in effecting satisfactory transmission of speech.

Contrasting the requirements for the standard broadcasting station with those of the ship phone transmitter, we find that the efficiency of the audio-frequency circuits in the case of the shore station are far more stringent. In this case, not only is it necessary to have amplifiers that will provide the modulator tubes with distortionless speech, but also with high quality music.

To produce satisfactory reception of music, it is necessary that the audio-frequency amplifier circuits at the transmitting station be impartial to all frequencies from 30 or 40 cycles per second to 5,000 cycles per second.

Going back to the ship telephone transmitter and the consideration of satisfactory transmission of speech, it is well to realize that the most important speech frequencies are between 200 and 2,000 cycles per second.

If the audio-frequency amplifier circuits chop off all the frequencies under 750 cycles per second, you can still understand what is being said, but you cannot distinguish the speaker.

A pertinent point to mention at this time is that there is a need for well trained men in the radio broadcasting field who are well paid for their services.

Now that the introductory remarks have been completed, it is logical to inform you how we propose to handle this subject.

First of all we will touch briefly on the consideration of the location of a broadcasting station. Then, having settled that point we will dive right into the heart of the entire subject of radio broadcasting, namely, the source of radio-frequency energy.

In discussing the methods used in establishing a source of radio-frequency energy, the primary power supply angle of the subject will be covered.

It seems logical to pick out several of the most popular standard types of broadcasting units having different power outputs and discuss them in detail, rather than treat the subject in generalities. Bearing this in mind, we will take up in detail a 500-watt General Electric Company transmitter, a 500-watt Western Electric Transmitter, a 1,000-watt General Electric transmitter and finally we will touch on a super-power station of the General Electric Company's design, having an output of 50,000 watts.

The necessity of maintaining a constant frequency of the radio-frequency output will be discussed and various methods of accomplishing this explained.

We will show how the sound waves that actuate the transmitting microphone are amplified and made to modulate the radio-frequency output from the transmitter.

Different types of microphones will be considered and the advantages and disadvantages of each explained. The high quality speech amplifier circuits and the functioning of the modulator tubes will be explained quite thoroughly.

Finally, we will consider the apparatus involved in broadcasting from a remote point and the linking up of a chain of broadcasting stations.

THE LOCATION OF THE STATION

When an option is taken on a site for a broadcasting station, it is sound practice to determine whether the station is going to "get out," before proceeding with the expenditure of several thousands of dollars on the equipment and installation. Most of you probably know that by the ability of the station to "get out," we refer to the distance the signals will carry and we are interested in the distance they will carry in all directions.

One way of obtaining sufficient quantitative data for determining the radio possibilities of a site for a broadcasting station is to install a low power portable radio transmitter at the desired location and take intensity measurements at equal distant points in all directions from the transmitter.

From the quantitative data so obtained, a signal intensity curve may be plotted and definite conclusions can be drawn as to whether there is an abnormal amount of absorption on any particular frequency or wave-length or on all frequencies or wave-lengths.

While the test is being conducted, readings are usually taken at different frequencies or wave-lengths throughout the entire broadcast band to determine whether the location in question is partial to any particular frequency or wave-length.

A transmission curve plotted on polar co-ordinate paper should take the form of a circle, as shown in Figure 1, with the transmitting station located at the center of this circle.

You will notice that intensity values are plotted along the radii which extend out in all directions from the point of transmission. Thus, the radius I_N represents the signal intensity at a definite distance due North from the transmitter, the radius I_W represents the signal intensity at a definite distance due West from the transmitter, etc.

If the signal intensity at the different points varied, the curve drawn through the points plotted would not be a true circle. It is easier to determine the different values of intensity at equal distances from the station than it is to determine the different distances from the station, in all directions, where the intensity values are equal.

Of course, it is desirous that the intensity of signals from the transmitter be equal at equi-distant points in all directions from the point of transmission but it is also important that these values be sufficiently high. In other words we might have a condition where signal intensity was equally poor in all directions.

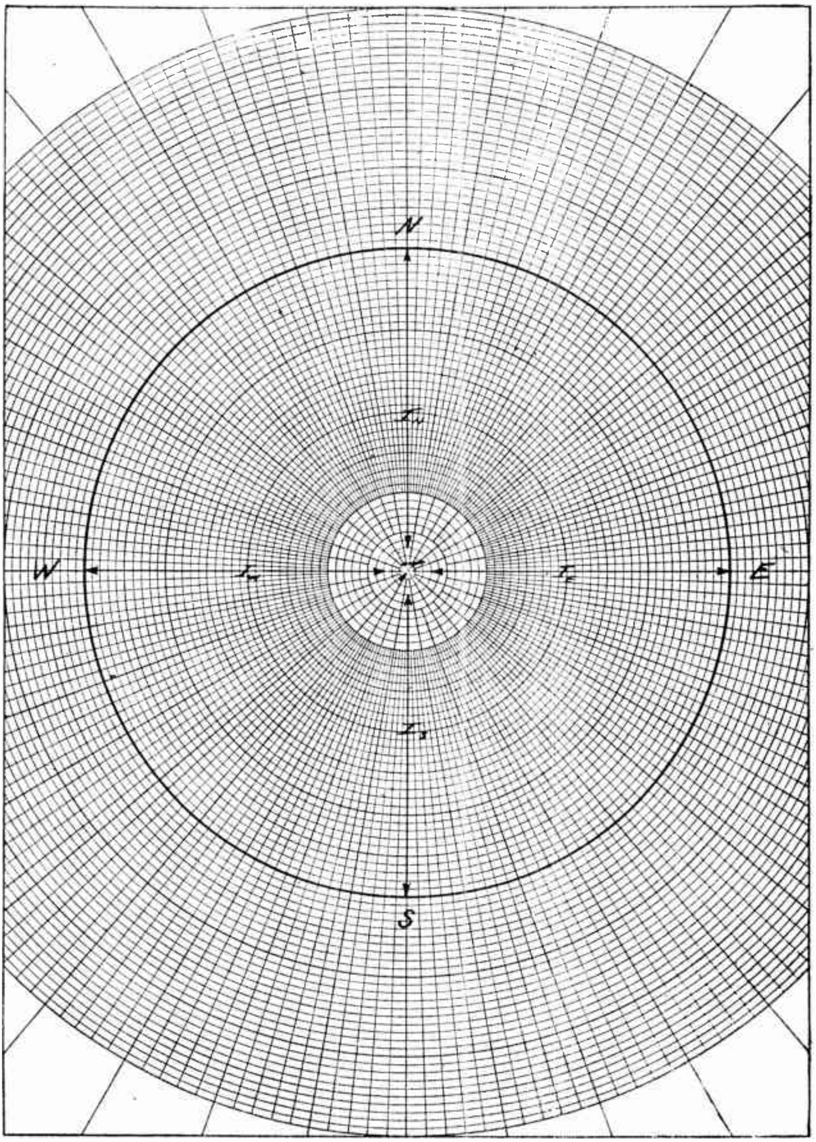

Fig. 1.—Transmission Curve, Using Polar Co-ordinate. (Station at the Center or Zero Point and Radii Represent Direction and Distance).

Assuming that the value of the intensity I_N, Figure 1, is satisfactory, then we may say that this curve would mean that the site for the transmitting station in this case is satisfactory.

POWER SUPPLY

After the site has been definitely decided upon, the next thing to consider is the availability of a sufficient amount of

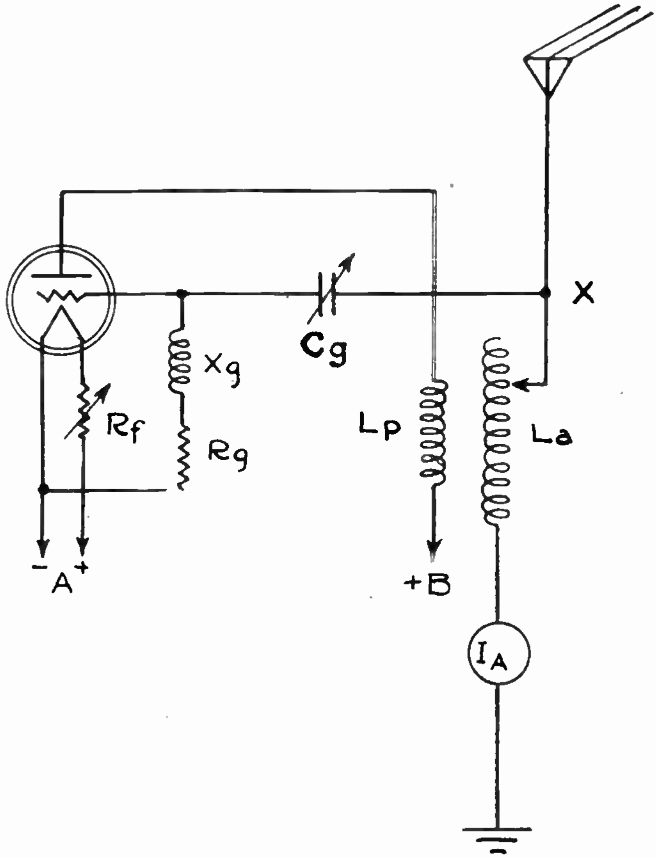

Fig. 2—Standard Tickler Coil Circuit With Inductive Plate Coupling.

electric power for operating the station of the power output contemplated.

Either direct or alternating current is satisfactory. This primary source of power is used to run motors which, in turn, actuate the generators of the proper electrical energy for applying to the points in the radio transmitter where desired.

We need low voltage alternating current for the filaments of the tubes. We need relatively high potential direct current for bias supply and we need high pressure direct current for the plates of the tubes.

In general, if the primary source of power is D. C., it is changed into low pressure A. C. for the filaments of the tubes by means of motor generator sets.

In this case, the grid bias voltage may be obtained by the following process: The low voltage D. C. is changed into low voltage A. C. by means of a motor-generator set and this supply of energy is then stepped up to the proper potential by means of a transformer. The high voltage A. C. obtained in this manner is then changed by means of suitable rectifier tubes into D. C. of sufficient potential for biasing the grids of power tubes.

THE HEART OF BROADCASTING—THE RADIO TRANSMITTER

The first broadcasting transmitter that we will discuss is one having a 500-watt output, located in New York, and manufactured by the General Electric Company.

The circuit arrangement is a modification of the "tickler coil" circuit with inductive plate coupling.

A typical circuit diagram of this type is shown in Figure 2. In this circuit the frequency determining elements are the inductance of the antenna coil (LA), and the inductance and capacity of the antenna itself.

The grid excitation is taken from the antenna circuit on the high side of the antenna coil (LA) and the value of this potential as it is applied to the grid of the oscillator tube is controlled by the value of the capacity (Cg). The larger the value of this capacity, the less will be its impedance to the flow of radio-frequency current, the less will be the potential drop between the point (x) and the grid of the tube; hence, the higher the potential of the grid excitation energy.

Theoretically we may mention the impedance of a condenser but, practically, the values of the resistance and inductance of a condenser are so small that the condenser may be assumed to contain nothing but capacity and in this case it wouldn't be necessary to call it an impedance, but think of it as pure capacity reactance, the symbol of which is (Xc).

If the value of the condenser (Cg), Figure 2, is decreased, capacity reactance increases, there is a greater impediment to the flow of radio-frequency current from point (x) to the

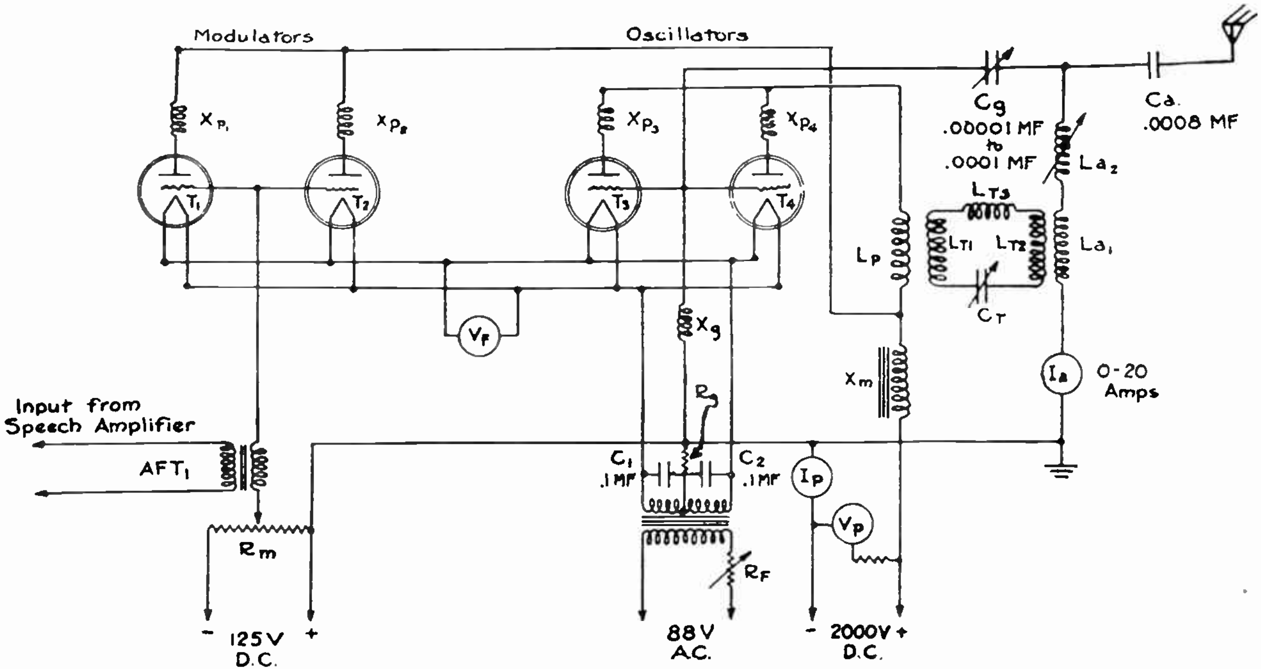

Fig. 3.—Schematic Wiring Diagram of General Electric 500 Watt Transmitter

grid of the tube, there is a greater drop in potential across the condenser (Cg), hence the potential value at the grid of the tube is decreased.

From the foregoing explanation you can see what a fine control of grid excitation can be effected by means of a variable capacity at Cg.

The choke coil Xg is connected in series with the grid biasing resistance (Rg) to keep radio-frequency currents from flowing through this circuit. Without this choke, there is a loss of about 20 watts in a 5,000 ohm bias resistance when the oscillator tube is of the 250-watt type.

This loss is 8% of the rated output of the tube so you can see that such a small unit as a radio-frequency choke coil, when applied at the proper point in the circuit, can greatly aid in the conservation of energy and hence, in the increasing of overall efficiency of operation.

When a radio-frequency choke coil is used, as at Xg the loss is decreased from 20 watts to ½ a watt which is from 8% to 2% (0.2 of 1% or 0.2%).

The plate potential is supplied through the coil (Lp) to the plate of the oscillator tube. The coil (Lp) is placed in inductive relation to the antenna tuning coil (La).

The theory of the generation of radio-frequency oscillations in this circuit is quite simple. When the filament of the oscillator tube is heated up to normal temperature and the plate potential is applied, there is a surge of current in the plate circuit of the tube. The direct result of this is that the antenna is forced or shocked into feeble oscillations. The frequency of these oscillations is a function of the inductance and capacity in the antenna circuit.

Due to the fact that the grid of the tube is coupled to the antenna circuit by means of the condenser (Cg), there is an alternating potential applied to the grid of the tube and obviously, the frequency of this alternating potential is the same as the frequency of the current in the antenna circuit.

The effect of this grid excitation is to cause the plate current through the coil (Lp) to vary in accordance with the variations in the antenna current and when the circuits are properly adjusted, these variations in the plate circuit will add to the effect of the original surge.

You can see that the actions that have been detailed are accumulative, and the limit is a function of the tube and antenna characteristics.

Figure 3 shows the schematic wiring diagram of a 500-watt broadcasting transmitter designed by the General Electric Company. You will note that this is the general type of circuit that has just been discussed but there are quite a few modifications.

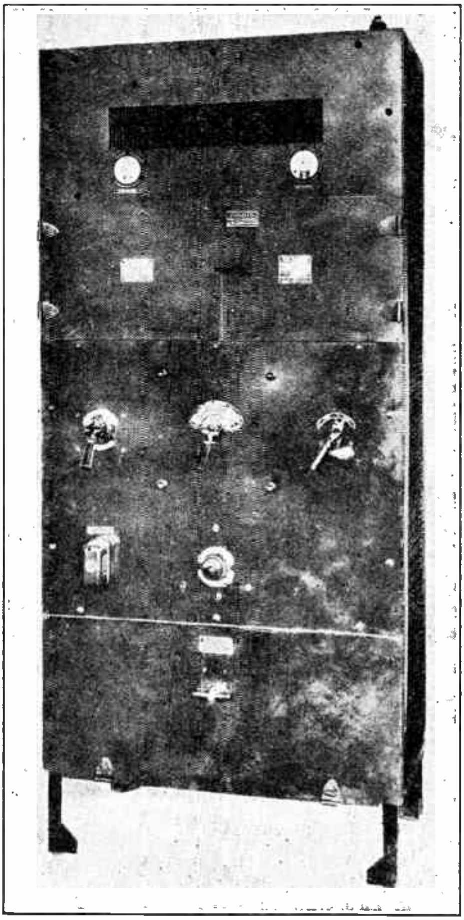

Fig. 4.—Front View of G. E. 500 Watt Transmitter Panel.

Four 250-watt tubes are used in this transmitter. T_1 and T_2 are modulator tubes, T_3 and T_4, are oscillator tubes. The filaments of these four tubes are all connected in parallel and they are supplied with energy from the secondary winding of the filament transformer.

The terminal voltage of this secondary winding is such that all volt potential is maintained at the filament terminals of the four 250-watt tubes.

There are two radio-frequency by-pass condensers connected in series between the two filament supply leads. These two condensers (C_1) and (C_2) each have a capacity of .1 Mfd. Their mid-point is connected to ground.

The plates of the two oscillator tubes (T_3) and (T_4) are connected to a 2,000 volt D. C. supply through the radio-frequency choke coils (Xp_3) and (Xp_4) respectively, the plate coupling coil (Lp) and the iron core choke coil (Xm). You will notice that this plate circuit is untuned, the same as was the case in the plate circuit of the fundamental diagram which preceded this one.

You will notice in Figure 3 that the plates of the oscillator tubes are not coupled directly to the antenna circuit, instead, there is an intermediate coupling circuit, which is termed a "tank" circuit. This "tank" circuit determines the frequency of the generated radio-frequency energy.

The object of the "tank" circuit is to maintain a constant radio-frequency source of energy. When the constants of the antenna circuit determine the frequency of the generated energy, there are apt to be changes in frequency due to the swinging of the antenna in heavy gales. Of course, this is sometimes counteracted by making the antenna system so rigidly secure that it is not likely to swing to any great extent.

The plate coil of the oscillator tubes is inductively coupled to the "tank" coil (Lt_1). The coil (Lt_3) is the "tank" variable tuning inductance. The coil (Lt_2) is used to couple the "tank" circuit to the antenna system. Ct is the "tank" tuning condenser.

La_1 is the antenna coupling coil which receives the energy from the "tank" circuit. La_2 is the antenna loading inductance, and the condenser (Ca) is inserted in series with the antenna lead to cut down the natural period of the antenna system where it is desired to transmit on a wave-length around 450 meters.

The grids of the two oscillator tubes receive the proper excitation from the antenna system through the grid coupling condenser (Cg).

The two oscillator grids are connected to ground through the grid choke coil (Xg) and the grid biasing resistance (Rg). The 2,000 volt D. C. grid current flowing through the grid resistance (Rg) supplies the proper negative bias to the grids of the oscillator tubes.

The choke coil (Xg) is put in series with the biasing resistance to keep radio-frequency current out of this circuit

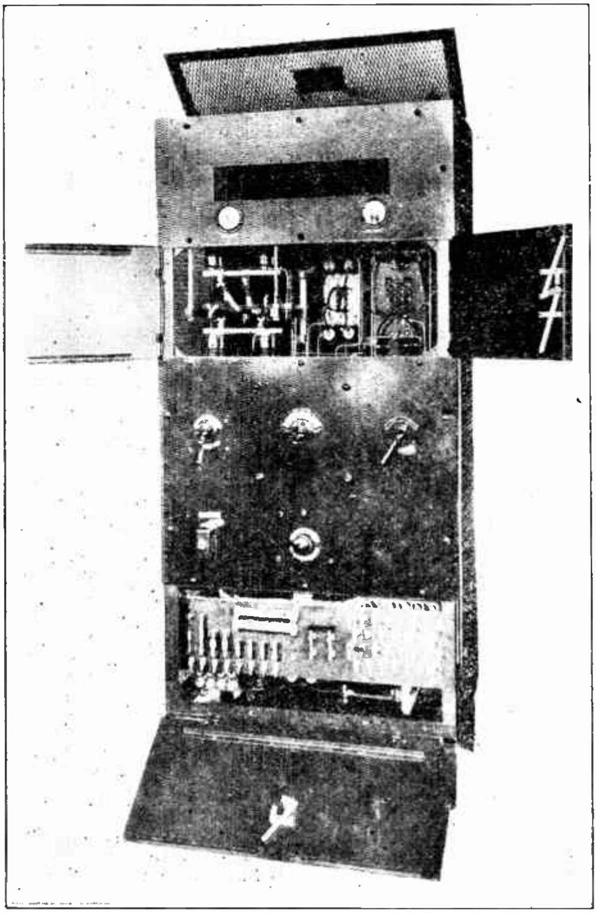

Fig. 5.—Control Panel of G. E. 500 Watt Transmitter, With Doors Opened.

and hence, decrease losses, which in turn increases the overall efficiency of operation.

The plates of the two modulator tubes (T_1) and (T_2) are connected to the 2,000 volt plate source through the two radio-frequency choke coils (Xp_1) and (Xp_2), respectively, and the iron-core plate reactor (Xm).

The grids of the two modulator tubes are connected in parallel through the secondary winding of the audio-frequency transformer (AF_1) to a variable contact on the modulator bias resistance (Rm).

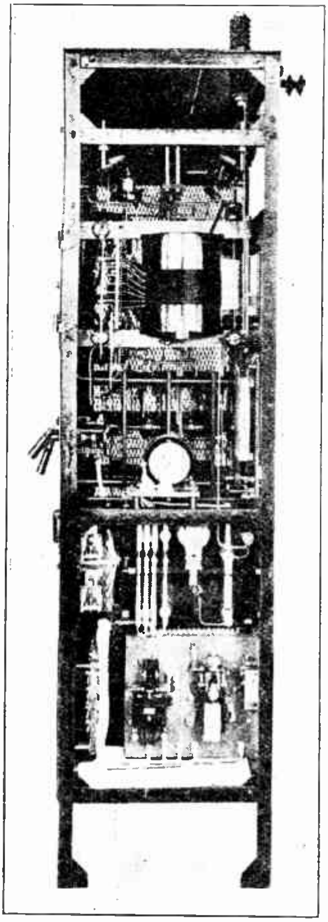

Fig. 6.—Side View of the G. E. 500 Watt Transmitter.

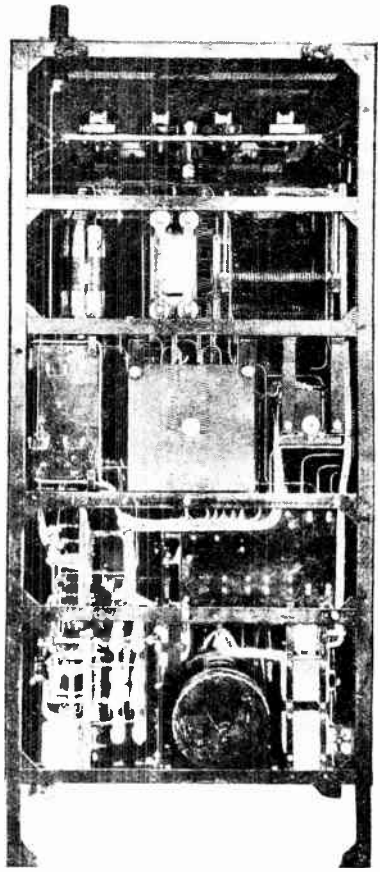

Fig. 7.—Back or Rear View of the G. E. 500 Watt Transmitter.

The extremities of this biasing resistance are connected to the positive and negative terminals of a 125 volt D. C. supply. The positive terminal of this D. C. supply is grounded; hence, it is possible to keep the modulator grids 125 volts below ground potential if so desired. In this case the grids of the

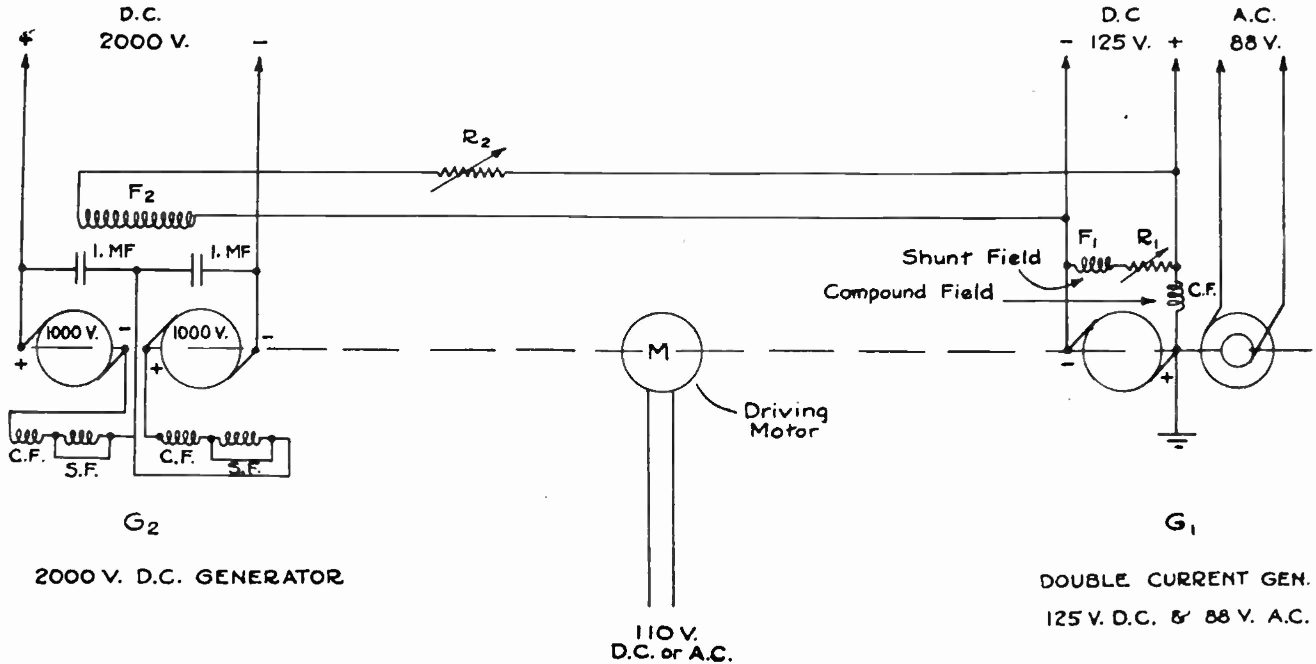

Fig. 8.—Motor-Generator for General Electric 500 Watt Transmitter. Schematic Wiring Diagram.

modulator tubes would not be kept so far negative, but the fact remains that they could be maintained at any negative potential between 0 and -125.

The audio-frequency output of the speech amplifier network is applied to the grid circuits of the modulator tubes, which are in common in this case, through the audio-frequency transformer AF_1. These audio-frequency currents are made to form an envelope for the constant radio-frequency energy that is generated by the oscillator tubes. This operation of controlling radio-frequency current with audio-frequency vibrations is called "modulation" and is effected by the modulator tubes (T_1) and (T_2). The way in which this is accomplished is quite simple and a discussion of the principals involved follows.

MODULATION

The sounds which emanate in the broadcasting studio are faithfully reproduced in the grid circuits of the modulator tubes in the form of audio-frequency currents, by virtue of the microphone, speech amplifier and the transformer coupled to the input circuits of the modulator tubes.

These audio-frequency variations in the grid potential of the modulators cause corresponding audio-frequency variations in their plate current. The plates of the modulator and oscillator tubes are all supplied in common through the iron-core reactor (Xm) and by virtue of this reactor, there is practically a constant current supply to the four tubes in question.

It is an inherent characteristic of any reactance that it tends to oppose any change in the current flowing through it. The greater the reactance, the greater the opposition. Here we have a large reactance in series with the plates of both the oscillator and modulator tubes.

If the modulator grids went positive at any particular instant due to the varying audio-frequency potential imposed thereon, their plate current would increase. Here is where the reactor functions. It would tend to oppose this increase in the current for the modulator tubes and the result would be that the modulators would draw some of the current away from the oscillator tubes.

A summary of this action shows that audio-frequency variations in the grid circuit of the modulators cause corresponding variations in modulator plate current which in turn raises and lowers the oscillator plate current. Thus, an audio-frequency envelope is formed over the outgoing radio-frequency oscillations.

POWER SUPPLY FOR 500-WATT G. E. TRANSMITTER

Figure 8 is the schematic wiring diagram of the power supply unit for the 500-watt type of transmitter which we have been discussing.

OPERATING HINTS ON THE 500-WATT G. E. TRANSMITTER

When the transmitter is first installed and tuned up or at any time it is necessary to make adjustments, they should be made at low power. The low power condition is effected by dropping the plate voltage to around 1,200 volts, in this case.

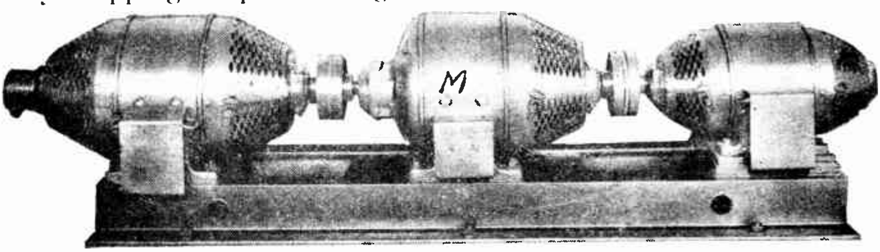

Fig. 9.—Picture of Motor-Generator Power Unit for General Electric 500 Watt Transmitter.

The plate potential is controlled by means of the rheostat (R_2), which is shown in Figure 8, in series with the field winding of the 2,000 volt D. C. generator.

Don't try to control the plate voltage by means of the exciter generator field rheostat (R_1). This rheostat should be adjusted to the point where the potential across the terminals of the exciter reads 125 volts. Then the rheostat in question should remain unchanged.

The plate voltage is recorded by means of the voltmeter (Vp Figure 3) which is virtually, a current measuring device in series with a high resistance across the 2,000 volt leads.

The filament voltage is controlled by means of the rheostat (Rf Figure 3) which is in the primary side of the filament transformer. This rheostat is so adjusted that the potential at the filament terminals of the tubes is 11.0 volts.

It is quite possible that an increase of ½ a volt in filament potential may raise the radiation a few tenths of an amp., but from an economical standpoint this is not worth while.

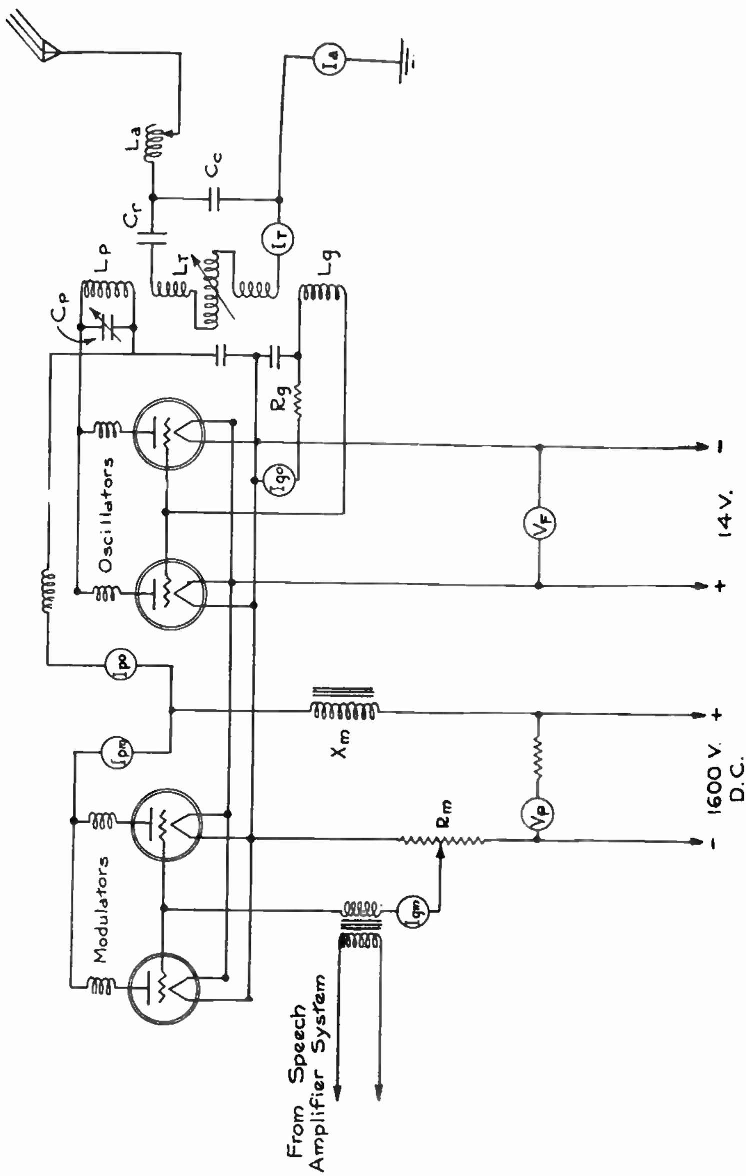

Fig. 10.—Schematic Wiring Diagram of Western Electric 500 Watt Transmitter.

If the filament voltage is left at 11.5 in this case for any length of time, it will greatly decrease the length of life of the tubes and if persisted in will cut the tube life about 50%.

The radiation current is measured by the antenna ammeter (Ia Figure 3).

The adjustments of the transmitter should be made with the aim of getting the maximum radiation with the lowest amount of plate current. The plates of these UV-204 tubes should not get hotter than is manifested by a cherry red color.

500-WATT WESTERN ELECTRIC BROADCAST TRANSMITTER

In the foregoing paragraphs we have covered the circuit arrangement and the theory involved of one 500-watt broadcasting transmitter. Since the fundamentals of the method of generating radio-frequency energy have been covered it seems logical now to touch, in general, several different types of transmitter circuit arrangements and then go on to the discussion of the speech amplifier circuits which function to supply distortionless audio-frequency to the grids of the transmitter modulator tubes.

Figure 10 shows the schematic wiring diagram of the Western Electric 500-watt broadcasting transmitter which is used at many broadcasting stations throughout the country.

Four 250-watt tubes are used, two modulators and two oscillators. The oscillatory circuit is of the Meissner type, with a few modifications.

In the standard type of Meissner circuit, both the plate and the grid coils are coupled to the oscillatory circuit, the plate and grid coils being untuned. We note here that there is a variable condenser shunted across the plate coil.

The function of this variable condenser is to adjust impedance conditions in the circuit to the optimum point for maximum efficiency.

The oscillator tubes are not coupled directly to the antenna circuit, but rather, they are coupled to the closed oscillatory or "tank" circuit which in turn is coupled to the antenna by means of the mutual capacity (Cc).

The "tank" circuit, or closed oscillatory circuit, is composed of the variometer (Lt), the tuning condenser (Cr) and the coupling condenser (Cc).

The antenna circuit is traced from the antenna, through the tuning inductance (La), the coupling condenser (Cc) and the antenna ammeter (Ia) to ground.

The system of modulation used in this transmitter is the same as that used in the preceding case that we have discussed.

The modulator grids are held at the proper negative potential in a somewhat unique manner. There is a resistance in series with the negative lead from the high potential plate supply generator to the negative filament terminal. The plate

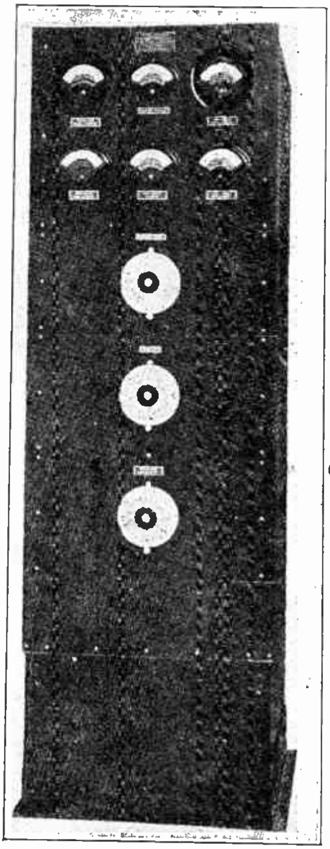

Fig. 11.—Front of Panel for 500 Watt Western Electric Transmitter.

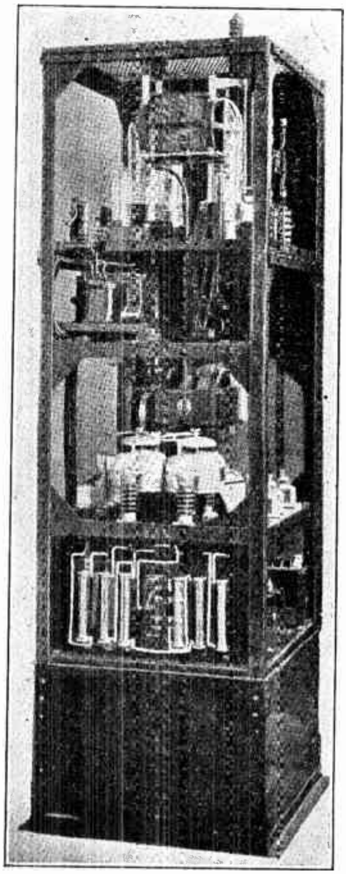

Fig. 12.—Rear View of the Western Electric Transmitter Panel.

current to all the power tubes (oscillators and modulators) passes through this resistance (Rm).

There is a drop in potential across the resistance (Rm) which is a function of the value of the resistance and the amount of direct current flowing in the plate circuit. The grid return from the modulator tubes can be tapped on to this biasing resistance at the point for proper negative bias.

This negative biasing voltage remains constant by virtue of the fact that the plate supply is a "constant current" supply system which in turn is due to the iron-core choke coil (Xm) in series with the positive plate supply lead.

The front view of this transmitter is shown in Figure 11. The three meters shown at the top of the panel are for oscillator plate current, antenna current and modulator plate current, reading from left to right, respectively.

These three meters are shown in the schematic wiring diagram in Figure 10 at Ipo, Ia and Ipm respectively.

The three meters just below are for oscillator grid current, "tank" circuit current and modulator grid current, reading from left to right respectively. These three meters are also shown on the schematic diagram, Figure 10, as Igo, It and Igm.

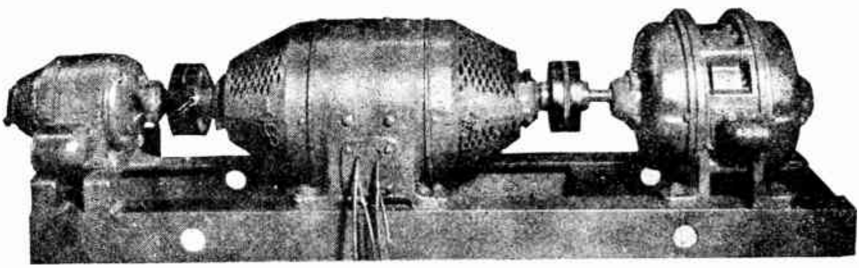

Fig. 13.—Western Electric Power Unit for 500 Watt Transmitter.

The three control dials which appear on the view of the front panel, Fig. 11, are, reading from top to bottom, the antenna tuning control, the frequency control and the oscillator adjustment.

The first control mentioned varies the inductance of the antenna tuning coil (La), Figure 10. The frequency control varies the inductance of the "tank" coil (Lt) and the oscillator adjustment is for changing the value of the variable capacity (Cp) which is shunted across the oscillator plate coil.

Figure 12 is a rear view of this transmitter and gives you a good idea of the arrangement of the apparatus.

POWER SUPPLY FOR WESTERN ELECTRIC 500-WATT TRANSMITTER

The power supply unit is shown in Figure 13. The driving motor is located on the right and may be of either A. C. or D. C. design as conditions warrant.

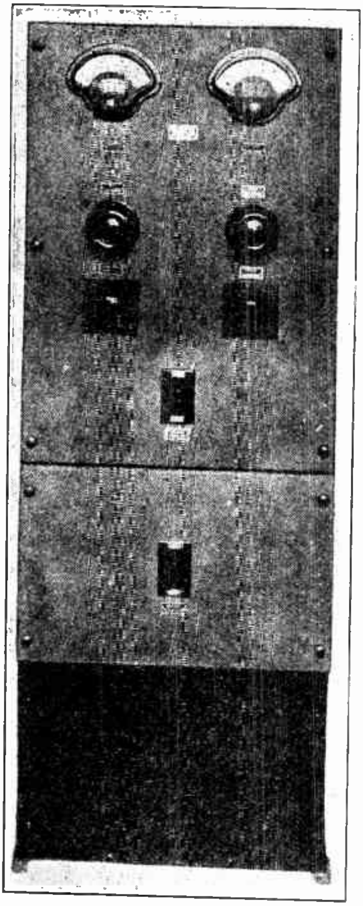

Fig. 14.—Front View of the Power Panel for the Western Electric 500 Watt Set.

The machine in the middle is a 1,600 volt generator having a capacity of 1.25 amperes, for supplying the plates of the tubes. This generator is of similar construction to the one in the case of the first transmitter described. It has two 800 volt armature windings and employs two commutators. The G. E. tubes require a somewhat higher voltage on the plates of the tubes (2,000), hence the plate supply generator has two 1,000 volt armature windings.

The machine at the left is a 16 volt, 30 amp. generator for supplying the filaments. The field current for the high volt-generator is supplied by the low voltage unit which is self-excited.

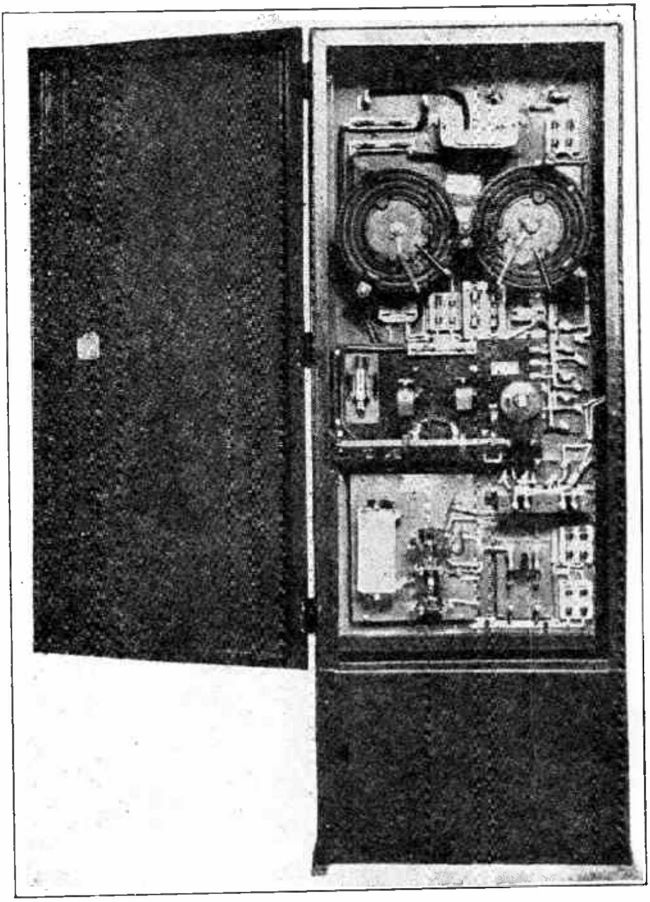

Fig. 15.—Rear View of the Western Electric Power Panel.

It might be noted here that the G. E. 250-watt tubes require 11.0 volts at the filament terminals and 2,000 volts on the plates; whereas, the W. E. 250-watt tubes require 14.0 volts on the filaments and 1,600 volts on the plates.

The front view of the power panel is shown in Figure 14. The filament voltmeter is shown at the top left and the plate voltmeter is shown at the top right. These meters are designated on the schematic as Vf and Vp respectively.

Figure 15 is a rear view of the power panel.

ONE KILOWATT GENERAL ELECTRIC BROADCASTING TRANSMITTER

Figure 16 shows the schematic wiring diagram for a 1 K. W. General Electric type of ship broadcasting transmitter. The power input to this transmitter consists of A. C. at a potential of 110 volts. The frequency may be either 60 cycles or 500 cycles with subsequent changes in the transformer design.

All the desired voltages are obtained by means of transformers and rectifiers with the proper filter circuits.

First of all, the 110 volt supply is stepped up to 25,000 volts by means of the plate transformer. This 25,000 volt winding is tapped at the mid-point and should be grounded on the wire running from the mid-point of the filament transformer to the ground. The extremities of this winding are connected to the plates of two 2.5 K. W. kenotron rectifier tubes, thus supplying a potential of 12,500 volts to each plate. This potential is controlled by means of the primary rheostat (Rp).

Next, the 110 volt A. C. supply is stepped down to 11.0 volts for the filaments of the rectifier tubes. This winding must be insulated for 15,000 volts since it is at plate potential.

The mid-point of this kenotron filament secondary winding is the positive terminal of the 10,000 volt D. C. plate supply. It is connected to the plates of the modulator and oscillator through the filter reactor (Xf) and the modulator reactor (Xm). Two filter condensers (C_1) and (C_2) are used to smooth out the ripple in the rectified supply to the plates. The primary rheostat (Rfk) controls the potential of the kenotron filament supply.

The closed oscillatory circuit is closely coupled to the antenna system through the coupling condenser (Cc). The antenna circuit is tuned by means of the variable inductance (La).

Up to this point we have considered the source of radio-frequency energy. Now we are going to consider the source of audio-frequency energy and the circuits used for amplifying it to the proper value for applying to the grid of the modulator tube.

While it is a comparatively easy task to build electrical equipment for a single desired frequency, the problem is greatly

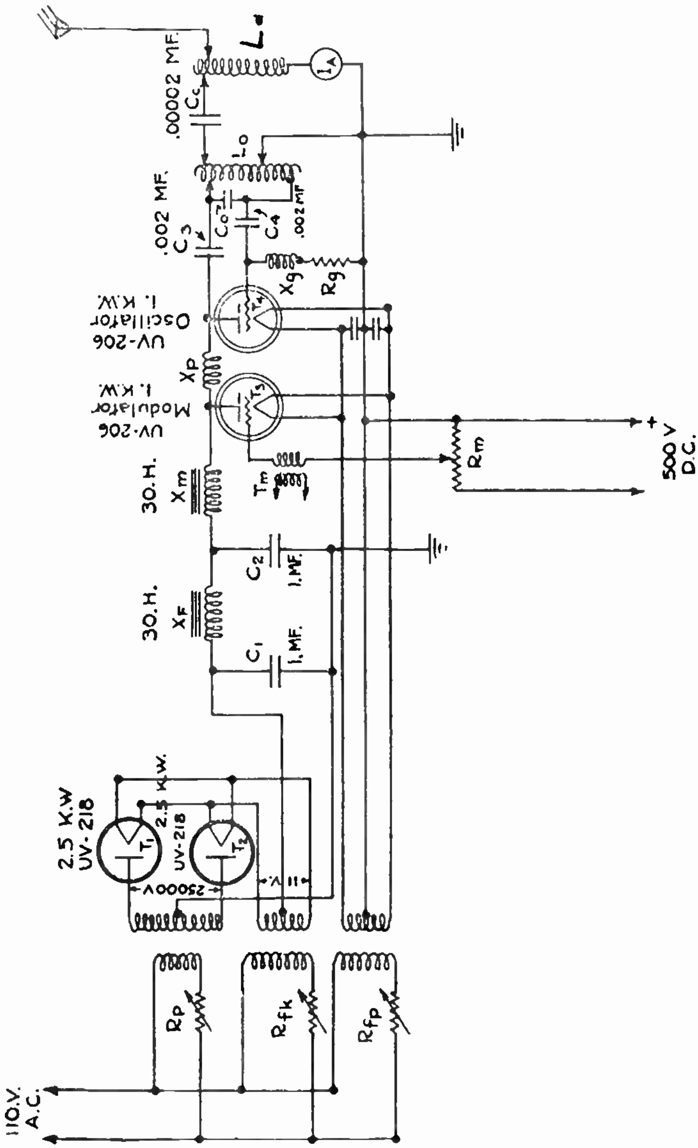

Fig. 16.—Schematic Wiring Diagram of General Electric Co., 1 Kw. Ship Broadcasting Set.

complicated where a large range of voice and musical frequencies are to be handled without distortion. Most of the poor broadcasting today is to be found in the reproduction rather than the transmitting end; and the same care that the builders of broadcasting transmitters employ would permit a more perfect condition to exist in reception.

The standard type of microphone today is the double button carbon, or push pull. This type comes more closely to supplying distortionless signals at all audio-frequencies with the exception of the condenser microphone. As all the faults of the microphone are amplified many times, regular inspection and test should be made to determine its condition. It should be opened and removed from its case only when it has ceased to function properly. If it has been overloaded, it will be found that the trouble is caused by the "freezing" of the diaphragm. This necessitates removal, and cleaning, and if seriously damaged, replacements.

In the studio usually two microphones are installed, one for the announcer and the other for the artist. In large studios where concert orchestras perform, two or more microphones are placed. The announcer's table usually holds a control box, or "mixing panel," whereby he switches the control from himself to the artist. The control room which contains the monitoring equipment is adjacent, and a window is usually placed to enable the operator to follow the studio activities. In the case of remote control, the operator in charge at the distant point must endeavor to supply a constant signal level to the line. In other words correct for the artist who is too near or far from the microphone.

The remote control equipment will be found to usually contain three microphones, the mixing or control panel, a two or three stage line amplifier and necessary batteries. Whereever possible an additional line is installed to which are attached the standard telephone and ringer box in order to enable operating instructions to be given during the period of broadcasting. The control panel is operated by the announcer while the operator devotes his entire attention to maintaining a steady outgoing signal. Figure 17 is a schematic diagram of the general layout for remote control operation.

In the control room of the broadcasting station will be found an equalizer panel and a three or four stage speech amplifier. (See Figure 18). This equipment is usually installed in duplicate not only for the purpose of maintaining constant operation, but in a case of remote control it permits

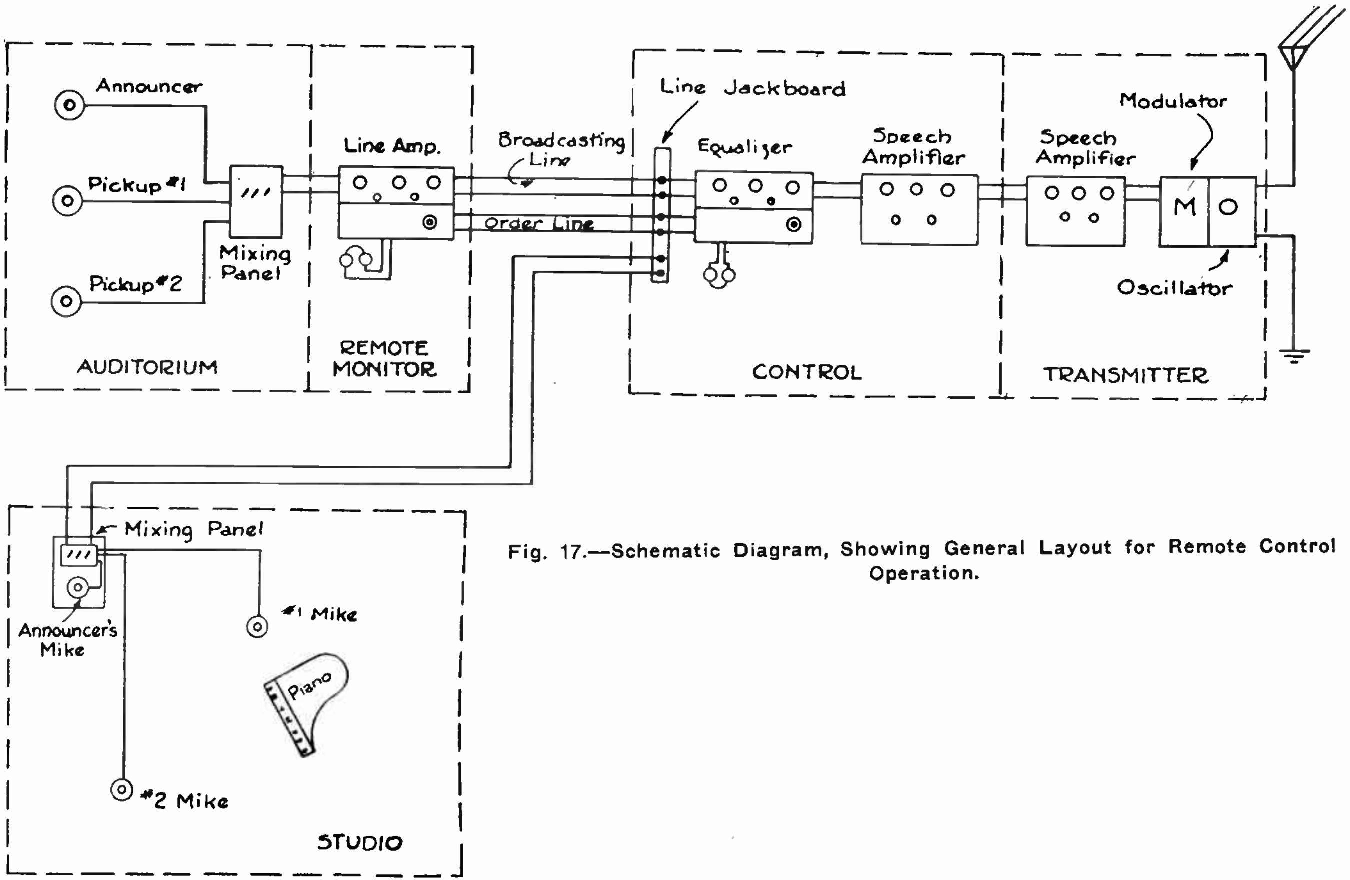

Fig. 17.—Schematic Diagram, Showing General Layout for Remote Control Operation.

the actual hooking up of the circuit previous to changing over from the studio program. In one of the New York stations the monitor panel contains fifteen amplifying panels. The need for so many being due to the large number of remote pick-ups and telephone interconnecting programs.

The equalizer panel contains artificial line circuits whereby a pick-up from a nearby point giving a signal of too great a volume may be reduced to the proper level without sacrificing quality. The artificial line is built of resistance coils and capacity until it similates a line of the desired length; usually twenty miles. Another use of the equalizing panel is that of balancing long lines which have a tendency of cutting off the higher frequencies. In an unbalanced line it is usually found that the lower notes predominate, and it is by use of the equalizer that these are retarded, and higher frequencies strengthened. The growing importance of pick-up programs means that the broadcasting engineer should lay particular stress on this phase of his profession.

Most broadcasting transmitters function best when between 50% and 70% of the carrier is modulated. It will be seen that even in a 500-watt set that our audible frequency current must be amplified many times, and that the results will be dependent upon supplying the modulator tubes with undistorted amplified current from the microphones. Like the broadcast receiver there have been many types of speech amplifiers and similarly they are all good if properly made and skillfully handled. The transformer and choke coupled type predominate due to the fact that fewer stages are necessary. Some stations are equipped with resistance coupled units and with proper care give good results. Figure 19 is a wiring diagram of a standard type of line amplifier.

Line amplifiers differ from speech amplifiers inasmuch as their output does not have to be as high. Two stages of transformer coupling are employed usually and this is more than sufficient for a good telephone or telegraph line. At the studio control room this is fed into a three stage speech amplifier, thence to a 50-watt tube at the transmitting station and then in the case of a 500-watt station to the 250-watt modulator tubes. For the higher power stations there is a progressive arrangement of speech amplifier power tubes starting with the 5 or 7½-watt tubes at the control room and then into a 50, 250, 1 kilowatt, and in the case of the super-power stations a 5 kilowatt, and then a 20 kilowatt water cooled tube. It is a

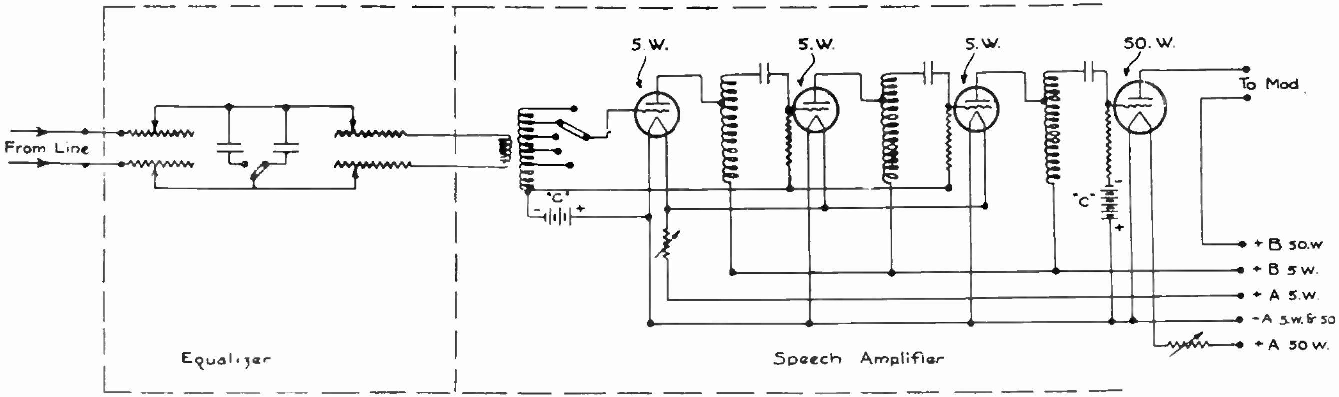

Fig. 18.—Wiring for the Equalizer and Speech Amplifier.

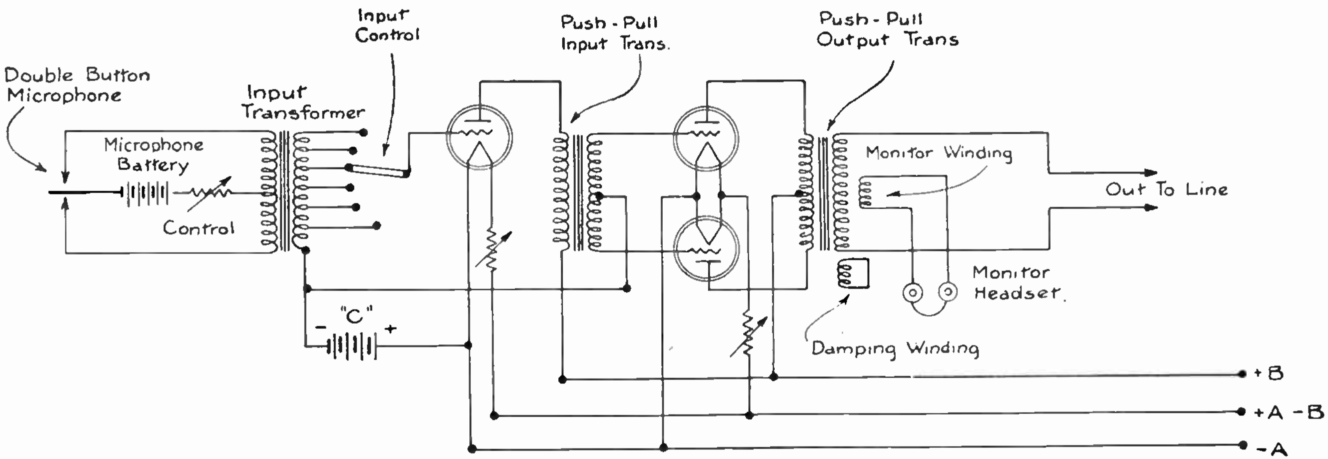

Fig. 19.—Wiring Diagram of a Standard Type of Line Amplifier.

usual practice to have equal modulator and oscillator tubes, and the final speech amplifier tube is about one-fifth of the output of the modulator tubes.

Today it is a general practice to build the transmittng station at some distance from the city that it is desired to serve, and we have the problem in the case of a pick-up program of a double line amplification and final speech amplification at the distant transmitter. This offers no difficulty if the lines are properly balanced between the remote pick-up point, and control room, and again between control room and transmitter. Several pairs are usually provided so that uninterrupted service may be given.

In many stations an instrument called an oscillograph is installed for showing visually the quality and quantity of modulation. The percentage of modulation is the measure by which the transmission station determines the efficiency of the modulating tubes, and is that portion of the carrier wave that is enveloped by the modulating current. The type of oscillograph usually furnished is of the string type; that is the moving element is a metallic string suspended between strong field poles. The incoming signal causes the string to vibrate, and its amplitude is proportional to that of the signal. In order to secure the true wave form it is necessary to employ rotating mirrors which give the proper lateral movement to the string image. There are many ways in which the oscillograph can be employed to advantage in order to determine the distortion not only of the amplifiers but also that of improper placing of the artists and instruments. Each instrument while tuned to a certain frequency will show the proper number of vibrations per second, but not the overtones and harmonics in sufficient amplitude. If an oscillograph is installed the broadcasting engineer should thoroughly instruct himself in its uses so he will have no reason to doubt his hearing.

As has been previously stated the broadcasting engineer will find many types of line and speech amplifiers, but they will all conform to the general layout as described here. In the matter of volume control several stations use a resistance box shunted across both line and speech amplifier. This simply absorbs a quantity of the outgoing signal. Many engineers prefer to control the input of the first tube, and claim that the equality is better. The types shown here are the transformer push pull line amplifier with input control, and the auto choke coupled speech amplifier with a similar volume control. These two types are recognized as probably being of the best type and if properly constructed show the flat frequency curve which is desired.

TEST QUESTIONS

Number Your Answers 38 and add Your **Student Number**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What is the range of frequency required of the amplifier circuits when broadcasting music?
2. Plot a curve showing the intensity of signals around a Broadcasting Station.
3. Draw a typical one-tube circuit to illustrate the theory of operation of the 500-watt General Electric transmitter and state how the plate and grid are coupled to the antenna circuit.
4. Name by letters the tank circuit in Figure 3 and explain its use.
5. Name of a few of the essential operating hints for the General Electric 500-watt transmitter.
6. Explain by reference to Figures 10 and 11 the three control dials for the 500-watt transmitters.
7. Explain in a brief manner the power unit used for the two types of 500-watt transmitters.
8. Give a diagram and brief description of the power supply for the General Electric 1,000-watt transmitter.
9. Show a wiring diagram for the equalizer speech amplifier panels in a broadcasting studio.
10. Draw a diagram and name the essential parts of a standard line amplifier.

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Transmission and Reception of Pictures by Radio

HISTORICAL

Like all forms of communication, the transmission of exact reproductions has risen to commercial application, only after a long period of development and research.

In 1848, Alexander Bain received the first United States patent for a system of picture transmission. This system was crude and unworkable, but it contained the fundamentals of our present-day methods.

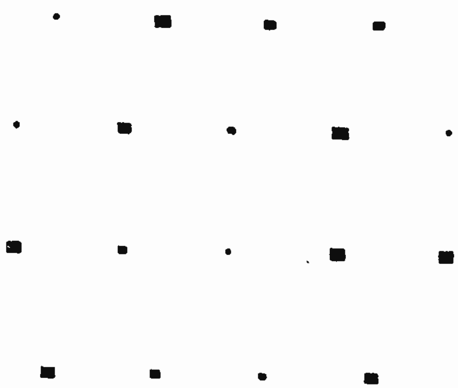


Fig. 1.—Korn Picture Receiving Typewriter Characters. A Nineteenth Character is that of Clear White.

It was not until May, 1891, that N. S. Amstutz, of Valparaiso, Indiana, sent a picture over telegraph wires twenty-five miles in length, accomplishing the first successful transmission.

Professor Korn, of Berlin, Germany, made further improvements and in 1906 transmitted pictures over several hundred miles of telephone wires. In 1908 he succeeded in accomplishing the transmission of pictures by radio.

The Great War, in 1914, forced the abandonment of plans for trans-Atlantic picture transmission, and it was not until 1923 that the development of long distance radio picture transmission was undertaken by various laboratories in the United States again.

The world is eagerly awaiting the inauguration of commercial radio pictures and radio-vision and the fact that the work is going on in earnest cannot be doubted, when it is realized that more than two million dollars per year are being spent in the United States alone in research work along these lines.

Practically all of our communication companies have developed systems for the transmission of photographs, and there are also several foreign systems.

To date some two hundred and forty patents covering the art have been issued, and as many more applications have been filed.

TYPES OF SYSTEMS

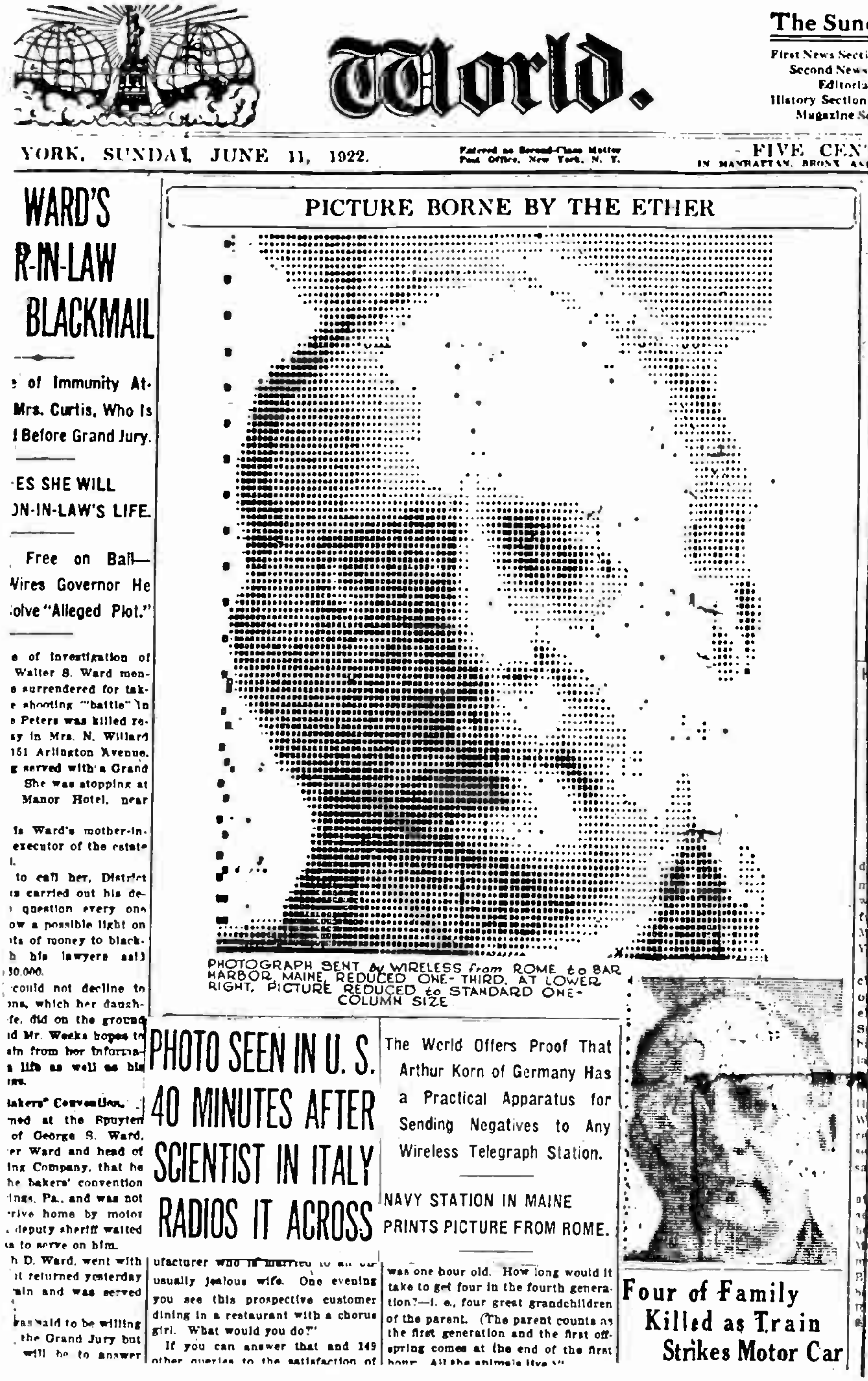
Today there are picture transmission systems working over telegraph, telephone and cable lines as well as over radio circuits. They may be classified under three headings, namely, *coded, dot-dash* and *modulated systems.*

CODED SYSTEMS. THE KORN SYSTEM

In coded systems no direct communication is employed. The picture to be transmitted is first coded by converting it into the form of a message composed of code letters. At the receiving end, the code message, which may be received over any existing telegraph or telephone circuit, is decoded by means of a chart or special decoding machine. Figure (1) shows the characters made by a special picture receiving typewriter for this system of transmission and from this an idea may be obtained as to how the different tonal values, of which the picture is composed, are put down on the recording paper at the receiver end of the circuit.

In June, 1922, the first picture was transmitted across the Atlantic Ocean by radio, (Figure 2). The transmitter was located at Rome, Italy, and the receiver at Bar Harbor, Maine.

This first trans-Atlantic radio picture transmission was accomplished by Professor Korn, by means of the coded sys-



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World.

YORK, SUNDAY, JUNE 11, 1922.

Entered as Second-Class Matter Post Office, New York, N. Y.

FIVE CEN
IN MANHATTAN, BRONX A

WARD'S
R-IN-LAW
BLACKMAIL

: of Immunity At-
Mrs. Curtis, Who Is
l Before Grand Jury.

·ES SHE WILL
ON-IN-LAW'S LIFE.

. Free on Bail—
Wires Governor He
olve "Alleged Plot."

e of investigation of Walter S. Ward men- e surrendered for tak- e shooting "battle" in e Peters was killed re- ay in Mrs. N. Willard 151 Arlington Avenue, g served with a Grand She was stopping at Manor Hotel, near

is Ward's mother-in- executor of the estate l.

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akers' Convention.

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h D. Ward, went with it returned yesterday ain and was served

was said to be willing the Grand Jury but will be to answer

PICTURE BORNE BY THE ETHER

PHOTOGRAPH SENT by WIRELESS from ROME to BAR HARBOR, MAINE, REDUCED ONE-THIRD. AT LOWER RIGHT, PICTURE REDUCED to STANDARD ONE-COLUMN SIZE

PHOTO SEEN IN U. S. 40 MINUTES AFTER SCIENTIST IN ITALY RADIOS IT ACROSS

The World Offers Proof That Arthur Korn of Germany Has a Practical Apparatus for Sending Negatives to Any Wireless Telegraph Station.

NAVY STATION IN MAINE PRINTS PICTURE FROM ROME.

ufacturer who is married to an un- usually jealous wife. One evening you see this prospective customer dining in a restaurant with a chorus girl. What would you do?"

If you can answer that and 149 other queries to the satisfaction of

was one hour old. How long would it take to get four in the fourth genera- tion?—i. e., four great grandchildren of the parent. (The parent counts as the first generation and the first off- spring comes at the end of the first hour. All the animals live ...

Four of Family Killed as Train Strikes Motor Car

Fig. 2.—First Picture to be Sent by Radio Across the Atlantic.

tem. The picture was converted into a regular code message and transmitted, as such, across the Atlantic.

At the receiving end the code message was translated into the original picture by means of the special typewriter having the nineteen characters shown in Figure 1.

Figure 3 shows a sample of the tape that comes out of the printer in the course of transmitting a picture by this system. This tape, which carries the picture in letter form, may be given to any telegraph operator who will handle it in the usual manner employed in the transmission of ordinary traffic.

kk kkxxa qummz xxxx xxrrr rrrxx xxqx xxmmmm

qqqvo ojddd dddd dhjjj jjjj goova mxxrr rrk

Fig. 3—Korn Picture Code Tape as Delivered by a Picture Transmitter. This Tape is Then Transmitted by Manual Operation Where Automatic Radiotelegraph Facilities Do Not Exist.

Where the picture is to be transmitted on an extremely fast radiotelegraph circuit, the picture impulse can be sent

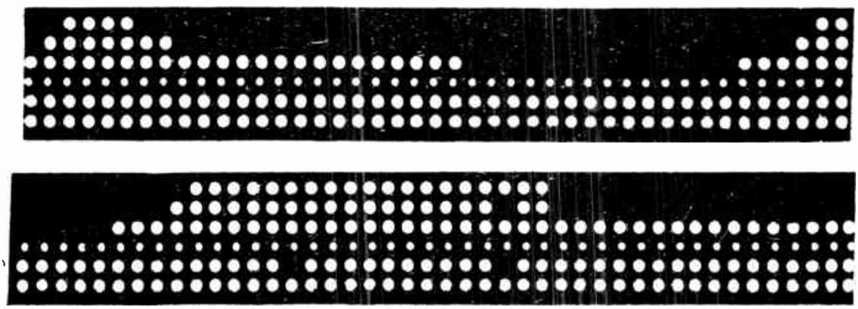


Fig. 4.—Samples of the Baudot Tape Used to Transmit Pictures by the Bartlane System.

directly into the keying circuit of the radio transmitter and when an automatic receiver is used, the transmission of the picture can be accomplished automatically, from start to finish. Where high-grade radiotelegraph circuits are not available, recourse to manual operation must be made.

When the code message is delivered to the operator of the picture receiver, he simply strikes the keys of a hand operated typewriter, whose characters are the eighteen values of picture gradation represented by the squares and dots of varying size, shown in Figure 1. The nineteenth character is "white."

In manual operation, to insure continuity in recording, it is customary to send the number of the line, immediately preceding the line itself.

Looking at the Korn picture shown in Figure 2, notice the similarity to the tonal construction of a newspaper half-tone. This characteristic in Korn pictures, permits their reproduction in newspapers, without putting them through any special process.

CODED SYSTEM. THE BARTLANE SYSTEM

We will now consider the Bartlane method of picture trans-

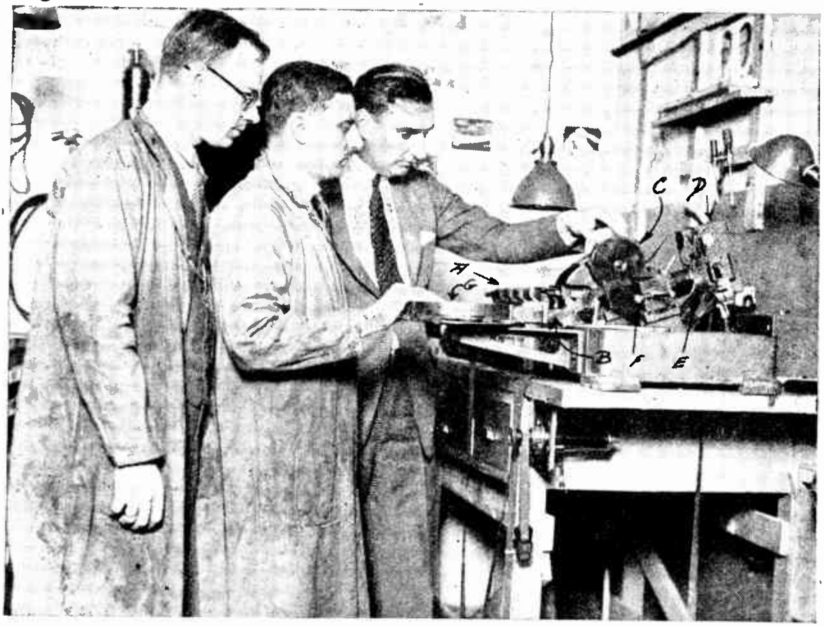


Fig. 5.—The Bartlane Transmitter.

mission which is at present being worked over trans-Atlantic cables, but which can be adapted to radiotelegraphic use.

The name Bartlane is coined from the names of its two inventors, Mr. Bartholomew and Captain MacFarlane, both of the Daily Mirror of London, England.

This system was invented in 1920 and the first trans-Atlantic cable picture was transmitted in 1921, between London and Halifax, N. S. It is like the Korn system, in that it employs the telegraphic typewriter to convert the picture values into those that will fit our standard forms of communication.

The Bartlane system utilizes the telegraphic typewriter to an even greater extent than the Korn system and one of the basic elements is the Baudot Tape.

Figure 4 shows samples of the Baudot Tape as used in the transmission of pictures by the Bartlane system. This type of tape is the one most used by English and American automatic telegraph printer systems. It consists of a central guide hole, three holes on one side of the guide hole and two holes on the other side.

The combination of certain holes, transmits certain impulses, which actuate the typewriter keys at the receiving station. Synchronism is positive and is effected by the central or guide hole.

In transmitting a picture by the Bartlane system, an ordinary photograph of the subject for transmission is made first. With the negative film thus obtained as a basis, five tint plates are made, by allowing five different periods of exposure.

Plate No. 1, for instance, might be exposed for two seconds; plate No. 2, for four seconds, etc. These plates are made of zinc and when they are developed, they will have a certain amount of insulating surface over part of the plate, which is, in effect, the half-tone characteristic. These plates will show an increasing amount of insulating area as the time of exposure, in the process of making the plate, is increased.

These five tint plates are attached to a rotating cylinder which is motor driven and synchronized with the tape punching equipment. Each of the tint plates has an electrical contact finger which operates its particular punch magnet, when a part of the tint plate having no insulating surface, touches the contact finger. In each unit length of tape, there is a space in which each of the five punches, operated by the contact fingers functioning on the five tint plates, may make a hole.

From the foregoing explanation you can get an idea how the tonal values that make up the picture for transmission, are changed into electric values by the contacts on the tint plates, and are then registered on the transmitting tape.

When there is a clear spot on all five tint plates, the contacts, "making" the circuit through the five punch magnets, will be closed and five holes will be punched in the transmitting tape.

As the cylinder is rotated spirally, all sections of the picture will eventually be passed over, and its respective shade punched in the tape. By use of this tape, signals will then be transmitted over the regular wire or radio printer circuit and on the receiving end will actuate what is termed a "reperforator." Figure 5 shows the arrangement of the Bartlane picture transmitter.

The "reperforator" is a machine which receives the incoming electrical impulses and translates them back into a tape that should be the exact duplicate of the transmitting tape.

In the receiver, a beam of light is focussed upon the tape as it is passed through. The amount of light that is permitted

Fig. 6.—Picture Transmitted and Reproduced by the Bartlane System.

to pass through this tape, is, of course, determined by the number of holes in the path of the beam of light.

This light after passing through the tape is focussed on a photographic film which is inside a light tight box. This film is wrapped around a cylinder which is the same size as the transmitter cylinder and its speed is regulated by means of the central synchronizing holes in the received tape.

A summary of the action involved shows that the picture for transmission is obtained in the form of a negative photographic film; five tint plates are made from this film and the picture is recorded on a transmitting tape, the five holes in the tape representing five different tonal values. Signals are transmitted to the receiver by means of the tape, these signals being translated back into the form of a tape again. Each of the five unit holes in the tape registers a definite tonal value on a recording film by means of a beam of light which is focussed on the tape as it passes through the receiving apparatus.

The outstanding features of the Bartlane system, are, *first*, automatic transmitting and receiving; *second*, the use of standard automatic telegraph tape; *third*, automatic synchronizing by means of the guide holes, and last, the transmission may be speeded up by breaking the tape at different points and transmitting the various sections thus obtained, over several channels, rejoining them before they pass through the picture receiver.

MODULATED SYSTEMS

Modulated systems are arranged to transmit pictures using signals of modulated character. Three methods will be explained, representative of the three different ways of producing modulated photographs. These three systems are the Belin Telestereograph, the Jenkins' method and the Phono-Photo, the latter being an invention of E. H. Hansen.

MODULATED SYSTEMS. THE BELIN METHOD

The Belin method, invented in 1908, was primarily designed for use on land lines. It was not used over radio circuits until 1922.

In the Belin system what is termed a "relief" cylinder, is used to carry the picture for transmission, rather than the varying light method produced by shining a light through the transmitting film, as in the cases of the transmission systems previously described.

The relief cylinder is made by taking an ordinary negative film, and printing through it, with a strong light, on a carbon-gelatine-bichromated paper. Upon development, the gelatine is swollen, due to the fact that the printing has baked the clear parts, hard, permitting the places where no light struck, to become soluble in water.

This print is transferred to a brass transmitting cylinder, and permitted to dry. When dry, it will be found that the lighter shades have practically no relief, and are down to the brass itself, while the darker tones attain a height proportional to their photographic value. The overall relief is some five thousandths of an inch.

Pressed against the cylinder, is a stylus, similar to a phonograph needle. This stylus rises and falls as it passes over the rotating cylinder, and this motion is transferred to the diaphragm of a microphone. The microphone is of the carbon granule type with a very thin diaphragm. Very little resistance, therefore is offered to the needle, thus preventing the scratching of the relief cylinder. As the diaphragm of the microphone moves up and down, the internal resistance of the microphone changes in accordance with these vibrations and a current, modulated in character, is produced in the microphone output circuit.

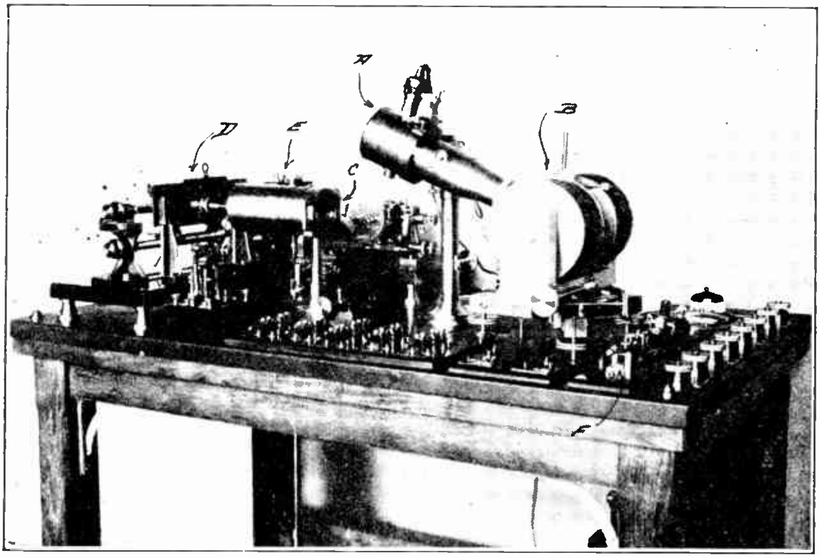


Fig. 7.—Belin Transmitter and Receiver.

The modulation frequency, which we may call "picture frequency," is very low, being from one to one hundred cycles. This frequency would be very inefficient if introduced directly into the modulating circuit of a radiotelephone transmitter so it is first used to modulate the output of a six hundred cycle tuning fork, which in turn, modulates the radio-frequency carrier wave.

These radio signals are received by an ordinary radio receiver, care being taken to provide for an efficient audio-frequency amplifier for the six hundred cycle modulation frequency.

In the output circuit of the audio-frequency amplifier, there is a step-down transformer to step down the voltage and step up the current for maximum effect upon the armature of the receiving oscillograph.

MODULATED SYSTEMS. THE JENKINS' METHOD

In the latter part of 1922, the first radio picture was transmitted by the Jenkins' system. This picture was transmitted

Fig. 8.—Reproduction from Transmitted Picture by the Belin System.

from the inventor's laboratory in Washington, D. C., to his home, located in the same city.

The outstanding feature of the Jenkins' system is the use of a prismatic ring for analyzing the surface of the picture to be transmitted. A beam of light, when passed through a rotating ring of this type, is caused to oscillate, having its hinged section, or line of action, fulcrumed, in the plane of rotation of the prism ring.

The oscillation is always in the plane of the diameter of the disc, from the point where the light passes through the prismatic ring section.

By the use of two of these rings, a beam of light can be thrown up and down, and from one side to the other. If both transmitter and receiver rings are rotating synchronously, the receiver beam will always be in the same part of the picture as the transmitter.

By means of a projection lantern and a transparent negative, the transmitter analyzes, or slices, the picture, and passes the beam of light from the source, on through to a photoelectric cell. This cell is arranged so that it converts the light variations impressed on it into electric energy, which in turn

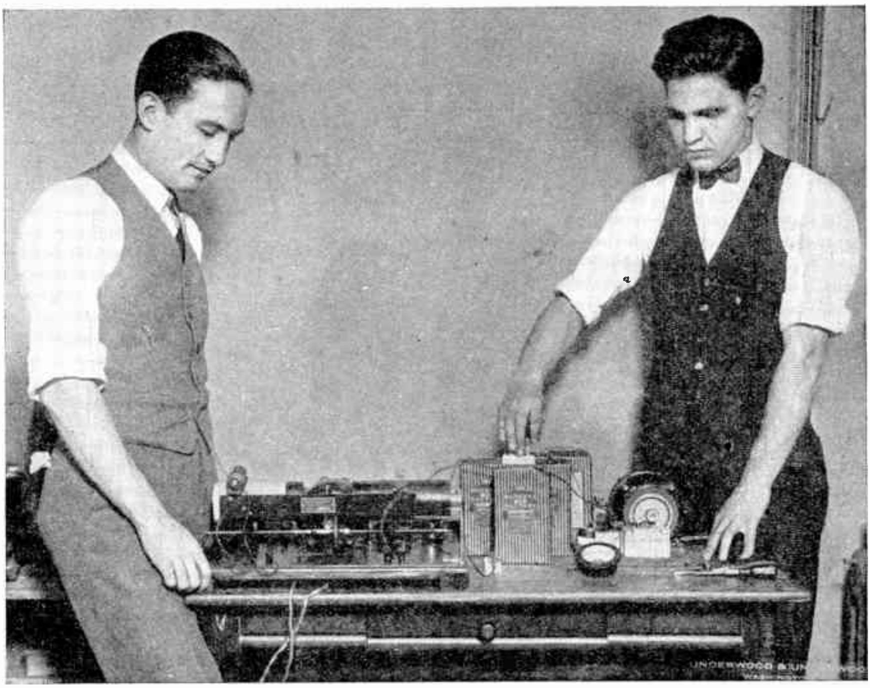


Fig. 9.—Jenkins' Small Machine for Sending Photos by Radio.

modulates the carrier-wave of the transmitter just as the voice frequency modulates the carrier-wave in radiotelephony.

The signals picked up at the receiver are applied to a pneumatic oscillograph, which reflects a beam of light through a set of prismatic rings. The rings allocate the light to its proper position on the flat recording plate.

The pneumatic oscillograph is a very clever invention of Jenkins' and is simply a radio headphone, with a mirror mounted in a small cap opening. The air pressure caused by the displacement of the diaphragm, causes the mirror to move and the beam of light is correspondingly shifted.

Synchronizing in the Jenkins' system is accomplished by synchronous motors driving the prismatic rings. In circuits where the transmitter and receiver cannot be supplied with the same alternating current for driving these synchronous motors, small dynamotors are used, their speed being maintained constant by electrically driven tuning forks.

The contacts of these forks are placed across the A. C. end of the dynamotor. Since both the fork and the A. C. generator have the same frequency, any attempt of the D. C. motor to speed out of phase, is checked by the torque of the coupling shaft of the A. C. machine.

A "Radio pen" which writes and draws pictures, tracing exactly the same lines as those laid down by a distant hand, is another device invented by C. Francis Jenkins, Washington, D. C.

MODULATED SYSTEMS. THE PHONO-PHOTO METHOD

This system, invented by E. H. Hansen, was first used in the transmission of pictures by radio, from the inventor's laboratory in New Jersey, to the New York Offices of the New York World.

In the modulated type of radio picture transmission systems, the results obtained are dependent upon keeping the received signal level, at a nearly constant value. The picture gradation depends upon the degree of modulation of the received signals.

In the Phono-Photo method, the modulation is accomplished by actually varying the transmitting wave-length. The receiving station is equipped with a radio receiver and separate heterodyne, set at a middle or mean value, and the transmitter varies the frequency from one side to the other of this middle frequency point. Thus, the received signal is of varying frequency characteristic rather than of varying intensity.

The transmitter consists of a cylinder, upon which is placed a black and white print instead of the negative film, ordinarily used in picture transmission systems.

A beam of light is focussed to a point on the print, which reflects an amount of light dependent upon the tonal value of the picture at that point. This reflected light is passed on to a light-proof box, within which is the photo-electric cell.

As the transmitting cylinder rotates, the spot of light passes over different sections of the print attached to the transmitting cylinder. Different values of light are reflected to the photo-cell and it changes these varying light values into varying values of electrical energy.

These varying electric currents in the photo-cell output circuit are amplified and used to control a solenoid operated condenser which is connected in the tuning circuit of the radio transmitter. This automatically variable condenser is applied in the master-oscillator tuning circuit of the type of radio trans-

Fig. 10.—Sample Picture Obtained by Jenkins' Method.

mitter employing a master-oscillator to control the frequency of the currents in the output circuit of the power amplifier tubes.

One of the advantages of this method is that it permits the full oscillator efficiency of the transmitter to always be employed instead of modulating the output as in the previous methods described.

The radio receiver is tuned to one frequency and the incoming signals of varying radio-frequency, subsequently set up signals of varying audio-frequency, in accordance with the varying light reflected from the transmitting print.

These received signals are applied to the coils of an oscillograph which actuates a mirror. The mirror reflects light on a sensitized recording film. The amplitude of the mirror varies in accordance with the frequency variations in the incoming signals and it is easy to see how the intensity of the signal output from the radio receiver would vary as the incoming frequency was the same or different from that to which the radio-frequency circuits of the receiver were tuned.

It will be noted, that although this system is classed as a modulated system, it is a frequency operated system, and is about thirty per cent more efficient, with a transmitter of a given capacity than the other modulated methods described.

Synchronism is obtained in this system by means of local chronometer circuits which actuate magnetic clutches. By means of commutators, the clutches traveling slightly faster than one revolution per second, are disengaged, and upon receiving the second impulse from the chronometers, are re-engaged. Phasing arrangements are provided, in order that daily corrections may be made, at either the transmitting or the receiving station.

Figure 12 is a sample of a picture that was sent by radio by the Phono-Photo method.

DOT-DASH METHODS. THE TELEPIX SYSTEM

The dot-dash method is the most reliable for operation over great distances. One of the systems of this method was inaugurated, in the United States, in 1923. It is called the Telepix system and is the invention of Ferree and Wisner, of Chicago, Illinois.

The transmitter consists of a motor driven cylinder which carries the picture to be transmitted, in the form of an insulating photograph, upon a copper plate. This plate is made by first obtaining a photograph negative and then obtaining a positive from it. A screen, having horizontal ruled lines upon it, is placed in front of the negative during the process of making the positive.

This positive, which looks like a picture composed of ruled lines, is then placed in a printing frame with a copper plate which has been sensitized with a coating of bichromated fish glue.

After being exposed for a suitable length of time, the plate is developed and when this operation is complete, the picture is represented on the copper plate, by horizontal insulating lines of varying width.

The copper plate thus obtained, is then wrapped around the transmitting cylinder and a contact arm swung into place. The cylinder is rotated and as the contact moves over the insulation and the copper, dashes of varying length are transmitted for each of the horizontal lines passed over. A lateral

Fig. 11.—C. Francis Jenkins and His Device, "The Radio Pen."

movement is imparted to the cylinder by means of a screw feed. This gives approximately thirty-two lines per inch. The dashes sent out from the picture transmitter operate the control relays at the radio transmitting station and radio-frequency energy is sent out, in the form of dashes of varying length.

At the receiving station, there is a relay which controls a current supply to the recording cylinder. The recording cylinder is similar in size and shape, to the transmitting cylinder, and carries a saturated paper sheet. The two leads carrying the current supply to the recording cylinder from the receiver relay are connected to the metallic cylinder, under the saturated paper, and to the contact arm which rests on the surface of the paper.

Whenever current passes from the contact arm, through the paper, to the metallic cylinder, electrolytic action takes place and the recording paper is discolored at this point, due to chemical action taking place in the solution with which the recording paper is saturated.

Synchronism is accomplished by means of impulses sent over the signalling circuit. These impulses operate friction clutches at the receiver in a similar manner to that described in the Belin process.

Figure 13 is a picture of the Telepix transmitter and receiver.

THE PHOTO-RADIO SYSTEM OF THE RADIO CORPORATION OF AMERICA

The system developed by the Radio Corporation of America for the transmission of pictures by radio, is called, "Photo-Radio." It is the invention of Captain Richard H. Ranger, one of the company's designing engineers.

Captain Ranger started on the problem of transmitting pictures by radio, late in the year 1922. Two years later, in November, 1924, the results of his work were manifested in the successful transmission of pictures by radio, from London to New York.

At the present time, the R. C. A. has a practical method of transmitting pictures by radio. Since it is one of the foremost radio picture transmission systems, and in view of the fact that this part of the course has to do, primarily, with "Radio Pictures," we shall allocate more space to "Photo-Radio" than to any of the other various picture transmission systems.

Figure 15 is a drawing of the fundamental elements in the "Photo-Radio" transmitter. First, we have a concentrated source of light (A), the light rays from which pass through the condensing lines (B). This keeps the rays from spreading out and passes then on to the deflecting lens (D) which is inside the glass cylinder (C).

At (D), the light rays are bent through an angle of ninety degrees and directed at the focusing lens (E). According to the diagram, the light rays from the source (A) pass through the open end of the glass cylinder at (x) and out through the glass wall of the cylinder at (y).

The lens (E) focuses the rays of light on a minute aperture (G), within the dark box (F). This small aperture is about one sixty-fourth inch square. The light passing through here strikes the deflecting mirror (H), which bends the rays through an angle of ninety degrees and passes them

Fig. 12.—Sample of Picture Transmitted by Phono-Photo Method.

out of the dark box at (I), and on to the photo-cell box, within which there is a sensitive photo-electric cell.

THEORY OF OPERATION

Let us assume that there is an important athletic event taking place in London, England, and it is desired that a picture of the victor, in the act of winning, be available in New York, as soon as possible, after the completion of the event.

A picture of the event is taken with an ordinary newspaper man's camera. The film thus obtained is developed and attached to the glass cylinder (C). Either a negative or a positive film can be used, although a positive is preferred. For this particular type of equipment, the five by seven inch size gives the best results.

When the film is in place, the light (A) is turned on as is the main driving motor. The rays from the source of light are concentrated in a minute spot of very high brilliancy, at the point (y), where they pass through the glass walls of the cylinder and the film which is attached thereon.

If the dark box remained in one position, the mirror (D) would remain stationary and the spot of light concentrated on the film would also stay in the same place. The dark box does not remain in one position—it moves back and forth on the tracks (K), at a leisurely rate of speed, in a horizontal direction.

The mirror (D) always has the same relative position with respect to the focusing lens (E) so it follows, that as the dark box moves back and forth, the concentrated spot of light, whose position is controlled by the mirror (D), moves back and forth across the film which is attached to the surface of the glass cylinder.

Starting at the beginning of a cycle of events, we will consider the dark box at the extreme left of its movement in that direction. It now starts to move towards the right and as it does so the little spot of light moves horizontally across the surface of the film on the cylinder until it reaches the extreme right of the film.

At this point, the direction of motion of the dark box and of the spot of light is reversed and the cylinder, with film attached, is moved 1/120 inch in the direction of rotation. Now the spot of light moves back across the surface of the film, on a line 1/120 inch below its path from left to right.

At the end of the stroke from right to left, the direction of travel of the spot of light is reversed, the cylinder steps ahead 1/120 inch and a new portion of the film is covered by the light spot.

In this manner, the entire film is covered by the spot of light.

If there were no film attached to the surface of the glass cylinder, the beam of light passing through the cylinder and reaching the focusing lens, would always have the same brilliancy. However, the film attached to the surface of the cylinder, is dense in some places and thin in others, thus the beam of light passing through it varies in intensity.

The translation of the picture into light values is the first step in the transmission of pictures by radio. The thinner the film, the greater the amount of light that gets through; the denser the film the less the amount of light that gets through. Hence we have the different degrees of film density translated at this point, into terms of light values of different degrees of intensity, each light value reperesenting a definite film density.

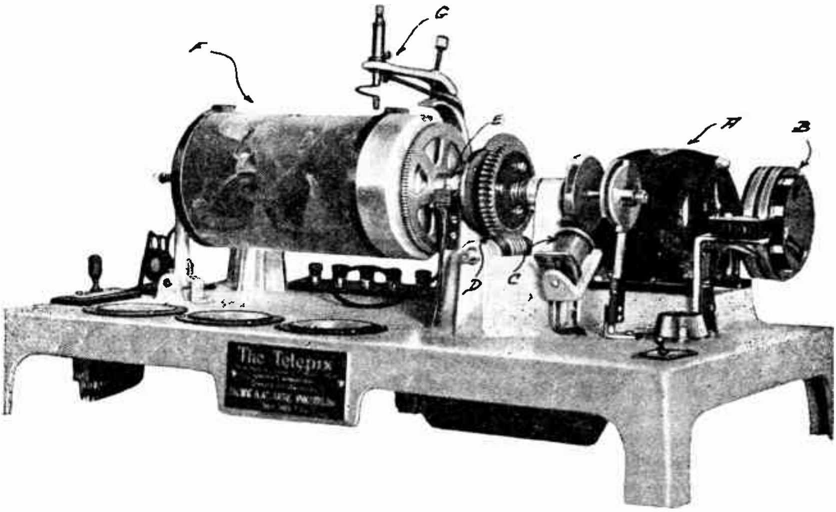


Fig. 13.—Telepix Transmitter and Receiver.

These varying light values are focused on the aperture (G), deflected by the lens (H) and enter the photo-cell box where they strike the sensitive surface of the photo-cell within.

We have translated the original film into light values but we can't send these light values very far and must eventually get them in terms of electricity if we wish to control the output of a radio transmitter.

The photo-cell is the device which is used to change the light values into electric values. The potassium type of cell is used, the selenium cell being too sluggish for picture transmission work. Fundamentally, it is a two electrode tube whose impedance can be made to vary in accordance with the amount of light shining on its sensitive surface.

In operation, it is kept inside of a dark box, isolated from all light, except that which comes to it through the film. With no light shining on it, the impedance of this tube is infinitely high and no current flows between the two electrodes, even though there is a high potential applied to the anode of the cell.

When light reaches the sensitive area within the cell, the impedance decreases to a certain value and there is a flow of current in the photo-cell output circuit due to the high potential applied to its anode.

The more light reaching the photo-cell, the greater the current flow in the photo-cell output circuit. However, even the maximum flow of current in the photo-cell output circuit is very small. In actual operation, if the photo-cell output current reaches 1. micro-ampere when the maximum amount of light strikes its sensitive area, this is quite sufficient for satisfactory results.

This, then, is the second step in the transmission of pictures by radio, the changing of the varying light values into varying electric values.

These minute currents are amplified by means of vacuum tubes and made to modulate the output of a 40 cycle oscillator. This oscillator, unmodulated, operates its output relay at the rate of 40 dots per second. A graphical record of the relay operation shows that its marking and spacing contacts are closed within an equal interval of time.

The Amplified currents from the photo-cell circuit modulate the output of this relay. The whiter or thinner the positive film on the transmitting cylinder, the greater the amount of light that gets through to the photo-cell, the greater the amount of current in the photo-cell output circuit, and the greater the spacing and the less the marking in the relay output.

This means that when there is a lot of light coming through the film, the output relay is making very light dots few and far between. When the maximum amount of light (the thinnest spot in the film), gets through to the photo-cell, the output relay doesn't go over to marking at all but remains on spacing.

When the beam of light from the source is passing through denser portions of the film, less light reaches the photo-cell, there is less current in the photo-cell output circuit and the oscillator output relay makes longer dashes with less spacing between them.

When the minimum amount of light is arriving at the photo-cell (due to the beam passing through the darkest portion of the film), the oscillator output relay remains on marking all the time.

This, then is the third step in the transmission of pictures by radio; the changing of the varying currents in the photo-cell output circuit into dots and dashes of varying length and frequency.

Fig. 14.—Sample of the Transmitting Plate for the Telepix System.

The photo-transmitter output relay puts polarized direct current on the control line to the transmitting station. (By polarized current we mean that the tongue of the relay is connected to the grounded neutral of a commercial 220 volt D. C. supply; the marking contact of the relay being connected to the positive 220 and the spacing contact to the negative 220 volt terminal. When the tongue of the relay is on marking, current flows down to the transmitting station in one direction and when the tongue of the relay is on spacing the control current flows in the opposite direction.)

These bidirectional direct current pulses control the output relays of the radio transmitter, and dots and dashes are sent out into the ether in the form of radio waves.

For transatlantic and transcontinental work, 200 K. W. radio transmitters are used. These stations are normally used in the transmission of long distance radiotelegraph traffic. When it is desired to send out a picture, the control is simply switched from the telegraph operator to the photo-transmitter. The high power radio station of the Radio Corporation of America, at Rocky Point, Long Island is used for this purpose. It puts around 500 amperes of radio-frequency current in the antenna.

These picture signals in the form of radio-frequency dots and dashes are picked up at a radio receiving station which has apparatus tuned to the wave-length on which the picture signals are transmitted. A station equipped to receive these signals has been built by the Radio Corporation of America, at Riverhead, Long Island. Here the radio signals are picked up on the receiving antenna, amplified, heterodyned, detected, amplified and sent in to the offices of the R. C. A., New York City, in the form of audio-frequency dots and dashes. These dots and dashes sound about the same as the dots and dashes that are made by opening and closing a 1,000 cycle buzzer circuit.

These audio-frequency dots and dashes are amplified at the New York end of the line, rectified, and applied to a push-pull relay as unidirectional direct current pulses. This relay changes the picture signals to bidirectional direct current pulses and as such, they are applied to the coils surrounding the armature which is attached to the recorder pen. The recorder pen moves up and down in synchronism with the dots and dashes, leaving a visible record of the incoming signals on the receiving paper.

A pen carriage moves back and forth, horizontally, in synchronism with the dark box carriage at the transmitter. At the end of the travel of the pen carriage in one direction, the paper roll advances 1/120 inch. The picture is unfolded at the receiver, taking about 6 minutes to each linear inch of picture.

The spot of light moves across the thin portions of the

ART NUMBER

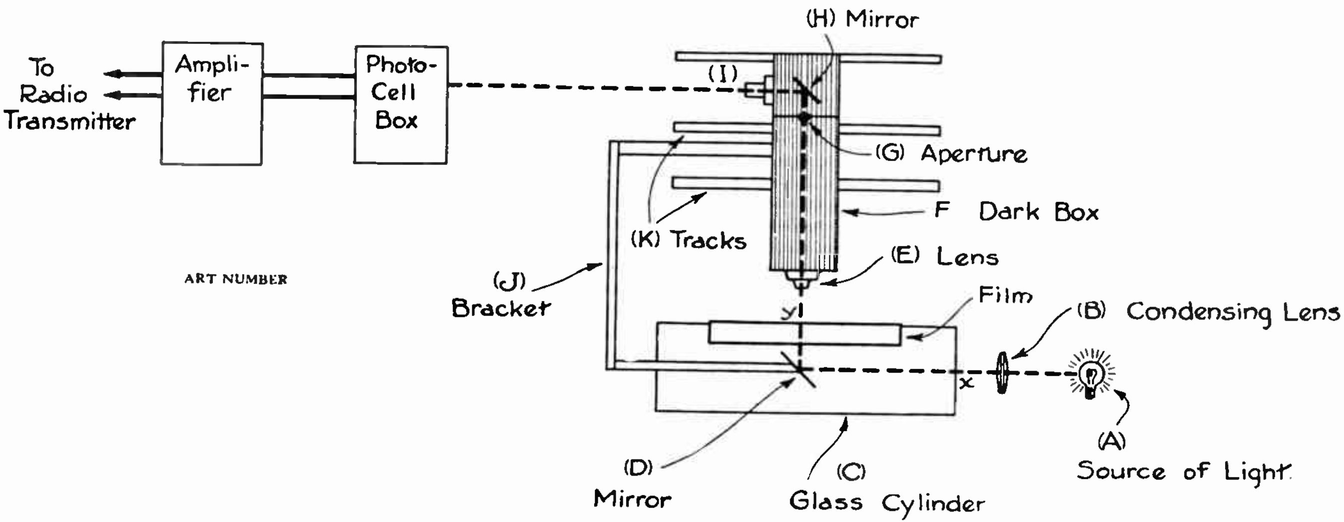


Fig. 15.—General Arrangement of the Fundamental Elements in the Photo-Radio Transmitter.

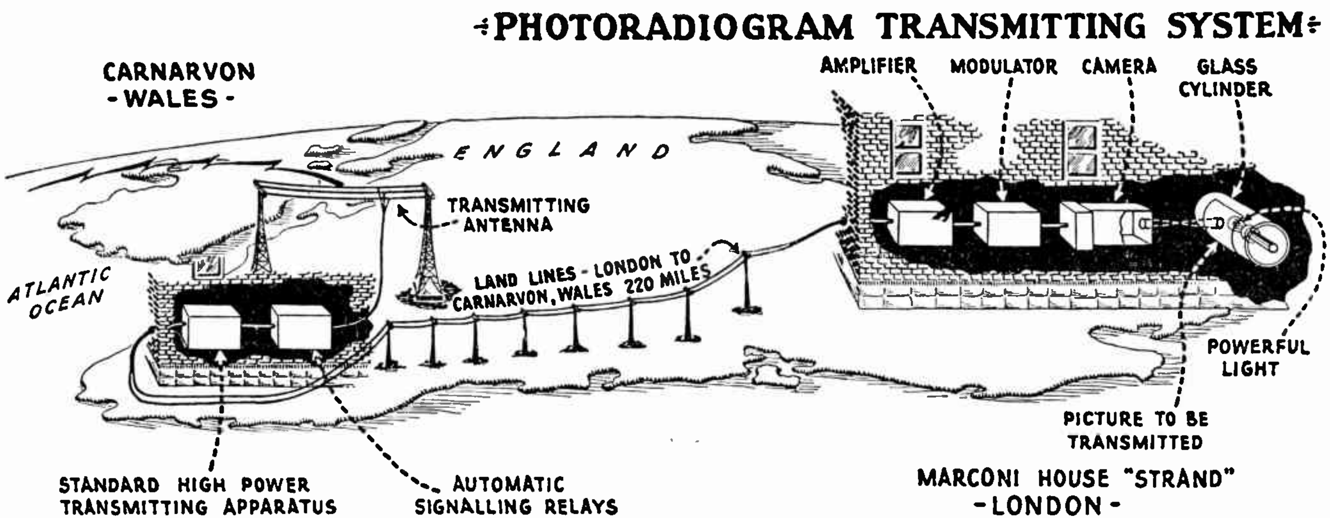
transmitting film and the incoming pulses at the receiver cause the recorder pen to make light dots as the carriage moves across the width of the recorder paper. As the denser parts of the transmitting film are covered by the light spot, the recorder pen makes long dashes as it travels across the paper.

Fig. 16.—Reproduction of Picture of Ex-President Coolidge, Transmitted from London, England, to New York City.

Normally, the recorded pen is not in contact with the paper; it is the signal currents passing through the armature coil that cause the pen to be pulled down against the paper.

One novel feature of the recording of the picture is that

(Continued on Page 27)



PHOTORADIOGRAM TRANSMITTING SYSTEM
CARNARVON
- WALES -
ENGLAND
TRANSMITTING ANTENNA
ATLANTIC OCEAN
LAND LINES - LONDON TO CARNARVON, WALES 220 MILES
AMPLIFIER
MODULATOR
CAMERA
GLASS CYLINDER
POWERFUL LIGHT
PICTURE TO BE TRANSMITTED
STANDARD HIGH POWER TRANSMITTING APPARATUS
AUTOMATIC SIGNALLING RELAYS
MARCONI HOUSE "STRAND"
- LONDON -

Fig. 17

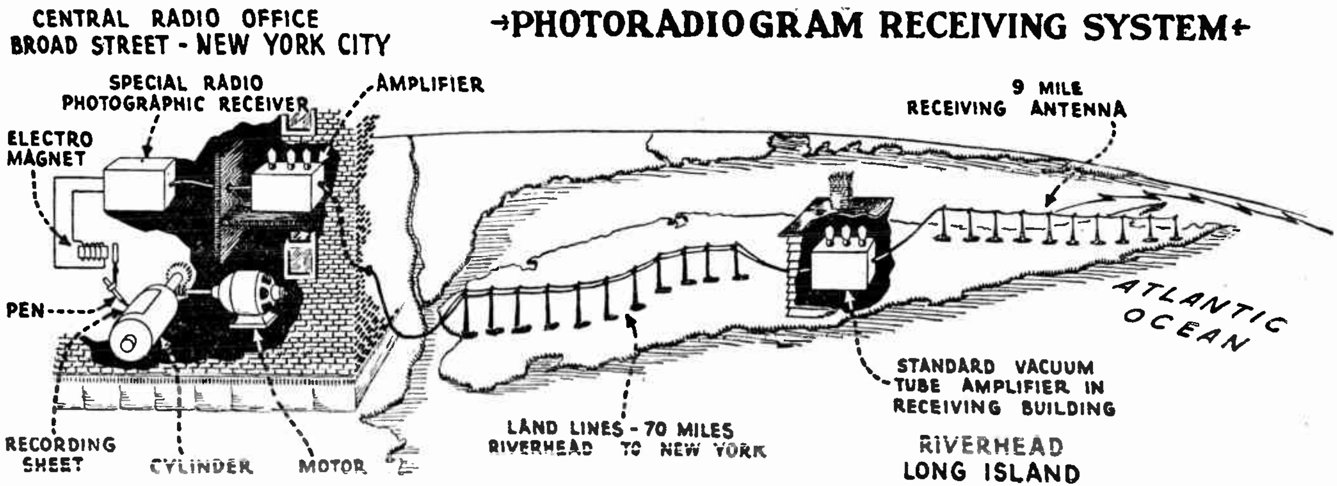

→PHOTORADIOGRAM RECEIVING SYSTEM←
CENTRAL RADIO OFFICE
BROAD STREET - NEW YORK CITY
SPECIAL RADIO
PHOTOGRAPHIC RECEIVER
AMPLIFIER
ELECTRO
MAGNET
PEN
RECORDING
SHEET
CYLINDER
MOTOR
LAND LINES - 70 MILES
RIVERHEAD TO NEW YORK
9 MILE
RECEIVING ANTENNA
STANDARD VACUUM
TUBE AMPLIFIER IN
RECEIVING BUILDING
RIVERHEAD
LONG ISLAND
ATLANTIC
OCEAN

Fig. 18.

(Continued from Page 24)

the record is made in wax, not ink. The pen is fed with colored wax from a little wax-well, which looks much the same as an ink well. A small heater coil is incorporated within the well to keep the wax in the liquid state.

It was found with the ink method, previously employed, that, due to the carbon in the ink, if the receiver was left shut down for any considerable period of time (a few hours), the pen would be clogged up when the receiver was again started up. Even during operation, the pen was quite apt to clog or run dry, thus spoiling the picture.

The wax method of recording removed a source of trouble due to clogging pens. A receiver could remain idle for a week, then when it was started up again and the wax heater coil turned on, the wax would thaw out and flow freely. As soon as the wax is deposited on the recorder paper it returns to the solid state and there is no danger of its running.

SYNCHRONISM

Obviously, one of the basic elements of success in the transmission of pictures by radio is the absolute synchronism between transmitter and receiver. The spot of light that moves across the transmitting film must reach the end of its travel in one direction at exactly the same instant that the recorder pen at the receiver reaches the end of its travel in the same direction.

Synchronism is effected by having driving motors, for the moving elements of the transmitter and the receiver, that run at exactly the same speed. This speed in each case is maintained constant by means of a tuning fork. Hence, constant speed tuning fork controlled motors are used at both the transmitter and receiver. Auxiliary apparatus is connected in such a manner as to afford an automatic check on the constancy of the speed of the driving motor. Any discrepancies are taken care of by a small correction motor which functions on the main motor drive shaft.

RADIO PICTURES FROM LONDON TO NEW YORK

The first public demonstration of the working of this system of picture transmission was held on Sunday, November 30, 1924, at the offices of the engineering department of the Radio Corporation of America, New York City, where pictures transmitted from the offices of the British Marconi Company in London, by radio, were received.

Figure 16 is a copy of the first picture to come by radio from London. Figures 17 and 18 show, schematically, the circuits involved in the London to New York picture transmissions.

The photo-transmitter was located at the London offices of the British Marconi Company. The pictures to be transmitted were translated from the original films into light values, then into electric values and as such were put on the 220 mile land line to the radio transmitting station at Carnarvon, Wales. Here, the picture signals in the form of direct current pulses were made to actuate the output relays of the radio transmitter. The signals were sent out into the ether as radio-frequency energy, on a wave-length of 14,000 meters.

The signals from England were picked up at Riverhead, Long Island and relayed to New York over a 70 mile land line. At New York, they were applied to the photo-receiver equipment, which translated them into pictures.

SUMMARY

Before closing the discussion on this system, let us summarize the action that takes place in the transmission of a picture from one point to another by radio.

The subject is first photographed, the film thus obtained is attached to the transmitter cylinder, the film is translated into terms of light values, the light values are changed into electric values and modulate the output of an oscillator or dot-maker. These bidirectional direct current dots and dashes operate the output relays of a radio transmitter, hence they are changed into radio-frequency dots and dashes (C. W.)

These radio-frequency dots and dashes are picked up on a receiving antenna and are amplified, heterodyned, detected, amplified, rectified, changed from unidirectional direct current pulses to bidirectional direct current pulses and as such are applied to the recorder pen on the "Photo-Radio" receiver.

TEST QUESTIONS

Number Your Answer Sheet 39 and add Your **Student Number**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Give the three classifications for transmitting pictures by radio.
2. Name the outstanding features of the Bartlane system.
3. Describe in a brief manner the underlying principles of one modulated method of sending pictures.
4. Explain how the picture frequency in the Belin system modulates the carrier wave.
5. Describe the action of the Photo-Electric cell in the Jenkins' system.
6. What is the usual method of synchronizing the receiving apparatus in the Jenkins' system?
7. Explain the essential feature of modulation in the Phono-Photo method by E. H. Hansen.
8. How is the picture recorded in dot-dash method by the Telepix system?
9. Show by a drawing the fundamental elements of the Photo-Radio transmitter.
10. What type of current is used to operate the control line to the transmitting station?

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TRANS-ATLANTIC RADIOTELEPHONE AND RELAY STATIONS

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TRANS-ATLANTIC RADIOTELEPHONE STATIONS

We are all acquainted with the various efforts put forth by broadcasting stations in the past three years to span the Atlantic with their respective programs. The results have invariably been the same—namely, a very weak signal capable of being tuned in upon multiple tube sets. For an equal time the American Telephone and Telegraph Company in conjunction with the Radio Corporation of America have been conducting actual transmissions day and night over long periods of time. The speech being of the same high quality as that upon a standard telephone trunk circuit.

Without a doubt this service will be greatly expanded in the near future, and many new highly paid positions will be available to those having the technical training. Services to all countries will be inaugurated, and will be the means of linking up all land line exchanges in all countries.

To the engineer who intends mastering this latest branch of radio art, there will present itself the necessity for an even more intensive training than that required to operate the usual radiophone station. This is due to the fact that in order to definitely link two vastly separated stations, apparatus of great power and efficiency must be employed.

Broadcasting differs from other types of communication in that it is a free service, and no liability attaches the station for failure to maintain schedules or reach all listeners-in. In the establishment of commercial telephone communications special care must be paid to the ability of the station as regards continuous operation.

While both the high-frequency alternator, and arc, are capable of being modulated at speech frequencies their efficiency is very low and tube transmitters are still the best radio-frequency oscillators and modulators for this purpose. At the present time their size is confined to the employment of twenty kilowatt tubes. Tubes on the order of one hundred kilowatts have been built, but they have not yet been introduced commercially. The number of oscillator tubes in parallel rarely exceeds ten so we find the present transmitters to be on the order of two hundred kilowatts input to the antenna.

The usual type of radiophone transmitter can only cover about sixty per cent the range of an equally powered radio-telegraphic transmitter due to the greater dispersion of energy in its larger frequency band which is required for the transmission of voice frequencies. For perfect speech transmission a band of thirty-five hundred cycles is required, and in trans-Atlantic telephony this is still further reduced to a band of from 200 to 2,500 cycles.

In the ordinary type of radiophone transmitter there are two side bands of equal amplitude from the center line of the

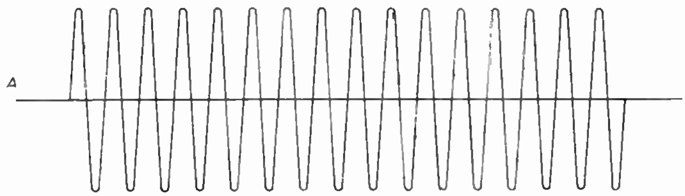

Fig. 1—Radio-Frequency Carrier Wave

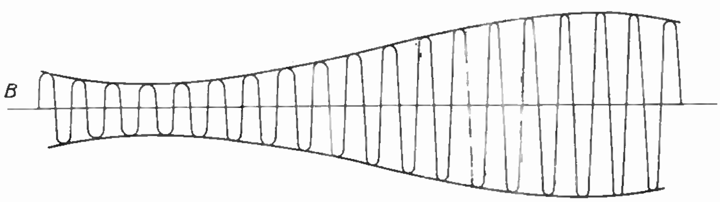

Fig. 2—Voice Frequency Envelope

carrier frequency. This is shown in Figure 1, being the emitted radio-frequency carrier and Figure 2 the voice frequency envelope. In broadcasting, where audio frequencies up to five thousand cycles are handled, the stations must have at least ten thousand cycles difference in wave-length in order not to overlap.

It is apparent that a transmitter confining its transmitted energy to a band of five thousand cycles has twice the output of one spreading over a band of ten thousand cycles. As before stated, it has been determined that good intelligible speech can be transmitted on a band from two hundred to two thousand five hundred cycles. In the ordinary type of transmitter this would require five thousand cycles for both side bands. Now if we eliminate one-half of this side band frequency and only transmit frequencies from two to twenty-five hundred cycles, we are restricting our emitted frequency variation, but we have increased our transmitter efficiency four times over that of the usual type. Our station of two hundred kilowatts then has the efficiency of an eight hundred kilowatt broadcasting station of the standard type.

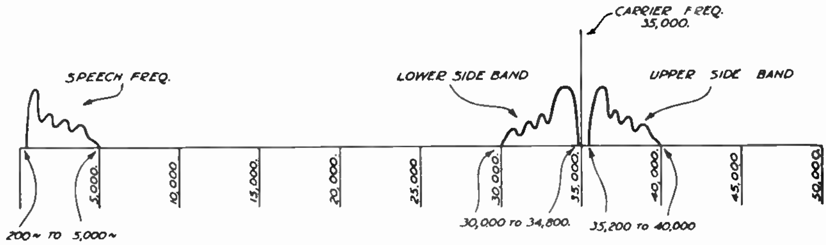

Fig. 3

Trans-Atlantic radiotelephony then has the following advantages over ordinary radiotelephony: First, it only occupies a frequency band region equivalent to that taken up by speech itself. It permits doubling the number of radio channels within a given frequency band. No carrier being transmitted, all of the energy is usefully employed, and this is a saving of two-thirds when compared to ordinary methods. By having a very narrow transmitting band extremely efficient receivers can be employed.

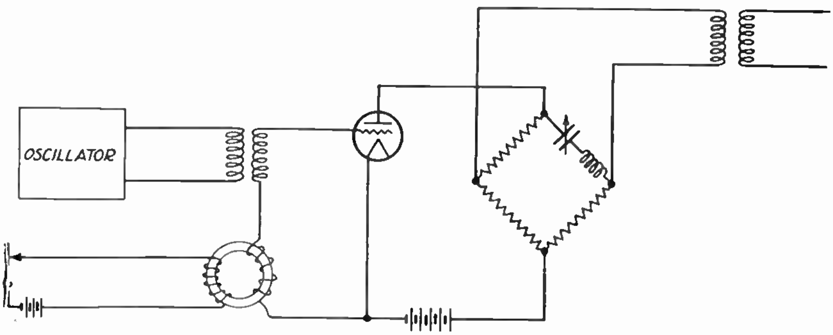

Fig. 4—Bridge Circuit Carrier Eliminator

Now having become acquainted with the advantages of this wonderfully efficient system let us see how it is accomplished. The frequencies produced when a carrier-wave is modulated are the carrier-wave, the carrier plus the speech frequencies, and the carrier minus the speech frequencies. This is represented in Figure 3.

Fundamentally then in single side band radiotelephony it is necessary to modulate a carrier with speech, pass this modulated frequency through a filter which removes the carrier and the undesired side band, and finally pass this current to our power amplifier tubes for radiation from the antenna.

Filters are resonant circuits whereby any desired frequency or band of frequencies may be eliminated. They can be built for all audio and radio frequencies. It is much more difficult to filter low frequencies than high ones and also much costlier. In the elimination of one of the two side bands considerable difficulty is encountered due to the proximity of these bands to one another.

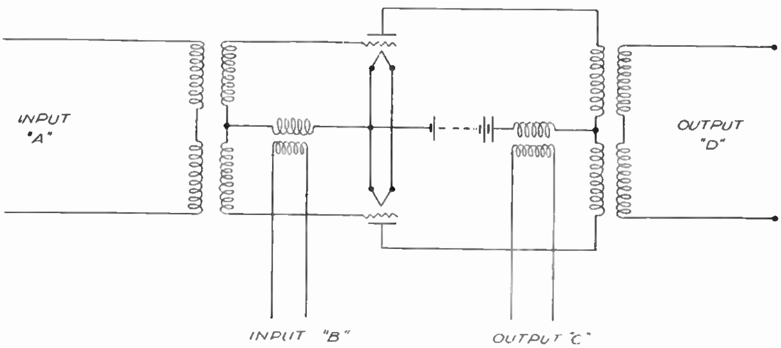

Fig. 5—Balanced Modulator

We will first consider the elimination of the carrier. Two methods in use will be described. That in Figure 4 is known as the bridge method and functions as follows: The bridge arrangement in the plate circuit of the modulator contains one arm tuned to the carrier frequency, and is balanced for it. The carrier cannot pass through this bridge network and nothing will reach the output transformer except the side band modulations that pass through the bridge which is unbalanced for any except the carrier frequencies.

The type of carrier-wave suppressor mainly in use today is that of the balanced modulator type shown in Figure 5. In this device two modulator tubes are employed wherein the carrier frequency is fed in through a parallel feed to the two grids at input B. Speech is introduced at input A and acts in opposition to the input B. The transformer marked output D will not deliver any of the carrier, but will merely transmit the side bands. Output coil C is used in conjunction with coil D and permits a greater flexibility in the phasing of the currents in this type of modulator.

Having now disposed of the carrier frequency it is next necessary to dispose of one of the side bands. This could be accomplished by means solely employing band filters. This

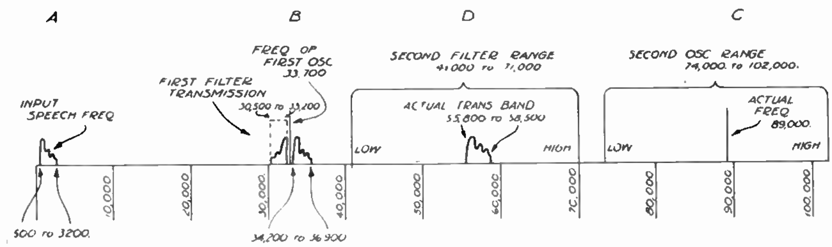

Fig. 6

is too expensive a process however, and an equally efficient and cheaper way is that of double modulation. This method permits the securing of a single side band at a frequency point that is most favorable to low priced filters and then using this output to remodulate an oscillator at a higher frequency.

This double modulation scheme of eliminating one of the side bands is really quite simple and considering it from a mathematical standpoint, is just a case of addition and sub-

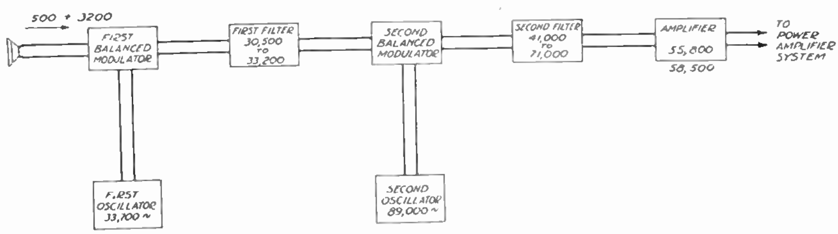

Fig. 7

traction. In order that you may understand this scheme thoroughly, let us consider a specific case, where the speech frequencies to be transmitted, lie between 500 and 3,200 cycles.

Right at this point let us recall something that has been stated before. "The frequencies produced when a carrier-wave is modulated by a speech frequency band, are the frequency of the carrier, the carrier plus the speech frequencies and the carrier minus the speech frequencies."

Let us consider Figures 6 and 7. The frequencies that we are interested with, at the start, are the audio-frequencies between 500 and 3,200 cycles (this is the frequency band of the speech to be transmitted). These speech frequencies are put into the first balanced modulator.

The energy from an oscillator having a frequency of 33,700 cycles is also applied to the first balanced modulator. This oscillator frequency can be termed the carrier frequency, at this point in the circuit. The resultant frequencies produced by the beating of this oscillator frequency with the speech frequencies named, are, 33,700 plus (500 to 3,200), or, 34,200 to 36,900 (the upper side band) and we also have the lower side band of 33,700 minus (500 to 3,200) or 33,200 to 30,500.

The carrier is eliminated by the balanced modulator and the first filter only passes those frequencies between 30,500 and 33,200 cycles, so only one side band passes through, the lower one, and the upper side band is eliminated.

The function of the first oscillator was to raise the side band frequencies to a point where a "not too expensive filter" could be used to remove one of the bands. You will note that this filter has to be quite sharp due to the proximity of the two bands, one of which is desired and one of which is not desired. Now, this resultant frequency band is beat with another oscillator which functions to produce two widely separated side bands, one of which can easily be filtered out, and the filtering process is complete.

So, from the output of the first filter, the frequencies between 30,500 and 33,200 are applied to the input of the second balanced modulator. The second oscillator frequency is applied at this point. The frequency of this oscillator is variable over a wide range to permit varying the wave-length of the signals emitted from the transmitter output circuit, since the wave-length in question is a function of the frequency of the second oscillator. In this specific case, the actual frequency of this oscillator is 89,000 cycles.

The resultant frequencies in the output circuit of the second balanced modulator are, 89,000 plus (30,500 to 33,200) or 119,500 to 122,200 (the upper side band) and 89,000 minus (30,500 to 33,200) or 55,800 to 58,500 (the lower side band). Here again, the carrier is eliminated by the balanced modulator, so the two side bands are passed on to the second filter, which

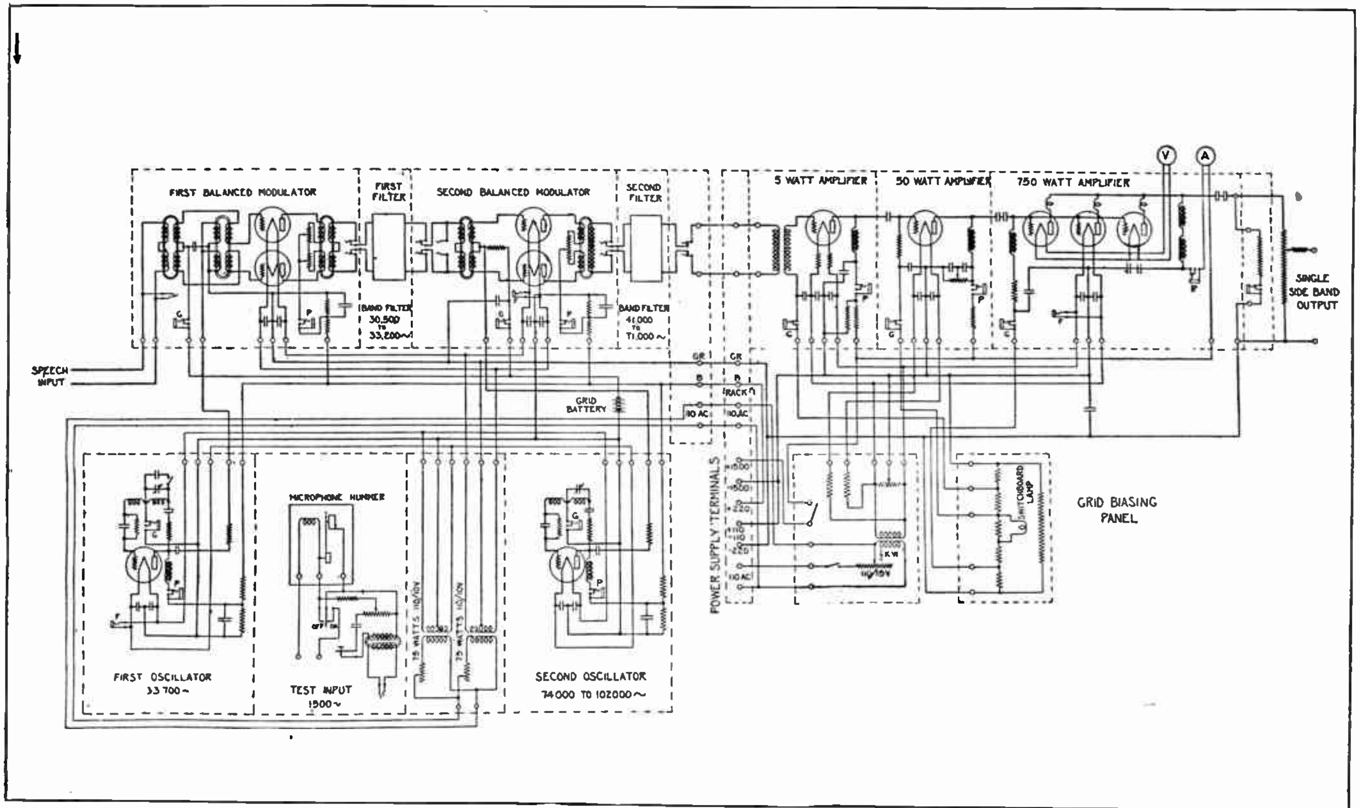

Fig. 8—Wiring Diagram of Speech Circuits.

has, as you will note, a comparatively broad range, namely, from 41,000 to 71,000 cycles. This filter passes the lower side band very nicely but eliminates the upper side band which you will see, is way above the range of the filter.

Now we have eliminated the carrier and have completely eliminated one side band, and the one remaining side band is the one to be transmitted. We now have the 2,700 cycle band between 55,800 and 58,500, which is passed through numerous stages of amplification and is finally radiated from the antenna system. Obviously the transmitted wave-length is a variable between the two limits, 300,000,000 ÷ 58,500 and 300,000,000 ÷ 55,800 or, 5,130 and 5,370 meters, approximately and respectively.

Figure 8 shows the wiring diagram of the entire speech circuits, up to the power amplifier circuits. which will be treated next. Before leaving the modulator circuits, it might be well to make the point clear, that the second oscillator and filter circuits are variable in order that changes of wave-length may be readily accomplished, to avoid interference.

The output of the second filter system is applied to a five watt low power amplifier as represented in Figure 8. This output is a single side band and without carrier. After amplification in the five watt stage the output energizes the fifty watt stage and hence a bank of three two-hundred and fifty watt tubes. The full power of these amplifier tubes is not realized due to the desire for distortionless amplification which cannot be attained when working power tubes at their full rating.

The input to the five watt amplifier was through the usual input transformer windings, and it will be observed that the last two stages which, are purely voltage step-up stages, are choke coil amplifiers. In Figure 8 is also shown a microphonic hummer capable of producing a fifteen hundred cycle note for test purposes. This hummer is similar to the ordinary buzzer, except that instead of the usual contacts a telephone microphone is employed. This gives a purer note than a contact buzzer, and is used to show the modulating efficiency of the circuit. It is connected to the point marked speech input.

The power supply for this low power amplifier is obtained from several sources. The modulators and oscillators are energized by the two twenty direct current circuit of the station. The power amplifier plates are fed from fifteen hundred volt direct current generators. The filaments are all supplied by means of step-down alternating current transformers.

The modulator, filter and low power amplifier apparatus is all located in a totally copper screened room. This was necessary in order to prevent any feed back from the high power amplifier which would cause singing. The power delivered from the modulator oscillator is only one thousandth of a watt while that of the high power amplifier to the antenna is on the order of over one hundred kilowatts. The ratio of these powers is about one to one hundred million, and it is easily apparent how some of the enormous antenna current could be induced into the modulator circuits.

THE HIGH POWER AMPLIFIER CIRCUITS

Unlike radiotelegraph tube transmitters, quality radiophone transmitters must not be operated at more than two-thirds of their rated capacity if distortion is to be avoided. Our output from the low power seven hundred and fifty watt amplifier is therefore on the order of five hundred watts. This power is eventually stepped up to an output of approximately one hundred and fifty kilowatt, although the last power amplifier is capable of an output of over two hundred kilowatt for telegraphic transmission.

These immense outputs are only available by means of water cooled tubes paralleled in banks of ten. Each tube is rated at twenty kilowatts output. Tubes of this order are very expensive and when operated together must be individually protected in order that the burning out of one tube would not cause an overload to be placed on the others. Each tube has an overload relay which cuts the plate supply off should the current drawn become too great to be safely handled.

Due to the immense quantity of current that is dissipated on the plates a continuous circulation of water is necessary and each tube is fitted with a water flow alarm. In case that a stoppage should occur a contact arm in a special type of valve would close and throw the main circuit breaker thereby cutting all plate current from the set. The value of each tube is about six hundred dollars, and the safety devices are the only insurance possible for maximum life of the tubes.

Figure 9 shows the high power amplifiers, rectifiers and output antenna circuits. It will be observed that we really have three different amplifiers, low, intermediate and high power.

The five hundred watt output of the intermediate power amplifier feeds the grids of two twenty kilowatt tubes which comprise the first stage of the high power amplifier.

This output is then connected to the grids of the last stage which consists of two banks of ten, twenty kilowatt tubes. Either bank may be operated singly or the two in parallel. This output is then loosely coupled to a multiple tuned antenna which will be described latter.

PLATE CURRENT SUPPLY

Current at a potential of ten thousand volts, and a capacity of two hundred kilowatts is necessary to energize the high power amplifier plates. Direct current generators at this voltage and current, are difficult to construct and maintain. A much easier way is to step up alternating current at a slightly higher potential than that required and then rectify by means of rectifier tubes, and filter circuits.

At the Rocky Point Radiotelephone Station the power supply is twenty-two thousand volts, three phase sixty cycles. A bank of twelve tubes each capable of an output of twenty kilowatts at ten thousand volts, rectify the alternating current, the form of which becomes the usual pulsating type. It is now necessary to smooth out this ripple, and this is accomplished by means of a filter circuit. This filter circuit is composed of series inductances and shunt capacity which opposes the varying current voltage level output of the rectifier tubes in such a manner that this ripple is reduced to practically a pure direct current.

It is necessary to supply the rectifier tubes with a voltage higher than the output potential on account of a loss in the filter circuit. This is shown in Figure 10. A is the applied alternating current. B is the rectified current of pulsating form, and C is the resultant filtered current of a practically pure direct current characteristic.

The plate current is then supplied to the first and second stage high power amplifiers through suitable protective chokes which prevents high-frequency surges. In addition, safety gaps are provided that present a ground path for any surges that should take place. Relays are also provided which automatically shut off the main power supply. The filter condenser consists of some twenty-five hundred paper telephone condensers in a

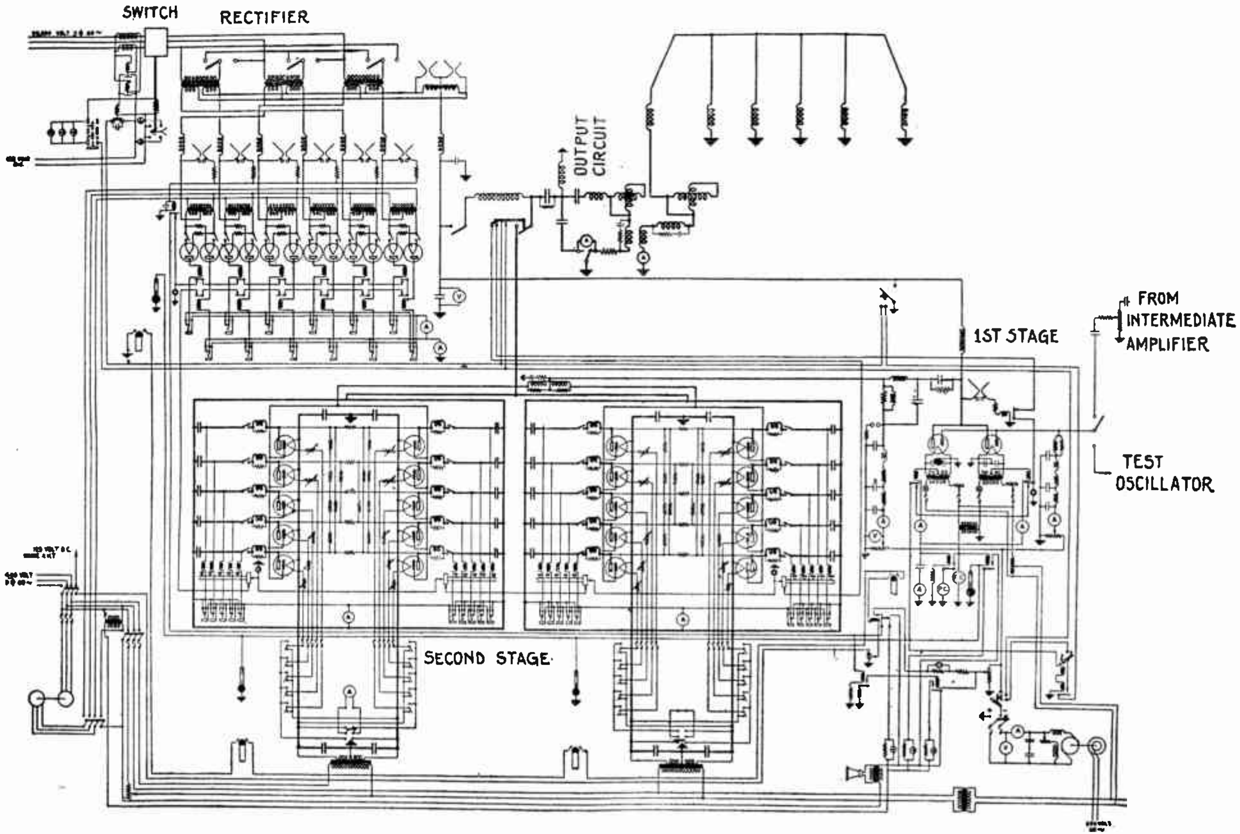

Fig. 9—High Power Amplifiers, Rectifiers and Output Antenna Circuits.

series-parallel arrangement giving a capacity of three micro-farads and a potential safety of seventeen thousand volts.

OUTPUT AND ANTENNA CIRCUITS

We have followed our input from the intermediate circuit to the modulating of the grids of the first stage of the high power amplifier and from there the output is used to modulate the twin banks of ten high power tubes. It must be remembered that we are also controlling the frequency of the transmitter simultaneously by means of oscillators. In coupling to the antenna we are primarily interested in efficiently coupling our

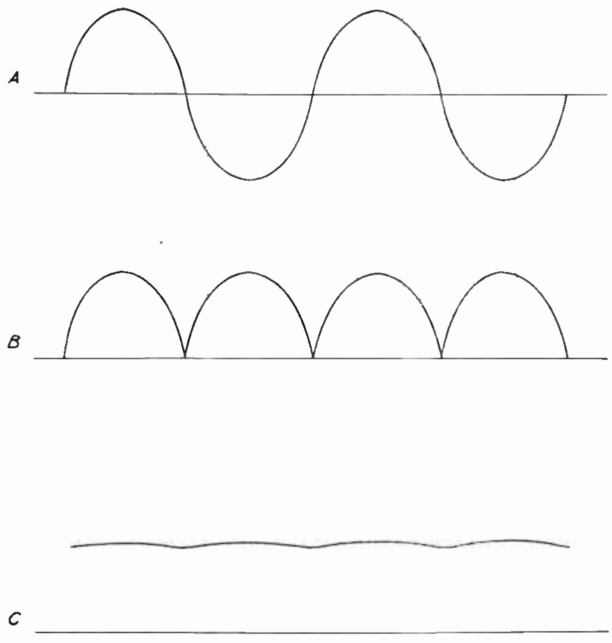

Fig. 10

amplifier system to the multiple tuned antenna. In other words, we must match the impedances of the power tubes and the antenna load in order that the transfer of energy is at its greatest value.

In order to do this we find it necessary to construct an intermediate circuit because of the wide difference between the characteristics of the power tubes and the antenna circuits. By means of this intermediate circuit we satisfy the requirements of both circuits and have an efficient transfer of current from the closed to open circuits. It is also necessary in this tank or intermediate circuit that all frequencies be passed with equal intensities otherwise distortion can take place.

Let us first consider the antenna we find in use. This is the multiple tuned type as invented by E. F. W. Alexanderson. This is shown schematically in Figure 11 and consists of ground connection, current meter coupling inductances, antenna proper, and the requisite number of down leads with their attendant inductances tuned to the desired frequency. This type of antenna has several advantages over the usual antenna methods. Primarily the chief advantage lies in a very low resistance and a correspondingly high antenna current. Another feature is that the arrangement is practically a filter circuit and suppresses harmonic currents. At the frequency used (57,000) the resistance is less than one ohm.

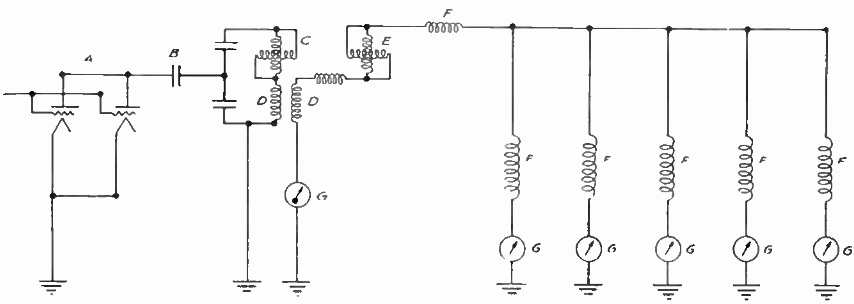

Fig. 11

Our tank or intermediate circuit consists of capacity, inductance and resistance and is tuned by means of one of the inductances being in variometer form which permits a variable control over the impedance of this circuit. Having a fairly high plate impedance, and a low antenna impedance it is the duty of this circuit to couple these two circuits efficiently. This tank circuit may be said to be comparable to an ordinary audio-frequency amplifier in that our plate impedance is matched by the primary and the grid impedance by the secondary.

This output circuit is shown schematically in Figure 11 where the output of the tubes is shown at A. B is a capacity branch which provides a low impedance path for harmonics, D being the inductances coupling antenna and tank circuit tuned by the variometers C and E. The F's are the antenna tuning inductances and are tuned for the proper input feed ratios. The G's are the radiation meters and all down leads must be added in order to secure the total current flow in the antenna.

It will be seen from this text that high power radiophone equipment differs radically in equipment and operation from that of low power stations. It will be well for the radio engineer desiring work of this nature to be well grounded in power plant equipment, and especially that branch that involves the use of multi-phase transformers.

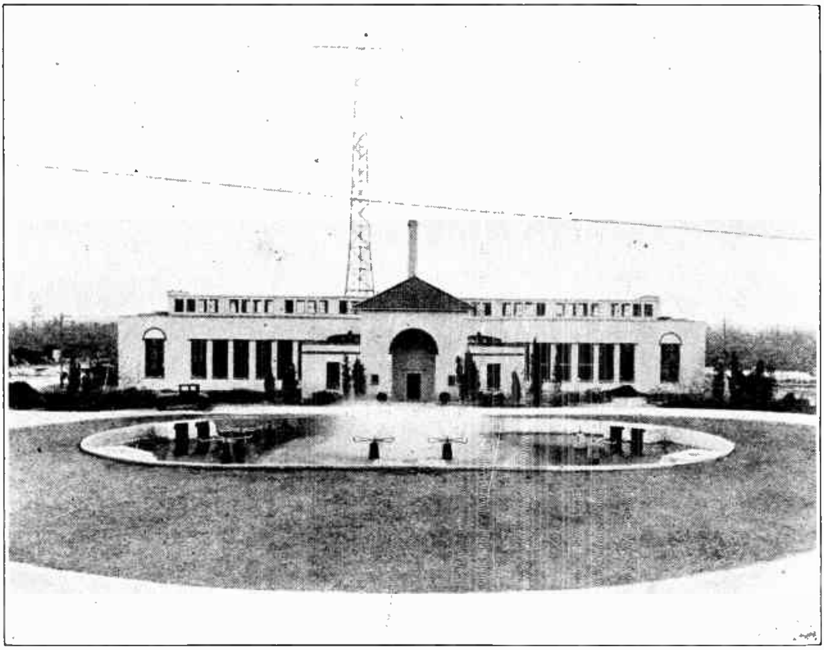

Fig. 12—Rocky Point Transmitting Station

There is considerable auxiliary apparatus in addition to that enumerated, and consists of testing oscillators, oscillographs for the proper adjustment of modulating currents, the usual power measuring equipment, electrical recording clocks for measuring the time the equipment is in operation and a multitude of safety devices for the protection of the equipment.

Long wave stations must also be protected against the carrying away of the antenna due to the weight of sleet. Special low voltage high current transformers are provided which are capable of actually raising the temperature of the antenna wires to a point where the ice will melt.

The trans-Atlantic Radiotelephone Station just described. is located at Rocky Point, Long Island, and is operated by the American Telephone and Telegraph Company in conjunction with the Western Electric Company.

Figure 12 is an exterior view of the Rocky Point Station which houses the single side band eliminated carrier radiotelephone transmitter described. You can see one of the 500 foot towers in the background that support the transmitting antenna.

Fig. 13—Main Control Panel, Rocky Point Single Side Band Eliminator Carrier Transmitter

Figure 13 is a view of the main control panel. The station operator's desk is shown in the foreground. Figure 14 is a view of one bank of twenty kilowatt tubes.

Figure 15 shows one of the enormous outdoor tuning coils used for tuning the antenna, in a multi-tuned antenna system. The power house is shown in the background and you can see the lead from the power house, to the first tuning coil, which carries the radio-frequency output energy to be radiated from the antenna system.

SINGLE SIDE BAND ELIMINATED CARRIER RECEIVER

Although it is true that fairly intelligible speech may be picked up on an ordinary type of receiving set, from the particular type of transmitter that we are discussing in this section, it is also true, that to produce anything like commercial quality, it is necessary to have a special type of receiver.

Figure 16 is a schematic layout of a receiver used in picking up signals transmitted from a single side band eliminated carrier transmitter. As you will see from the diagram, reception is carried out in two steps. The received side band is passed into the high-frequency detector circuit where it is combined with energy from a local oscillator having a frequency of 89,000 cycles.

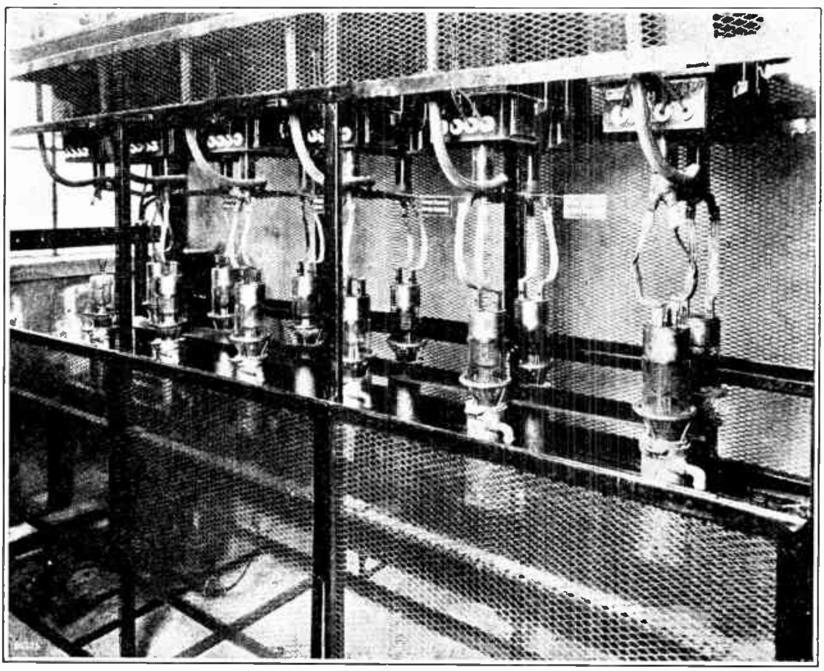

Fig. 14—20 K. W. Tubes in Rocky Point Single Side Band Transmitter.

The resultant frequencies are, 89,000 cycles, 89,000 plus (55,800 to 58,500) or, 144,800 to 147,500 and 89,000 minus 55,800 to 58,500) or, 30,500 to 33,200 cycles. This energy passes through a filter having a range of from 30,500 to 33,200 cycles, thus eliminating the carrier and the upper side band and the lower side band is passed through to the intermediate

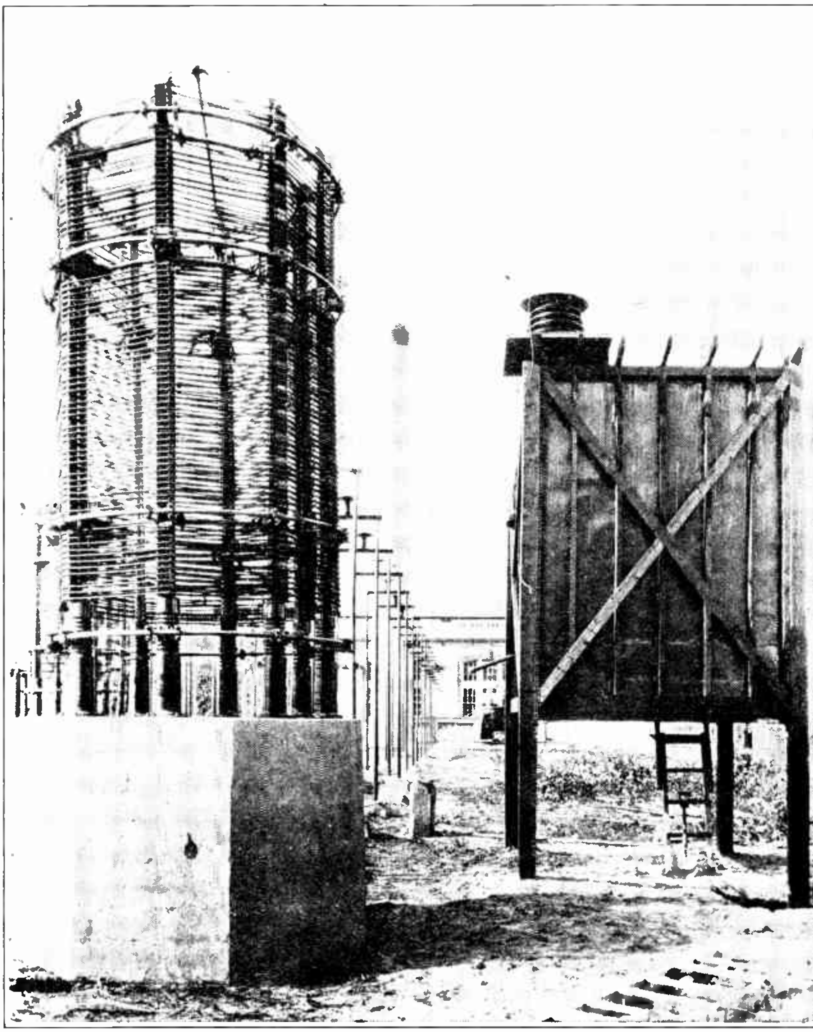

Fig. 15—Outdoor Tuning Coil for Rocky Point Single Side Band Transmitter

frequency amplifier and thence to the low-frequency detector where it is beat with another oscillator having a frequency of 33,700 cycles.

The resultant frequencies in the detector circuit are 33,700, 33,700 plus (30,500 to 33,200) or, 64,200 to 66,900 and 33,700 minus (30,500 to 33,200) or, 3,200 to 500 cycles. In this part of the circuit, it is only with the different frequency band that we are concerned, it being audible and the carrier as well as the upper side band being of too high a frequency to be audible to the human ear. So you will see that we have arrived back at a point where we have exactly the same speech frequency band as we started with, namely, 500 to 3,200 cycles.

COMMERCIAL TRANS-ATLANTIC TELEPHONY

The American Telephone and Telegraph Company have installed a 200 kilowatt telephone transmitting station, of the type described in this section, at Rocky Point, Long Island, and there is no question that all of their tests will culminate in the inception of commercial trans-Atlantic radiotelephony.

During 1925, the company in question spent a considerable amount of time and money in the development of the transmitting and receiving equipment, explained, in general, in this section. The first part of 1926, found the status of the situation such, that, "finis" was written to the major part of the development, and it was decided, to hold a demonstration, before members of the press, showing them, so they could tell the world at large, the feasibility of trans-Atlantic Radiotelephone Communication.

On March 7, 1926, Sunday, two-way radiotelephonic communication was carried on between people in New York City and people in London, England. Numerous separate conversations were carried on, the total time involved for all the conversations being four hours. This, together with the fact that on Sunday after Sunday, tests have been carried on between New York and London, the two points being in constant telephone touch with each other for eight hours at a stretch, gives you an idea of the consistency of this trans-Atlantic radiotelephone service.

During the two-way communication tests, it is necessary to have a transmitter and a receiver at each end of the circuit. For instance, on the American end of the circuit, the receiver is located at Houlton, Maine, and the transmitter at Rocky Point, Long Island. The person talking to London may be located anywhere in the United States, but let us assume that he is talking from New York City.

The speech from the gentlemen located in New York is sent over land lines to the Rocky Point transmitter where it is subsequently "put on the air." This radio-frequency energy is picked up on the English side of the circuit and is applied to the ear-phones of the Englishman who is talking from London.

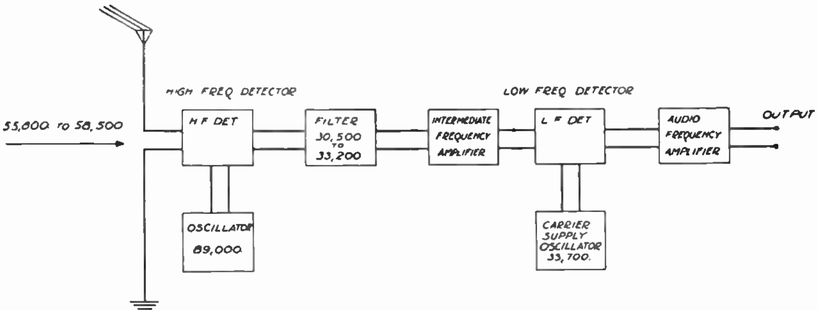

Fig. 16

The speech from this last named gentleman goes out over the land lines to the transmitting station over there, and thence by radio to the receiving station at Houlton, Maine, where it is picked up and sent over the land lines, in the form of speech frequency currents, to the ear-phones of the gentleman talking from New York. That completes the circuit.

RADIO RELAY STATIONS

A radio relay station is one that picks up radio signals and relays them, by radio, to more remote points. A relay station in a radio circuit is analogous to a repeater station in a telephone circuit.

In this section we are going to consider the methods involved in the relaying of transatlantic broadcasting signals; the relaying of transatlantic telegraph signals; the relaying of transcontinental radio picture signals and the relaying of the Arlington time signals.

RE-BROADCASTING EUROPEAN BROADCAST PROGRAMS IN THE UNITED STATES

A most elaborate re-broadcasting test was successfully carried out on January 1, 1926, when a program of music from the Club Ciro in London, England, was re-broadcast by a chain of radio stations throughout the United States. This test was conducted by the Radio Corporation of America and convincingly showed the possibility of American radio fans "listening in" on European broadcast programs, but it also showed the necessity of a radio relay station to make this possible.

There are a vast number of people in the United States who derive a great deal of pleasure from "listening in" on broadcast programs from the other side of the Atlantic. There are very few of these folks who are able to pick up European broadcast signals, direct, (on their own receivers), for two main reasons. The first is, that in the majority of cases, their radio receivers are not sufficiently sensitive and the second reason is, that their geographical location is not sufficiently favorable to transatlantic reception.

In order to receive transatlantic broadcast signals here in the United States, direct from Europe, with any degree of consistency it is necessary to have a supersensitive receiver and to be located at a point conducive to good reception from Europe.

Now it isn't everyone that is in the proper location, and, of those that are, there are few that can afford to invest in the type of receiver necessary.

It devolved upon the Radio Corporation of America to utilize the facilities at their command to attempt to supply the American radio fan with broadcast programs from Europe.

Intensity tests were made all along the eastern coast of the United States in the search for the ideal location. From a summary of the quantitative data thus obtained, they found that the territory around Belfast, Maine, is particularly free from static disturbances and the intensity of radio signals from Europe is, also, particularly good.

They built a radio receiving station at Belfast, Maine, and equipped it with the most sensitive receiving apparatus available.

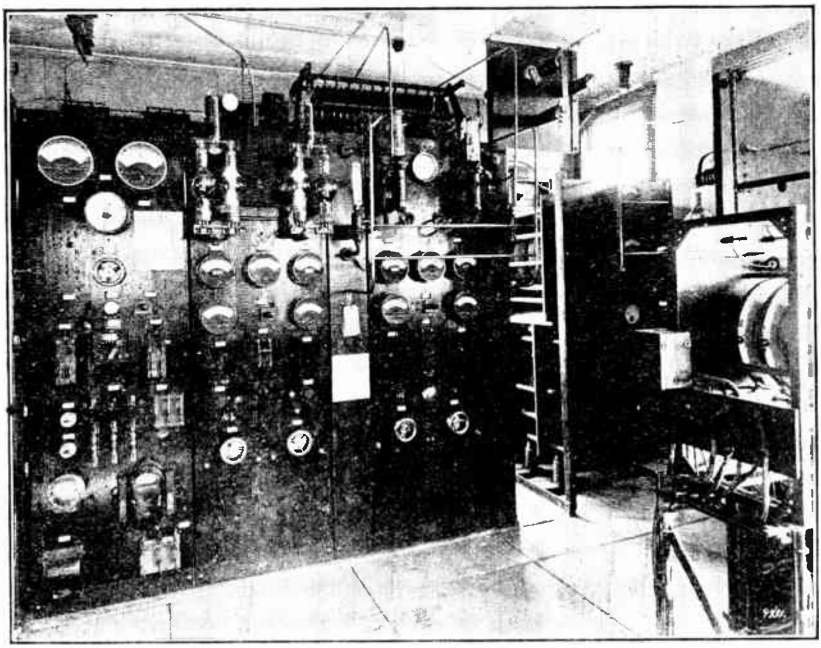

Fig. 17—Interior View of Station, Belfast, Maine.

A "wave antenna" is used for picking up the signals. This antenna consists of two wires elevated from the ground about twenty feet by telegraph poles, the length of the antenna being a function of the wave-length of the signals that it is desired to receive. This antenna is made approximately one wave-length long for best results, hence in the case of 1,560 meter signals, the antenna is about 1,560 meters long or, in other words, about a mile long.

The "wave antenna" is unidirectional, in that one of its inherent characteristics is to receive signals best from one direction, and to receive practically nothing from all other directions. Obviously, this characteristic tends towards a reduction in static—signal ratio. When a "wave antenna" is designed to receive from one particular direction it has the effect of receiving an amount of energy from that particular direction, equivalent to the amount that would be picked up by an ordinary receiving antenna, 1,000 feet high.

This combination of ideal location and sensitive receiving equipment resulted in the consistently satisfactory reception of European broadcast signals, and with these signals available at Belfast, the next thing to consider was the problem of getting them to the different broadcasting stations to be put on the air.

In view of the fact that high grade telephone circuits were not available for the use of the R. C. A. between Belfast and New York, at the time the receiving station was built, it was necessary to build a transmitting station for relaying the signals on to more remote points in the United States where conditions were not conducive to consistent reception for Europe.

A transmitting station was built at a point about three miles from the receiving station. This transmitting station was equipped with transmitters, designed to operate on various wavelengths. The transmitter that we wish to consider at this time is the one that was designed to operate on 70 meters. We will just consider this transmitter in general, because it is the one that was used to relay the European broadcast signals from Belfast to New York.

Figure 17 is interior view of the transmitting station.

Figure 18 is a schematic diagram which gives you a general idea of the circuit arrangement at the relay station and shows the method of producing and modulating the "carrier."

A crystal oscillator is used to insure constant frequency. The energy from the crystal oscillator circuit is applied to the grid of the 5 watt tube (T_1). The output circuit of this tube is inductively coupled to the input circuit of another 5 watt tube (T_2). The output circuit of (T_2) is coupled to the input circuit of a push-pull amplifier consisting of the two 5 watt tubes (T_3) and (T_4).

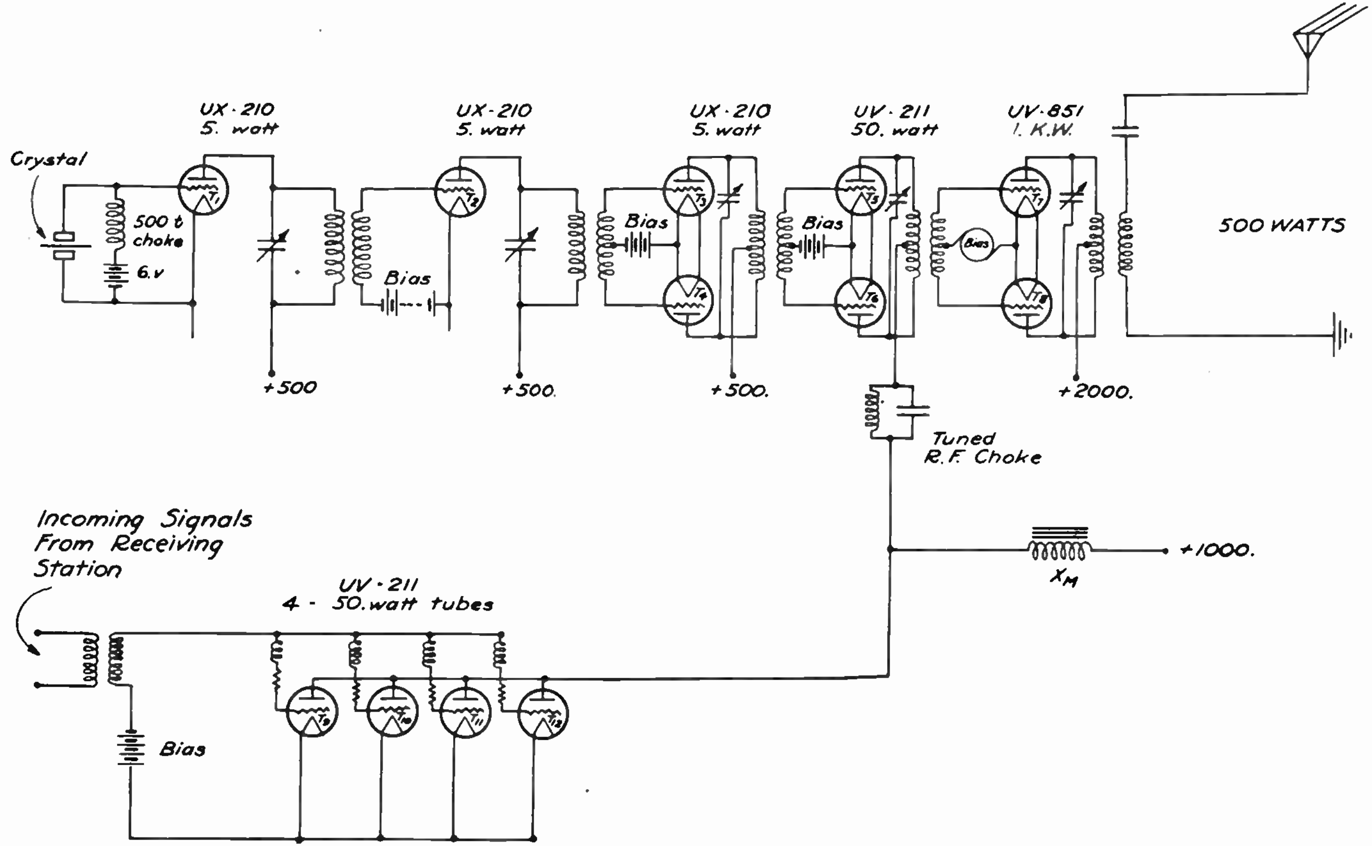

Fig. 18

SCHEMATIC WIRING DIAGRAM OF BELFAST 70 METER RADIO RELAY TRANSMITTER

The output circuit of the 5 watt push-pull amplifier is coupled to the input circuit of another push-pull amplifier consisting of the two 50 watt tubes (T_5) and (T_6). Modulation is effected in this stage and we will come back to that shortly.

The modulated radio-frequency energy in the output circuit of the 50 watt push-pull amplifier stage is applied to the grids of the two 1. kilowatt tubes (T_7) and (T_8) which, with their associate circuits, form another push-pull stage of amplification. This last stage of amplification must be linear, obviously, or distortion will occur. The output circuit of this last stage of amplification is coupled to the antenna.

Now let us go back a bit and consider what happens to the European signals when they are produced in the output circuit of the apparatus at the receiving station. This energy, in audio-frequency form, is "piped" over to the transmitting station on a pair of wires. At the transmitting station it is applied to the grids of four 50 watt amplifier tubes, (T_9), (T_{10}), (T_{11}) and (T_{12}), these tubes being connected in parallel.

The plates of these tubes are supplied from a 1,000 volt D. C. source of energy through the iron-core choke coil (X_m) and you will note that the plates of the two oscillator tubes (T_5) and (T_6) in the 50 watt push-pull amplifier stage, are also supplied from the same source and through the same choke coil (X_m).

The presence of this choke coil in the common plate supply to the two oscillators mentioned and the four modulator tubes, functions to maintain a constant supply of plate current. This means that when the grids of the modulator tubes go positive due to signal voltage being applied to their grids, the current flow to the modulator plates increases and since the choke coil (X_m) tends to maintain a constant supply of plate current to the six tubes involved, the increase in plate current flow to the modulator tubes will result in a corresponding decrease in plate current flow to the oscillator tubes.

It is in this manner that modulation is effected and the peak current values of the radio-frequency pulsations in the output circuit of the 50 watt push-pull amplifier tubes will rise and fall in synchronism with the audio-frequency variations in the voltage applied to the grids of the four modulator tubes due to the European broadcast signals as they are supplied from the output of the audio-frequency power amplifier at the receiving station.

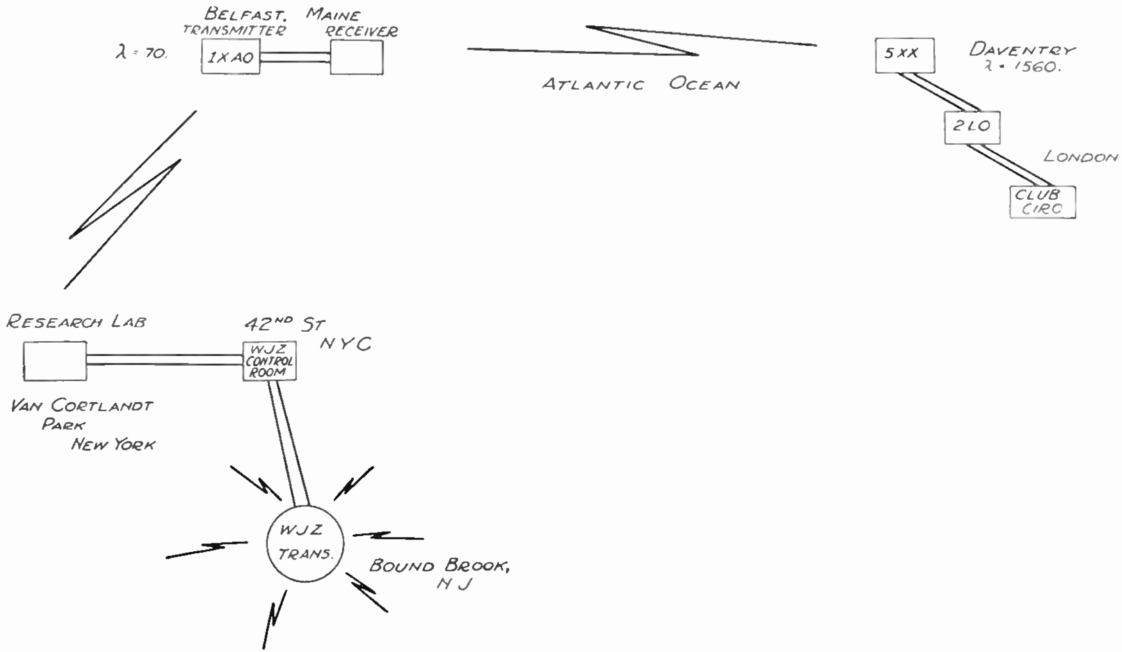

Fig. 19—This Shows the General Schematic Layout for Relaying Broadcast Programs.

Thus the signals from Europe, picked up at Belfast on 1,560 meters, are made to modulate the 70 meter radio relay transmitter and they are again put on the air, but this time, on a wave-length of 70 meters. These signals are picked up at the research laboratory of the R. C. A. located in Van Cortlandt Park, New York City. They are tuned in on a short wave receiver, detected, amplified and put on a direct pair of wires to the control room of WJZ, in the Aeolian Building, on 42nd Street in New York City.

In any event, signals that come into the control room are "piped" out to the transmitting station of WJZ, which is located at Bound Brook, New Jersey.

Now we come to a summary of this whole situation. A great many folks throughout the land know that it is possible to pick up signals from Europe here in the United States and they know that European broadcast programs have been received here and re-broadcasted from local stations, but there are comparatively few who know of the exact circuit arrangements involved. Figure 19 shows the general schematic layout.

As has been said before, the first really successful attempt at re-broadcasting European broadcast programs in the United States, took place on January 1, 1926, (Figure 19 shows the circuit arrangement involved in the tests in question).

A program of music from the Club Ciro in London was rebroadcast in the States for a period of half an hour. This music, originating in the Club Ciro, was transformed into electrical pulsations of audio-frequency by means of the microphone and its associate circuits. These audio-frequency currents were piped over to the control room of broadcasting station "2LO", in London, on a pair of telephone lines.

At the control room of station "2LO", these audio-frequency currents were diverted into two separate channels. One led to the modulator tubes of the British station in question and the other, to the experimental transmitting station at Daventry, England. In the former case, the signals were broadcast over station "2LO" on 360 meters, for reception by British radio fans and in the latter case they were sent out from "5XX" on 1,560 meters, for reception by American fans, although in this latter case the signals were not, in general, received directly, by the fans, but only after the interplacement of a radio relay station. Since it is with radio relay stations that we are concerned in this section, we will follow the path of the signals on their journey from the source in London to the points where they were put on the air for reception by American radio fans.

The audio-frequency signals arriving at Daventry, England, were amplified and applied to the grids of modulator tubes which in turn function to modulate the radio-frequency output of station "5XX". Hence, the sound waves, produced by the playing of the musical instruments in the London Club and which were transformed into electrical pulsations of audio-frequency by the microphone and its associate circuits at the Club Ciro, underwent another transformation at Daventry. where they were sent out into the ether in the form of modulated radio-frequency electro-magnetic energy.

These signals were picked up at the relay station at Belfast. Maine, on 1,560 meters. They were amplified, detected (hence changed into audio-frequency energy), amplified at audio-frequency and "piped" over to the Belfast radio relay transmitting station "1XAO." Here the signals were applied to the grids of the modulator tubes of the "1XAO" transmitter, the modulator tubes functioning to modulate the radio-frequency energy generated and subsequently radiated.

So, here again, the music originating in the London Night Club were "put on the air," but this time on a wave-length of 70 meters. These 70 meter signals were picked up at the Research Laboratory of the R. C. A., at Van Cortlandt Park, in New York City. They were amplified, detected, amplified at audio-frequency and put on the pair of telephone wires connecting the research laboratory with the control room of WJZ at the Aeolian Hall Building, on 42nd Street, in New York City.

In the control room at WJZ the musical program from London was passed through audio-frequency amplifiers and distributed by high grade telephone wires to the various broadcasting stations throughout the United States that were linked up for simultaneous re-broadcasting. These signals were also sent out over the control line to the Bound Brook transmitting station of WJZ where the program was "put on the air" on a wave-length of 455 meters and subsequently received by those "listeners-in," within range of this station.

That tells the story of the important part that the radio relay station plays, in the re-broadcasting of European broadcast signals. The reason for having the relay station is obvious.

It would be possible to have the same receiving equipment used at Belfast, installed in the Van Cortlandt Park Laboratory, but the possibility of receiving European broadcast signals with any degree of consistency would be much less than the possibility of consistent reception at Belfast. Another thought to consider here, is, that the antenna used at the receiving station, for best results in receiving 1,560 meter signals, should be of the "wave antenna" type and its length should be approximately one mile. This is far more feasible at a point way off in the country than it is at a point in or near a big city like New York City.

The reason, then for using a radio relay station for making possible the re-broadcasting of European broadcast signals, is the fact that sensitive receiving equipment installed at the various broadcasting studios would not be sufficient to pick up broadcast signals direct from across the Atlantic. But sensitive receiving equipment installed in an ideal location for trans-atlantic reception, is sufficient for European broadcast reception and these signals can then be relayed with sufficient power to carry them through to the points desired.

In concluding, let us consider the rated output values for the stations mentioned in connection with the foregoing discussion.

Station	Wave-Length	Power
2LO	360 meters	1.5 K.W.
5XX	1,560 meters	25. K.W.
1XAO	70 meters	½ K.W.
WJZ	455 meters	1. K.W. minimum
		50. K.W. maximum

TEST QUESTIONS

Number Your Answers 40 and add Your Student Number

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Is continuous operation necessary in Commercial Telephone Stations?

2. What frequencies are used for good speech transmission?

3. Why are filters used in transmitting circuits?

4. Draw a diagram of a balanced modulator used for carrier elimination.

5. What precautions must be taken in the installation of the modulator, filter and low power amplifier?

6. State the capacity at which a radiophone transmitter should be operated to avoid distortion.

7. How are expensive power tubes protected from being burnt out?

8. What is a radio relay station?

9. Why was Belfast, Maine selected as the location for a relay station?

10. Show by a diagram how the different stations are connected for re-broadcasting European programs in U. S. What wave-lengths are used?

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PIEZO-ELECTRIC CRYSTAL-CONTROL FOR TUBE TRANSMITTERS

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PIEZO-ELECTRIC CRYSTAL CONTROL FOR TUBE TRANSMITTERS

Introduction

The importance of producing vacuum tube transmitters which generate a constant frequency has never been seriously considered until recently, when the advent of broadcasting stations and the increasing number of ship and shore radio stations has demanded that such transmitters be made available.

The Naval Radio Service has been faced with this problem for a number of years particularly in the operation of the United States Fleet. Such a fleet generally consists of a group of vessels, numbering from 150 to 200 ships, which move as one unit and, for the greater part, their movements are controlled by radio. These vessels have one or more transmitters on board and are required to be in constant touch with each other and also with a group of shore stations. When we consider such a large number of stations, as represented by this Naval force, it is very easy to imagine the confusion that may result if no means are employed to maintain a constant frequency for each station's transmitter.

Various means have been employed to hold constant the frequency of transmitters, but no absolutely satisfactory means has been devised which will maintain a constant frequency in vacuum tube transmitters which employ self-oscillating circuits. This statement has special reference to transmitters which are required to operate over a band of frequencies and are dependent for plate and filament supply power upon the usual ship's dynamo or shore station power sources.

When we consider that the beat note of a continuous wave transmitter has to remain within a certain range, say 350 cycles, it can be realized that the constant frequency condition becomes harder to meet as the frequency of the transmitter is increased. This can be readily seen when we consider that the frequency of a 4000-Kc. transmitter cannot be changed more than 1/100 of one per cent. before it has exceeded the specified frequency range.

Realizing, after years of experimentation, that we could not meet the demands made on us by the Fleet with vacuum tube circuits employing the self-oscillating principle, it was necessary to turn to some other means for meeting this demand. One means which has proved successful is the piezo-electric crystal-controlled transmitter. Such a transmitter has been found to meet all our requirements if suitable means are provided to keep the temperature of the crystal constant.

THE PIEZO-ELECTRICAL CRYSTAL

There are a number of crystalline substances such as quartz, tourmaline and Rochelle salts which have excellent piezo-electric and pyro-electric properties. All these are from an optical standpoint doubly refracting and of unsymmetrical atomic structure. Bragg and Gibbs show that alpha quartz which is piezo-electrically active has an unsymmetrical hexagonal atomic structure, while beta quartz which has no piezo-electric properties is of a regular hexagonal atomic structure.

It is only natural to assume that any crystalline body which has double refracting properties and whose atomic structure is unsymmetrical should be piezo-electrically active. F. Pockels states that 20 out of 32 crystalline substances show some piezo-electric properties.

Considering the three commonly known piezo-electric crystals, i. e., quartz, tourmaline and Rochelle salts, we find that quartz is to be preferred. Rochelle salts although it has ten times the piezo-electric properties of quartz is not reliable. It is fragile, extremely hard to manufacture and its physical dimensions can be easily changed by handling, especially when subjected to contact with water. It also will not stand any electrical load; for instance, if used as a resonator in connection with the output of an oscillator of a few watts capacity it will break down. This breakdown will either be in the form of a series of mosaic cracks throughout the crystal or it will consist of a melting process wherein the crystal suddenly flattens out and assumes an isotropic state. If the power is increased the salts will return to a liquid state.

Repeated attempts have been made to make Rochelle salt crystals function as well as quartz, for controlling the frequency of a vacuum tube transmitter, but no success has been obtained in this endeavor. The Rochelle salt crystal is not mechanically strong enough to withstand the vigorous vibration which is met with in the quartz crystal when controlling the frequency of a vacuum tube transmitter. It is also possible that the hysteresis losses in the Rochelle salt crystal are such that they tend to damp out any properties of the crystal for generating a return piezo-electric voltage required for maintaining a vacuum tube circuit in an oscillating condition.

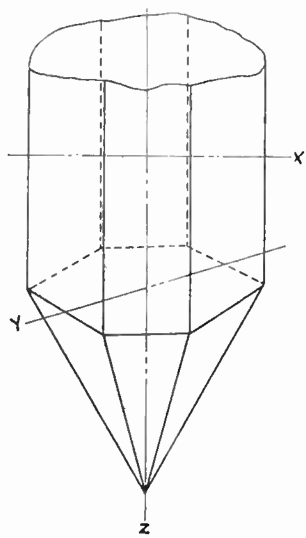

Fig. 1

There is no literature available which shows the application of Rochelle salt crystals as a means for controlling the frequency of a vacuum tube circuit.

Tourmaline is too expensive to be considered as a commercial product and therefore result has to be made to the use of quartz.

Quartz can be obtained in reasonable quantities in Brazil, Madagascar, Japan and the United States. Any quartz which has no flaws, intergrowths or optical twining can be so manufactured that it has excellent piezo-electrical oscillating properties. By this we mean that such a crystal can be used to control the output of a vacuum tube oscillating circuit at one definite frequency and with maximum output.

Quartz will retain its physical dimensions if kept at a definite temperature. It will also stand considerable abuse, which accompanies its use in oscillation test circuits, where the crystal is heated momentarily to temperatures in excess of 45 deg. cent. and is subjected to frequent washing. Experience has demonstrated that crystals will hold the original oscillation frequency for periods in excess of ten months, when operated continuously in a high-frequency transmitter system. Other exacting tests have proved that quartz is the only material known which is satisfactory for use in crystal-controlled vacuum tube circuits.

The quartz crystal is hexagonal in shape and when in its true form has an apex at each end. The methods of mining and also the process of growing are such that the two apexes are rarely found on crystals which are purchased from the importers. In the majority of cases, it is rare to obtain crystals having sides and one apex which are not chipped or cracked due to rough handling or poor mining methods.

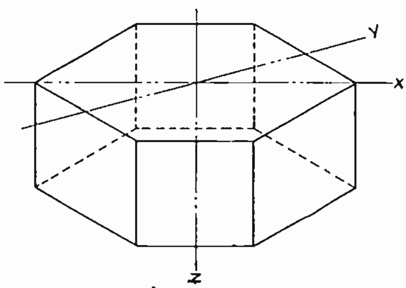

Fig. 2

The usual crystal when received is similar in shape to that shown in Fig. 1. In this crystal the optical axis is parallel to an imaginary line *Z* which is drawn between two apexes. The electrical axes are of two types, one which is parallel to a line *X* drawn between the corners of the hexagonal sides and the other which is parallel to the line *Y* which is drawn between the opposite flat faces of the hexagonal sides. From this we note that there are three *X* electrical axes and three *Y* electrical axes and one optical axis. The optical axis is always at right angles or perpendicular to any of the electrical axes.

Now cut a slab of quartz from the crystal as shown in Fig. 2 making this cut at right angle to the optical axis *Z*. Then in order to obtain a workable crystal, we cut a slice from this slab as shown in Fig. 3. This slice is so cut from the slab that the slicing produces a crystal whose sides are parallel to one of the *Y* electrical axes and at right angles to one of the *X* electrical axes. We now have a crystal whose thickness represents an *X* axis, whose length a *Y* axis and the depth an optical axis.

Methods of manufacturing the crystal from this point on to the perfect oscillating condition is a specialty in itself.

Having completed the cutting of the crystal which we will term the "Curie 3" or "zero angle cut" we find that there are three frequencies to which the crystal will resonate. One frequency corresponds to the *X* dimension, one to the *Y* dimension and the other to a frequency which is between *X* and *Y* axis frequency and is termed the coupling frequency. This coupling frequency depends on the dimensions of the *X* and *Y* axes. In round crystals as shown by Dr. Hund, the *X* dimension will produce 101.6 meters per mm., the *Y* dimension 110.5 meters per mm. and the coupling frequency is equal to 0.71 of the *Y* dimension wave-length. In rectangular crystals the meters per mm. for the *X* dimension vary from 103.5 to 105.0 while for the *Y* dimension it varies from 110 to 117 meters per mm. The meters per mm. obtained for the coupling frequency cannot be stated because this depends on the dimensions of the rectangular form which may be square or any shape which the requirements demand. These figures are based on the true Curie cut and on crystals whose *Y* dimension is between 20 and 28 mm. If any cut is made which is at an angle from the Curie cut the meters per mm. will be greater, especially for the *X* dimension oscillation.

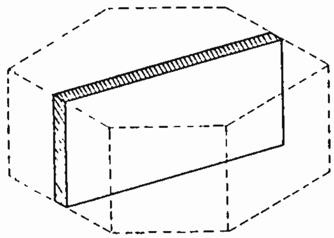

Fig. 3

Rectangular crystals are to be preferred to round crystals, first because they are cheaper to make and second because they will control a greater radio-frequency output without cracking or chipping. The latter condition is probably explained by the uneven stress conditions present in round crystals when they are oscillating under influence of radio-frequency currents.

HISTORY

P. and J. Curie first investigated quantitatively the piezo-electric properties of quartz and derived equations showing the relation between the applied pressure and the piezo-electric charge on the faces of the crystal. They also showed the converse effect where an electric charge on the crystal would produce a change in crystal dimensions.

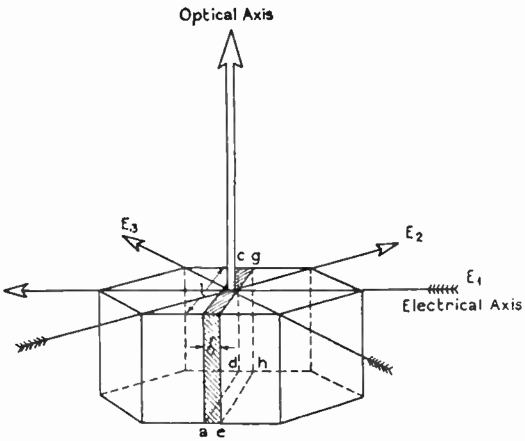

Fig. 3-A Illustrates More in Detail the Different Axes for the Crystal and Shows How the Crystal is Cut from the Rough Quartz.

Since this disclosure, various uses have been made of piezo-electric crystals, namely, as pressure gauges, loud-speakers and sound transmitters for underwater signalling.

Cady first discovered that quartz could be employed as resonators and as such to be used as standards for precision frequency determinations. Cady later discovered that crystals could be used to hold the frequency of self-oscillating circuits constant and also that crystals could be made to control the frequency of a vacuum tube circuit. It is this feature of crystal control that we are most interested in and in order to present this subject we will consider each step made by various investigators in producing vacuum tube circuits which would be capable of obtaining maximum radio-frequency output from a quartz crystal.

Cady's work may be summarized by reference to Figures 4, 5, and 6. The circuit shown in Figure 4 is essentially a self-oscillating vacuum tube circuit with a crystal placed across the grid tuning condenser. When the circuit is adjusted to

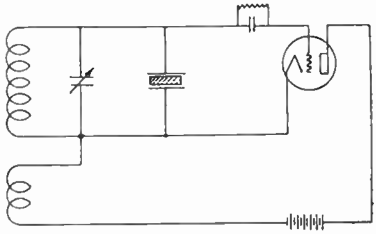

Fig. 4

the resonant frequency of the crystal, there is a tendency in the crystal to keep the frequency of the circuit equal to that of the crystal. If the plate voltage, filament voltage and load remain the same, the crystal will hold constant the frequency of the circuit, but if one or more of the above conditions are changed the circuit will oscillate at any frequency which the circuit conditions permit.

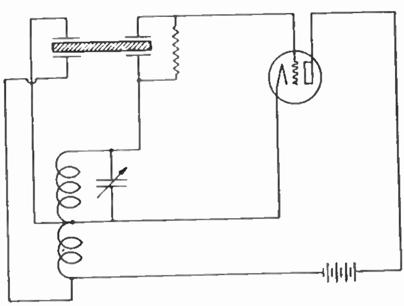

Fig. 5

Figure 5 is an elaboration of Figure 4 and is employed to obtain a greater piezo-electric voltage for controlling the frequency of the circuit. The greater piezo-electric voltage is obtained by the use of the plate feed-back principle represented by the extra set of plates on the crystal. The operation of this circuit is limited by the same conditions which are cited for the circuit shown in Figure 4.

It has been our experience that any method which depends on any self-oscillating conditions in a vacuum tube circuit in addition to piezo-electric control is dangerous for two reasons: i. e., first, because of the danger of frequency shifting and second it is very easy to crack or chip crystals in such circuits. This latter case is exaggerated when we

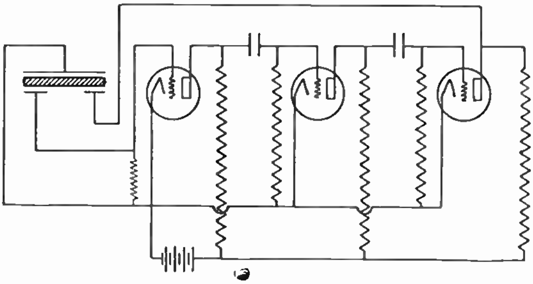

Fig. 6

tie in the crystal oscillating circuit with an unbalanced amplifying system where the radio-frequency current feed-back from the amplifying circuit is sufficient to supply enough additional current through the crystal to cause it to heat up and crack.

Figure 6 is the first circuit known to the art wherein the crystal with the associated amplifying circuits comprise a

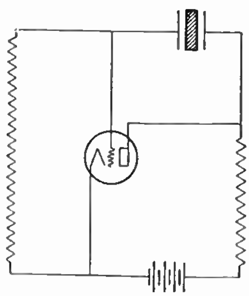

Fig. 7

system in which the crystal is the only control for the generator frequency. In this circuit the initial piezo-electric charge on the grid is amplified through three stages of resistance-coupled amplification, and by the means of a third contact plate on the crystal this amplified charge is applied to the crystal in the right phase relationship to reinforce the initial charge and by this process assist the circuit in generating radio-frequency currents.

Pierce later developed a circuit shown in Figure 7 which is capable of generating, by the use of crystal control, a source of constant frequency. In this figure the crystal is placed between grid and plate of a vacuum tube and a resistance load is inserted in the plate circuit. A grid leak is employed to hold the grid at a certain voltage with respect to the filament.

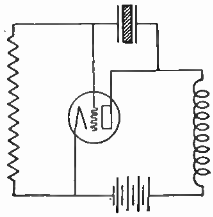

Fig. 8

Figure 8 is a modification of Figure 7, wherein an inductance is substituted for the plate resistance. Both of the Pierce circuits function in the same manner as the old De Forest Ultraudion circuit. In the Ultraudion circuit, a tuned circuit was interposed between grid and plate as shown in Fig. 9 and a choke coil was employed as a load in the plate circuit. This choke coil was so constructed that it acted as a capacitive load for all frequencies to which the tuned circuit was resonant.

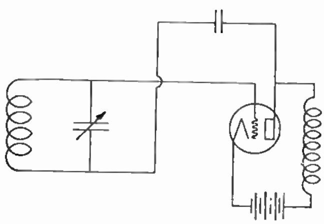

Fig. 9

In the Pierce circuits the crystal functions as a tuned circuit having a preponderance of inductance, while the plate load for the condition of oscillation has to be capacitive. To accomplish this end, Pierce uses a very large inductance coil in the plate circuit. The true inductance and the distributed capacity of the coil system used in this circuit has to be such that it will resonate to a lower frequency than that of the crystal before the circuit will oscillate. In the case where resistance is used, as in the plate circuit of Fig. 7, it is the distributed capacity of the resistance together with plate-filament capacity that affords the capacitive reactance required for the oscillation condition.

If the proper precautions are observed with the Pierce circuit with respect to the capacitive plate load condition, any crystal can be made to trigger off this circuit into the oscillating condition. In view of the fact that a grid leak is employed and the plate load is a resistance or a large inductance, it is not possible to obtain the rated power output from a given tube with this circuit. This statement is based on the fact that the I^2R losses in the resistance and inductance are considerable and the grid leak method of biasing is inefficient for reasons which will be explained later in this book. There is another objection to the Pierce circuit and that is the broad impedance curve of the plate circuit, which

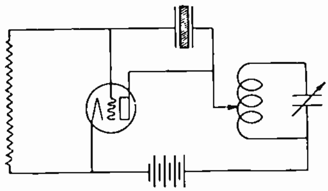

Fig. 10

permits the generation of a number of oscillations at one time should the crystal be so constructed that there are two possible oscillations, for the *X* dimension or the *Y* dimension frequency may be very close to the coupling frequency with the result that both frequencies will be heard.

PIEZO-ELECTRIC CRYSTAL RESEARCH WORK AT THE NAVAL RESEARCH LABORATORY

Realizing the limitations of piezo-electric crystal circuits then known to the art, further development work was carried on at the Naval Research Laboratory to determine whether piezo-electric crystals could be employed to control any system which could permit a reasonable radio-frequency output.

J. M. Miller, formerly of this Laboratory, developed the circuit shown in Fig. 10. This circuit is similar to Pierce's circuit with the exception that Miller employed a tuned plate circuit and a variable tap on the inductance. The tuned circuit permitted tuning to any desired frequency, thus excluding undesired frequency oscillations. The variable plate tap permitted matching of tube impedance to circuit impedance whereby maximum power transfer was possible. Low loss inductance and condensers were employed thus reducing I^2R losses in the tuned circuit to a minimum.

Miller also developed the circuit shown in Fig. 11, which circuit is the fundamental Navy circuit. In this circuit the crystal is placed between grid and filament instead of between grid and plate as in Fig. 10. With this circuit the load for the plate circuit should be inductive in order that a condition for oscillation be obtained. The action of this circuit with reference to the oscillating condition is similar to the well known Hartley self-oscillating circuit. This may be better understood by stating that the crystal, being equivalent to an inductance, is similar to the grid coil of the Hartley circuit, while the inductive load in the plate circuit of the crystal oscillator is identical to the plate coil of the Hartley system.

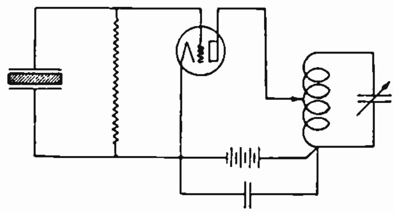

Fig. 11

Miller demonstrated that he could make both circuits oscillate with crystals of different frequency ratings. Preference was given to the use of the circuit shown in Fig. 11 because in such a circuit there is no tendency for short-circuiting the high-voltage plate circuit should the crystal crack or slide out from between the contact plates, thus causing the plates to come in contact with each other. Experiments with high-frequency crystals show that good output is obtained with high as well as low-frequency crystals when employed in the circuit shown in Fig. 11.

The problem of obtaining greater output from the crystal oscillating circuit and the amplification of this output on low frequencies was assigned to A. Crossley. The Miller circuit Fig. 11 was used as a foundation and efforts were made to increase its radio-frequency output.

A study of this circuit showed that the crystal-controlling voltage was reduced materially by the fact that a grid leak was shunted across it. This grid leak provided a shunt path for the radio-frequency piezo-electric control voltage and at the same time carried the rectified grid current required for obtaining the negative voltage for biasing the grid. Miller suggested the use of a choke coil in series with the grid leak to eliminate that part of the radio-frequency voltage loss that is due to the direct flow of current through the grid leak resistance. This materially increased the output of the crystal oscillating system.

Crossley eliminated the second load on the crystal by substituting a battery for the grid leak, connecting the negative terminal of the battery to the low radio-frequency potential side of the choke coil shown in Fig. 12.

The object of the use of the battery was to keep the swing of the crystal-controlling voltage over on the negative side of the grid voltage plate current characteristic curve, thus eliminating the load in the grid-filament path which is obtained when the grid swings positive past the zero grid voltage point on this curve. The act of swinging over the positive side of grid voltage plate current characteristic curve causes a current flow between grid and filament which represents an I^2R loss. Any method for eliminating this grid current flow or rendering it of negligible value will also permit the crystal controlling voltage to be kept at a maximum and therefore permit a maximum output to be obtained from the circuit.

In actual practice, there is a small amount of grid current flowing, but the grid voltage swing is for the greater part over on the negative side of the grid voltage plate current characteristic curve. This grid current flow is due principally to the fact that the grid battery employed does not block the plate current to zero, because a small amount of plate current is necessary before the crystal circuit will start oscillating.

The use of the battery increased the output of the circuit tremendously. Using a 600-Kc. crystal, it was possible to obtain one watt output with the original circuit employing the grid leak while with the choke and battery, an output of 21 watts was obtained. The tube used in this experiment was the UV-210 type rated at 7½ watt allowable plate dissipation. The efficiency of this circuit was 65 per cent. figuring plate input watts against radio-frequency output. The plate voltage for this test was 650 volts, while the grid battery was 80 volts.

Further experiments with 50 Watt tubes and also special tubes have shown that as high as 100 watts output can be obtained when employing high-frequency crystals in the 3000 to 4000-Kc. band. It is not possible to obtain such outputs when employing higher or lower frequency crystals. With the lower frequency crystals, the feed-back afforded by the grid plate capacity is proportional to the frequency, while the capacity between crystal plates is reduced as the frequency of the crystal is decreased. In other words, the charge on the crystal is reduced as the frequency of the crystal is decreased and correspondingly the piezo-electric controlling voltage from the crystal is likewise reduced. To make up for the reduced charge on the crystal, it is customary when using lower frequency crystals to increase the plate and grid battery voltage.

There is, however, as stated before, a certain high frequency where maximum output is obtainable and on either

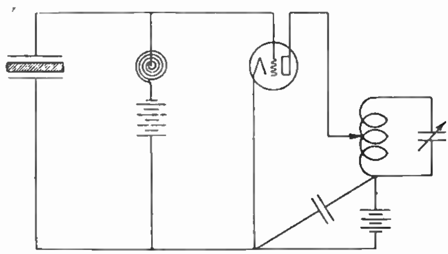

Fig. 12

side of this frequency there is a slow decrease in output. Around 3500 Kc. is approximately the peak output frequency point, while 12,000 and at 100 Kc. are the frequencies where minimum output is obtained. These output ratings are based on safe crystal current-carrying ratings, which was first shown by A. Hoyt Taylor. Taylor shows that for the different frequency crystals, there is a safe working current at which the crystal can be operated and if this point is exceeded the crystal will heat up and crack.

This condition can also be tied down to a safe wattage dissipation in the crystal, but not knowing the resistance of the crystal, we can only consider it from a current standpoint. In the 3000 to 4000 Kc. band, electrostatic voltmeter and thermal ammeter readings in the crystal circuit show approximately five watts loss in the crystal. It is only at this and higher frequencies that an electrostatic voltmeter can be used to measure the voltage across the crystal, because the shunting effect of the capacity of the meter at the lower frequencies is such that it seriously reduces the output. When measurements were made with a 500-Kc. crystal, the placing of an electrostatic voltmeter across the terminals of crystal holder was such as to reduce the output to less than one-half of the original output. This reduction in crystal piezo-electric controlling voltage is due to the fact that the plate grid feed-back voltage is divided between the two capacities, i. e., the voltmeter capacity and the crystal capacity, while at the lower frequencies the crystal capacity is nearly equal to the voltmeter capacity.

This can be shown further by reference to Fig. 13 where *Cr* is the capacity equivalent to the crystal, capacity *Cv* represents the voltmeter capacity and *Cf* the grid-plate feed-back capacity.

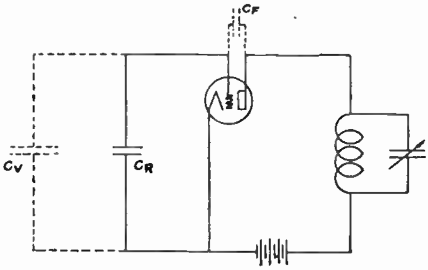

Fig. 13

From the above figure, we can note that it is not possible to obtain true voltmeter readings due to the presence of the shunt capacity *Cv* which divides the feed-back charging voltage into two paths, thus robbing the crystal of the maximum charging voltage from the plate circuit. Although we have cited the case of the shunt capacity afforded by the voltmeter, it is also true that any extraneous capacities, such as long leads from crystal to grid, poor design of crystal holder which permits additional capacity other than that of the crystal contact plates, and choke coils which have high distributed capacities, will also produce the same effect.

The capacity between contact plates of crystals in the range between 100 and 12,000 Kc., respectively, varies from 12 to 125 micro-microfarads. When we consider the capacity of the crystal and the fact that the grid plate feed-back capacity is constant, it can be readily seen, when using the same plate voltage, that the charge delivered to the crystal is reduced with the decrease of frequency. An example of this case is cited by comparing charges delivered to two crystals, i. e., a 500 and a 4,000 Kc. crystal when employed in a 7½ watt UV-210 tube circuit. With the 4,000 Kc. crystal, the charge is 64 times as great as that delivered to the 500-Kc. crystal. This increased charge on the crystal with the increase of frequency explains why it is possible to obtain greater radio-frequency output at high frequencies and why we have to be so particular about low-frequency crystals and their associated circuits. With the low-frequency crystals, it is imperative that we employ the right amount of grid biasing voltage for the condition of maximum output, while with the high-frequency crystals, it is possible to eliminate the biasing voltage and still obtain good output. It is, of course, understood that the elimination of the biasing battery means a reduction in the efficiency of the circuit and sluggish oscillating action of the crystal, especially when we use the crystal as a master oscillator.

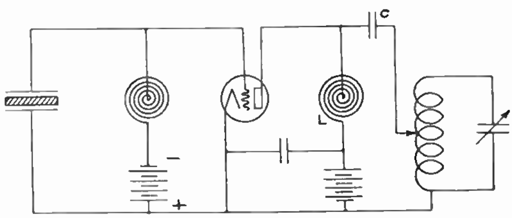

Fig. 14

An improvement on the Miller circuit was made by Crossley and is shown in Fig. 14. This improvement provides for the isolation of the radio-frequency output circuit from the high voltage direct current circuit, thus preventing the operator from accidentally coming in contact with the high voltage direct current supply. The insertion of the choke coil *L* and the condenser *C* in the circuit permits the segregation of the radio-frequency and direct current circuits. It is good practice to make the resonant period of the plate choke coil *L* equal to a frequency which is lower than that of the crystal, thus making the choke coil a capacitive reactance at the crystal frequency.

CRYSTAL HOLDERS

The subject of crystal holders is very important. Experiments conducted by Crossley, particularly in the low-frequency range, show that the crystal will become inoperative if any dirt or moisture comes in contact with the crystal. If a crystal is placed in a circuit and started oscillating and a minute drop of water or oil is placed on the crystal, it will immediately stop oscillating. The stopping of oscillations may be explained when we consider that for best operation, the top crystal contact plate is separated by a minute air cushion from the surface of the crystal when the crystal is oscillating and the introduction of moisture in place of the air causes a load to be placed on the crystal. This latter condition is similar to the use of mercury as a contact surface for the crystal, which type of contact adheres so closely to the crystal that it damps out any oscillation that tries to start up.

From the above facts it is imperative that the crystal be placed in a hermetically sealed container where no moisture or dirt can come into contact with it.

It is necessary that capacities other than that between the crystal contact plates be kept as small as possible, thus eliminating the charging losses occasioned by extraneous shunt capacities. For reliable operation and maximum output, the crystal contact plates should be intimately touching the surface of the crystal. Lapped surfaces on these plates are to be preferred, while the weight of the upper plate should be kept to a minimum. No restriction of up and down movement of the upper plate should be tolerated. Light spring pressure can be applied to this plate but for best results no pressure other than the weight of the plate is necessary.

Retaining rings of bakelite or other insulating material or brass retaining pegs can be employed to hold the crystal in one fixed position with respect to the sides of the container. A holder having all these features together with means for restricting the tendency for the crystal to jump clear of the retaining pegs when being transported is shown in Figure 15.

Experience has shown that any air-gap between upper surface of crystal and the contact plate means a great reduction in output and when used in a regular power circuit, the air-gap causes brushing between the surface of the crystal and the plate which, in turn, causes the crystal to heat and crack. Crystals which have been subjected to the brushing effect show a discoloration on the surface of the crystal at the place where the brushing occurred.

The frequency of any crystal changes with temperature and for absolute constancy of frequency it is necessary that some type of temperature control be applied either directly or indirectly to the crystal. One method is to place the crystal in a hermetically sealed container and by use of a thermostat and heating unit in this container maintain the crystal at a predetermined temperature. The second method is to place the crystal in a crystal holder of a similar type as that shown in Fig. 15 and to secure this holder on a metal plate which can be maintained at a constant temperature. The heat from the plate will be conducted through the lower crystal contact plate direct to the crystal.

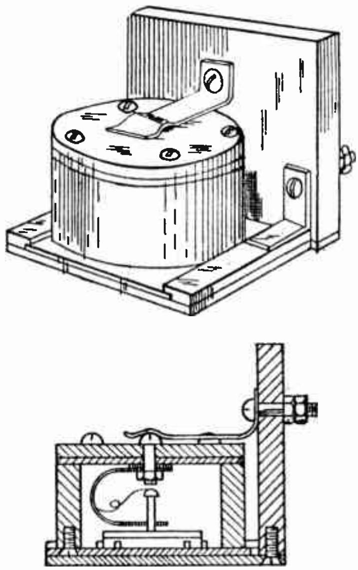

Fig. 15—Typical Crystal Holder.

The metal heating plate can be kept at a constant temperature by circulating water through it, or a sub-compartment with suitable heating unit and thermostat can be attached to this plate. A thermostat can be employed with the water circulating system to turn on or off the current in a heating coil which is placed in the water intake line to the plate. This latter water-cooling method was developed by Taylor and applied by E. L. White to the high-power high-frequency transmitters at this Laboratory.

The importance of constant temperature control is appreciated when operating high-frequency crystals, as a change of 10 deg. cent. will change the frequency as much as one kilocycle in the 4,000-Kc. range. Extreme changes in temperature met with on board Naval vessels when cruising can change the crystal frequency as much as three kilocycles, which change is very detrimental to perfect communication conditions. A remedy for this is to provide a thermostatic control which will maintain the crystal temperature above that which is ever encountered, throughout the year. This is identical with the practice now in force with reference to our Navy Standard 25 Kc. crystal calibrator, which is used as a standard of frequency for the Navy.

Recent data on temperature co-efficient in quartz crystals obtained by the Naval Research Laboratory show for the *X* axis there is a frequency change of 25 parts in a million per degree centigrade, while with the *Y* axis a change of 50 parts in a million is noted. These data on electrical characteristics appear to show that the temperature co-efficient of the elastic constant along the *Y* axis is approximately double that of the *X* axis, as we can assume that the frequency change must tie in with the mechanical change. This statement is based on our previous experiments on the resonant condition, in crystals, namely, the relation of meters per millimeter for respective electrical axes.

Several types of multiple crystal holders have been developed. One type employs the holder shown in Fig. 15 which was placed on a circular disk with a knob and pointer on the front of a panel for rotating the disk. Two contactors were placed behind the panel for making contact with each crystal holder as it was rotated past the indicated point.

CRYSTAL CONTROLLED POWER AMPLIFIERS

Having obtained reliable operating conditions with the crystal controlled oscillator, our next and most important problem was to amplify this output.

The first attempt to amplify the crystal oscillator output was made by resorting to two stages of amplification. The first stage consisted of a 7½-Watt tube, while in the second stage two 50-Watt tubes were employed. Grid leaks were used to bias the grids of the amplifier tubes. An output of 96 watts was obtained with this power amplifier at a frequency of 600 Kc. Another stage of amplification consisting of three 250-Watt tubes was added to this amplifier and the maximum output obtained was approximately 700 watts.

About this time Dr. Taylor and L. C. Young demonstrated that amplification of power from a 3,000-Kc. crystal oscillator was possible.

Considerable trouble was experienced from self-oscillations in the amplifier system. Various methods were employed to eliminate these undesired frequencies with no satisfactory result. Crossley discovered that these oscillations were in general of a high-frequency nature and that the only method of eliminating them was to place a resistance of a certain value in the plate lead, preferably as close to the plate as possible. The location of this resistance in the plate lead placed a load on the high-frequency circuit, and if sufficient resistance was inserted the load would be too great to permit the grid-plate feed-back to cause a condition of self-oscillation. The maximum value of the resistance should not exceed 300 ohms at 300 Kc. and can be very low on sets of very high frequency; that is, small enough to have a negligible effect

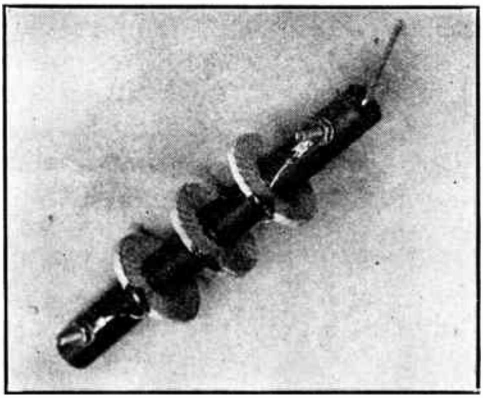

Fig. 16—Choke Coil.

on the output of the amplifier circuit at the amplified frequency. This can be better understood when we consider that the plate circuit impedance at the desired frequency is at least 5,000 ohms at medium frequencies for all types of tubes other than the one-Kw. type, and the additional resistance placed in this circuit for purpose of stopping self-oscillations never is greater than 6 per cent. of the total circuit impedance. The impedance of the plate circuit which is resonant to the self-oscillation frequency is low, and the resistance referred to above is so located that it is in series with this resonant circuit.

The importance of shielding each stage of amplification was soon apparent and this was accomplished by providing metal containers for each stage. It was noted that there was sufficient feed-back through the grid plate capacity of the amplifier tubes to prevent maximum power amplification per stage. L. A. Gebhard and Miller suggested and demonstrated the power amplification gain which is possible when neutralizing the feed-back and also applying a high value of biasing voltage to the grid of the amplifying tubes.

The neutralizing of the feed-back in the amplifier tubes permitted maximum grid excitation while the use of the high value of grid biasing voltage reduced grid filament circuit losses to a minimum. A power amplification of 80 is obtainable by the method proposed above. A concrete case of this condition was cited when we amplified the output of a 7½-Watt tube circuit by use of a UV-851 one-Kw. tube and obtained 600 watts. From the above it can be noted that it is possible to reduce the number of stages of amplification very materially, thus eliminating troubles experienced with the excessive number of stages which are required when employing the old method of cascade amplification.

One more source of trouble was experienced in the development of the amplification system, and that was in the choke coils. It was found during numerous incidences that the choke coils would burn up, particularly the plate choke coils. These choke coils were of the single-layer and the pancake universal wound type. An investigation of the reason for this burning effect showed that the burning occurred at frequencies which were close to the second, fourth, sixth, and other even harmonic frequencies of the fundamental of the choke coil. It then became necessary to make our choke coils such that the danger or burning frequencies would be other than that of the operating frequency of the transmitter.

If the transmitter is required to cover a broad band of frequencies, a radical change has to be made in the choke coils. This change consists of using at least three choke coils, preferably of the universal wound type, in a series connection. Each coil should have the same number of turns and the same shape and arranged on a bakelite or pyrex rod or form in such a way that the magnetic fields add. This multiple choke arrangement provides a method of obtaining in a concentrated form a choke coil which has nearly twice the inductance and two-thirds the distributed capacity of the best type single-layer choke coil. It also has, by virtue of the addition of impedance of the respective coils, a high value of impedance at the dangerous harmonic frequencies. This latter characteristic makes this type of choke well suited for use in transmitters which employ the principle of frequency doubling or tripling to obtain super high-frequency oscillations. A choke coil similar to the type referred to above is shown in Figure 16.

Having solved the major problems involved in the crystal controlled transmitter with reference to output, the next problem was that of keying the system. Various methods were tried and abandoned due partly to sluggishness of action or the fact that too large a load was taken from supply source which furnished the necessary negative voltage for blocking the grid of the control tube. A satisfactory system was finally obtained and may be explained by reference to Figure 17.

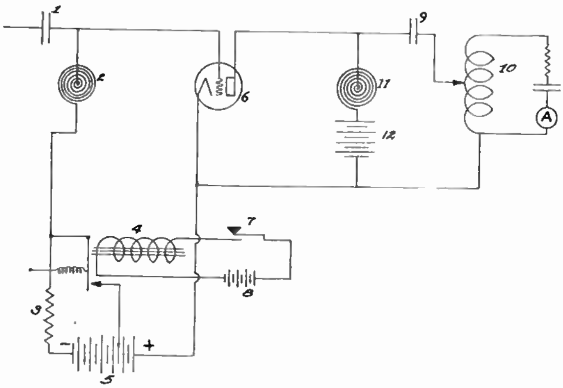

Fig. 17

In this figure there is shown one of the stages of amplification which it is intended to key. The grid circuit consists of the blocking condenser 1, choke coil 2, relay 4, high resistance 3 and the battery 5. Associated with the relay 4 is the key 7 and relay battery 8. The plate circuit is of the conventional type and consists of blocking condenser 9, antenna or dummy circuit 10 with the usual plate choke 11 and plate potential source 12.

The keying is accomplished by changing the grid biasing voltage from an operating voltage to a high blocking voltage through the agency of the relay 4 and the associated circuits. With the key 7 closed, current flows through the relay 4 and closes the contacts, thus permitting the grid lead to be connected to the low-voltage tap on the battery 5. The high-resistance 3 is then placed across the remainder of the battery and, due to its high value, it takes no appreciable load from the battery 5. When the key is up or in the open position, the contacts on relay 4 spring back and disconnect the low voltage tap on the battery 5, thus through the resistance 3, making a path for the high blocking voltage to be impressed on the grid. The fact that there is no current flow through the grid circuit also indicates that there is no *I R* drop over the resistance 3, thus we can, by means of the relay, change the grid voltage from an optimum operating value to an absolute blocking value. The use of the high-resistance also cuts down to a minimum the sparking and sticking of the contacts on the relay. With this method of keying it is possible to key at speeds in excess of 100 words per minute.

COMPLETE TRANSMITTER

Further work on this problem of amplification at frequencies from 150 to 600 Kc. proved that it was possible to obtain an output of 13 Kw. into a dummy antenna system. The complete details of the system which is capable of delivering this radio-frequency power output may be explained by reference to Fig. 18.

In this figure three stages of amplification are shown. The first stage consists of a 50 Watt impedance coupled amplifier which feeds into a 1-Kw. tuned amplifier stage and from this stage to a 20-Kw. amplifier circuit.

The crystal controlled oscillator consists of a multiple crystal holder with the associated grid circuit which comprises the grid radio-frequency choke and the source of biasing voltage. The plate circuit of this oscillator employs the parallel feeds through agency of the multiple choke coil, a source of high direct voltage, a 0.004 mfd. radio-frequency bypass condenser and a resonant circuit consisting of an inductance and two condensers with a suitable radio-frequency ammeter. Two condensers, one of which is variable, are employed to permit tuning to resonance with the inductance over a given range of frequencies.

Voltage required for exciting the grid of the first amplifier tube is obtained from a tap on the inductance of the resonant circuit. Proper biasing voltage for the grid of the amplifier tube is obtained from a potentiometer and flows through the inductance of the resonant circuit direct to the grid. This method of biasing the grid of the amplifier tube eliminates the usual grid condenser and choke coil system.

The plate circuit of the first amplifier tube comprises a multiple radio-frequency choke coil with the usual high voltage direct current source and a resistance load circuit. The radio-frequency output of the choke coil is delivered to the resistance load through the two by-pass condensers shown in the diagram.

The choke coil system is so constructed that it is resonant to a lower frequency than that of the range of the transmitter and therefore provides a capacitive load. This capacitive load prevents any tendency for feed-back in the amplifier, thus saving the crystal circuit from any surge effects which tend to overload and break the crystal.

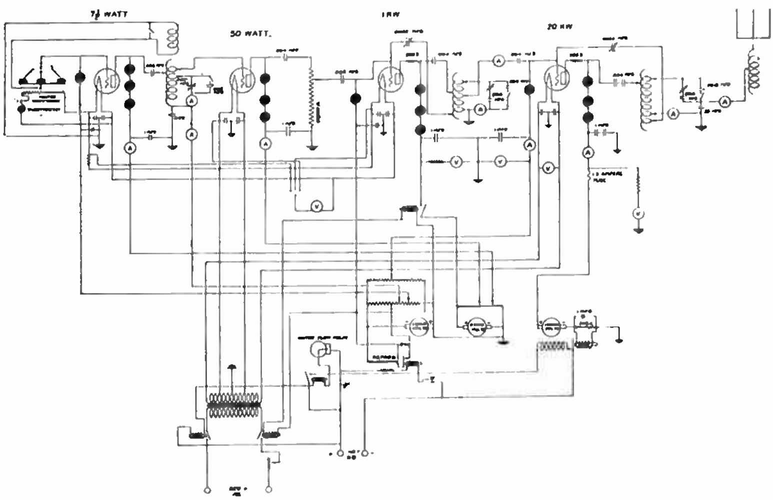

Fig. 18

A variable contactor is used on the load resistance for obtaining optimum controlling voltage for the grid of the second amplifier tube. A 0.001 mfd. by-pass condenser segregated the radio-frequency resistance load circuit from the grid biasing system. It will be noted that the grid biasing system of this tube includes the keying system referred to previously in this text.

The plate circuit of the second amplifier has the usual parallel radio-frequency feed circuit and in addition there is the balance or neutralizing circuit which comprises the counter-inductance and a .0002 mfd. variable air condenser.

This balance or neutralizing system is found to be very reliable and easy to adjust.

The third amplifier stage is identical to the second stage with the exception of the addition of the antenna load system. As will be noticed, the voltage for feeding the antenna is obtained from the drop across a condenser which is placed in series with the plate resonant circuit. This condenser was a 0.25 mfd. mica condenser with five taps of 0.05 mfd. each. This condenser in addition to supplying required voltage for the antenna system also functions by virtue of its low impedance in reducing harmonic frequencies to a low value.

PROTECTIVE DEVICES

Various kinds of protective devices were employed in this transmitter. The first and most important protective device was tied in with the biasing battery circuit and functioned in opening the filament and 2,500 Volt supply when no current was being supplied from the biasing battery.

The second device consisted of a water flow protective relay circuit. When there was no flow of water through the water-cooled tubes, the device opened the filament supply circuit and also the field of the high-voltage generator.

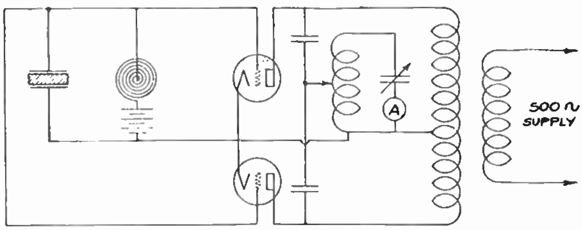

Fig. 19

A circuit breaker was placed in series with the negative terminal of the high voltage generator and when an overload was placed on the generator it opened the generator field circuit.

As a safety-first precaution, a condenser and a resistance was placed across the coil of the circuit breaker. These units maintained the negative side of the generator at ground potential should the breaker coil accidentally open. They also had a tendency to reduce line surges to a great extent by acting as a damping means.

MISCELLANEOUS

Very small output is obtainable from a crystal on the lower frequencies required of the transmitter and for this reason a small amount of regeneration was employed in the crystal circuit. The regenerative feature is shown in Fig. 18, by the grid feed-back coil in the crystal oscillator circuit. On the higher frequencies this coil was short-circuited, for as previously stated, regeneration, especially at higher frequencies than 400 Kc., is liable to crack the crystal.

The 50 Watt stage of amplification was required for the low-frequency amplification, but can be dispensed with at the high frequencies. With well made crystals and proper circuits, it is possible to use only two stages of amplification

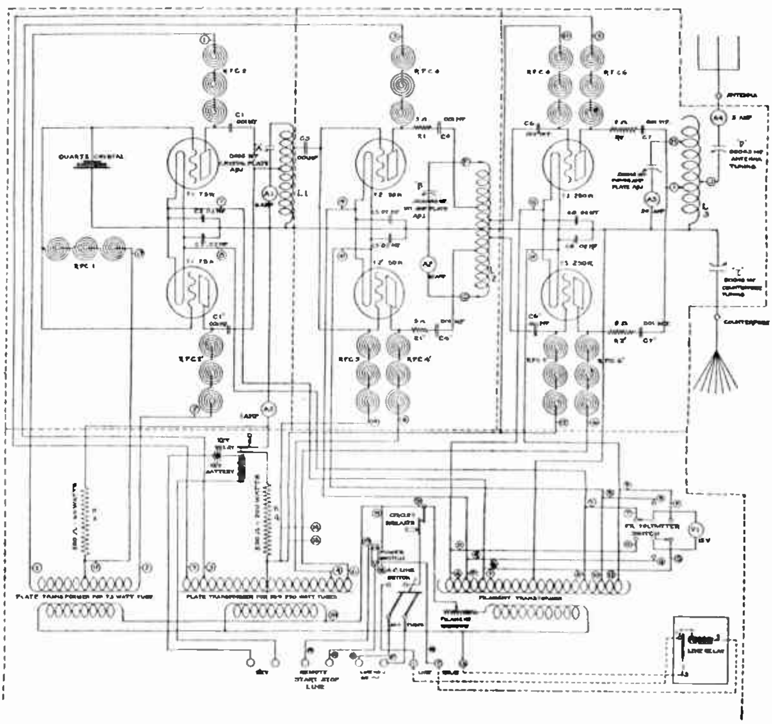

Fig. 20—Schematic Circuit of Crystal-Controlled Transmitter.

and obtain outputs in excess of 10 Kw. when operating the transmitter over the range from 400 to 600 Kc.

There was no need for frequency doubling in this transmitter and consequently no mention was made of it. Frequency doubling and tripling circuits were developed by Taylor and have been used very extensively in our numerous high-frequency transmitters which are in operation at N. K. F. This principle is also used in transmitters furnished by the Naval Research Laboratory to the Coast Guard, Army, Naval ships and stations.

The work covered in the construction of the low frequency transmitter was undertaken by A. Crossley with the assistance of W. F. McBride. Messrs. Gebhard, Young, White and Taylor were responsible for the development of the high power high-frequency transmitters.

The development of the low power high-frequency transmitter which derives its source of plate potential from alternating current circuits was undertaken by R. B. Meyer. Meyer developed the crystal oscillator circuit which employs one crystal and two tubes with the split transformer plate supply circuit. Best results are obtained with such a circuit when the frequency of the supply source is 500 or more cycles. The Meyer circuit is shown in Fig. 19. This circuit is used in transmitters designed and built for the Army and the Marine Corps. A schematic wiring diagram of this transmitter is shown in Fig. 20. An inspection of this diagram will show the automatic balance which is obtainable in the amplifier circuits when one resorts to the use of an alternating plate current supply. This balance is obtained by using approximately the same number of plate turns in each amplifier tube circuit.

This transmitter is designed for frequency doubling and is capable of covering a frequency range from 3,500 to 9,000 Kc. The rated output of the transmitter is 500 watts.

Figures 21 and 22 are photographs of this transmitter showing front and side views.

A method for obtaining more piezo-electric controlling voltage was developed by Taylor. This is accomplished by employing two crystals which have identical frequency characteristics and connecting these crystals in parallel with each other in the conventional circuit. Series stabilizing choke coils are placed in each crystal circuit for the purpose of holding both crystals in synchronism should temperature effects tend to change the natural frequency of the respective crystals.

Taylor also developed a method for obtaining three-phase source of radio-frequency by employing three synchronized crystal circuits which feed into a *Y*-connected output circuit.

Among other developments of the Naval Research Laboratory is a means for obtaining a crystal-controlled oscillating circuit which by use of stacked crystals and retuning of plate circuit can be made to generate currents of a frequency which corresponds to that of any crystal employed in the stack. The Western Electric type 211D tube is well adapted to crystal control.

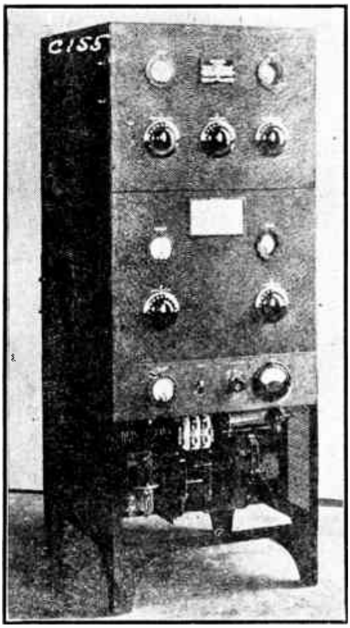

Fig. 21

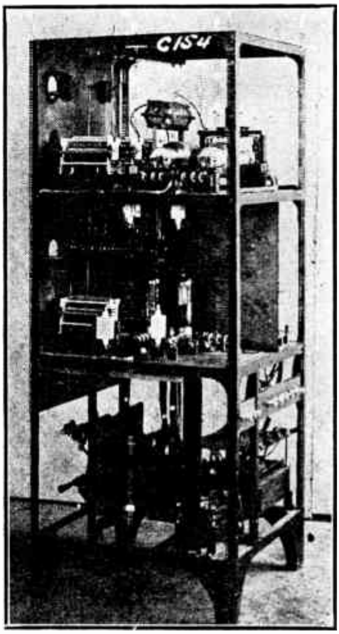

Fig. 22

CRYSTAL CONTROLLED BROADCAST AMPLIFIER

A schematic diagram of a 1-Kw. crystal-controlled amplifier which is used in some of the General Electric broadcast stations is shown in Fig. 23. The crystal-controlled tube, type UX-210, operates with the crystal connected between its grid and filament circuits. The plate circuit of the tube is tuned by means of a variable condenser which is designed to cover the broadcast frequency band. The crystals themselves are mounted on a temperature-controlled compartment and a thermostat is supplied in order to maintain the temperature constant at 45 degrees C. Provision is made for mounting four crystals, any one of which may readily be selected by means of a switch on the panel.

A second UX-210 tube is used to amplify the output from the crystal-controlled tube and this in turn is followed by a

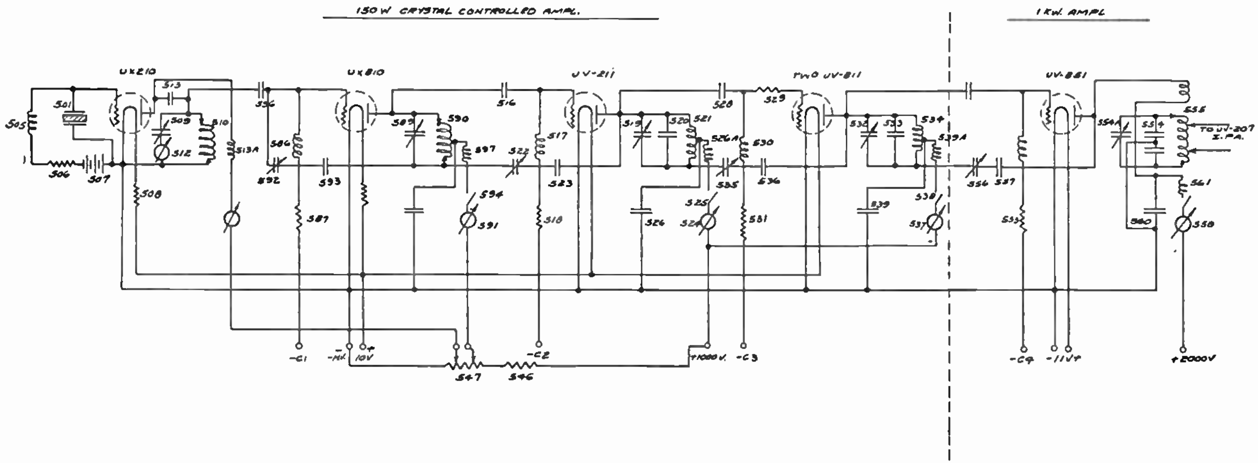

Fig. 23—Schematic Diagram Illustrating Various Circuits Employed in Crystal-Controlled Unit.

UV-211, 50 watt tube. Two additional UV-211 tubes connected in parallel amplify the output from the first UV-211 tube and these are followed by a 1-Kw. tube type UV-851. Straight amplification is employed throughout this unit, the crystal being ground for the final output frequency that is desired. Sufficient energy is available from the UV-851 stage to excite one or two water-cooled radio amplifier tubes.

TEST QUESTIONS

Number Your Answers 41 and add Your **Student Number**

1. State the material used and show, by a figure, how the crystal is cut from it.

2. Name several persons who contributed largely in the development of the piezo-electric crystal-control systems.

3. Draw a diagram of the fundamental Navy circuit crystal oscillator.

4. When employing a high-frequency crystal oscillator in the 3,000 Kc. band, how many watts output may be obtained?

5. What may stop a crystal from oscillating?

6. Will a change in temperature change the frequency of an oscillating crystal?

7. Can the power from a 3,000 Kc. crystal oscillator be amplified?

8. What is the chief trouble in the amplifier system of a crystal oscillator?

9. Draw a diagram showing how keying may be accomplished in a crystal oscillator.

10. What kind of tubes are mentioned in this lesson as being suitable for use in a crystal oscillator?

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LESSON TEXT No. 42

CONSTRUCTION AND OPERATION OF POWER AMPLIFIERS

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An aim in life is the only fortune worth the finding; and it is not to be found in foreign lands, but in the heart itself.—ROBERT LOUIS STEVENSON.

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

INTRODUCTION

The term "Power Amplifier" is applied to radio-frequency and to audio-frequency amplifiers. in radio transmitting and receiving equipment. In this text we are only concerned with audio-frequency amplifiers. We will consider their design, construction, and theory of operation, starting with the so-called "Low Power Amplifiers" and ending with the units that are termed "High Power Amplifiers," as far as audio-frequency amplification in the course of radio reception is concerned.

A power amplifier, for audio-frequency amplification in a radio receiving installation, is an amplifier which employs one or more power tubes.

A power tube is a tube that is used in an audio-frequency amplifier to obtain greater amplification without distortion than can be obtained with a receiving tube of the UX-201-A type. In other words, a power tube is one that can produce 100 milli-watts, or more, of undistorted audio-frequency output, when employed under normal operating conditions.

You will observe that the definitions given in the preceding paragraphs are relative, that is, a 100 milli-watt tube would hardly be called a "Power Tube" if it were to be used in a radio transmitting system, but it could be so called when employed in a receiving set. Therefore, it is well to bear in mind the fact that the preceding definitions, and those that follow, are given with the understanding that they are applicable, primarily, to audio-frequency amplifiers which are used in connection with radio receiving systems.

The UX-201-A is an excellent receiving tube for amplifying the small electric currents that enter the input circuit of the receiver, for changing these high-frequency currents into audio-frequency currents, (detector action), and for effecting a small amount of audio-frequency amplification. However, you cannot supply a loud-speaker with enough volume from the output circuit of a UX-201-A to cause that unit to produce a great amount of volume without distortion. It might be well to mention the fact that the UX-201-A was not designed for supplying more than 55 milli-watts of audio-frequency energy in an undistorted form.

The chief reason for the poor quality output signals that are heard from the output units in more than 50 per cent of the radio installations today is that the tubes used are being overloaded. The reason that you get distortion when you use tubes of the UX-201-A type to drive a loud-speaker is that you are overloading one or more of your tubes in trying to get plenty of volume.

When we say that a tube is overloaded we mean that the potential variations on the grid of the tube in question are of such a magnitude that they cause values of plate current which are off the straight line part of the characteristic curve of the tube used, hence you effect non-linear amplification which is manifested in the loud-speaker output by distortion.

Now, as long as the potential variations on the grid of an amplifier tube are kept within the range of the straight line part of the characteristic curve of the tube used, it will be possible to get linear amplification and undistorted output signals. If, in the course of following the path of the signals through an audio-frequency amplifier, we come to a stage where the grid voltage swing is too great for the tube used in this stage, we should substitute a tube having the proper characteristics to handle a grid swing of this magnitude, hence the use of the "Power Tube" in the "Power Amplifier".

The "Power Tube" is so designed that the straight part of its plate current-grid voltage characteristic curve covers a greater range of grid voltage than in the case of the UX-201-A, hence it will allow for greater grid voltage swings before the values of plate current reach points that are off the straight part of the curve.

Just as we have our 7.5 watt (UX-210) transmitting tube; our 100 watt (UV-203-A); and our 250 watt (UV-204-A) Radiotrons for radio-frequency amplification; so do we have in receiving, our 15 milli-watt, (UX-201-A); our 330 milli-watt (UX-171-A); and our 1.5 watt (UX-210) Radiotrons, etc., for audio-frequency amplification. You will note the difference in the rating of the UX-210 at radio and audio-frequencies, namely, 7.5 watts at radio-frequencies and 1.5 watts at audio-frequencies. It might be well to note the fact that the audio-frequency ratings given above are the power outputs for undistorted audio-frequency signals and that higher outputs may be obtained at audio-frequencies, with the tubes mentioned, but with some distortion along with it.

The term "Power Amplifier", you see, is really a relative term. In transmitting it is usually applied to the last stage of radio-frequency amplification. In receiving it is applied, in many instances, to the last stage of audio-frequency amplification. In the latter case we can be more specific and say that the term is applied, in general, to any amplifying unit which employs a tube of greater power output at audio-frequencies than the UX-210-A.

AMPLIFIER TUBE CONSTANTS

Before discussing the details concerning different types of power amplifiers, let us first consider some of the constants of the different types of power tubes that will be mentioned in the following text, as well as the receiving tubes that are used ahead of these power tubes. We shall bear in mind the fact that we are primarily interested in the amount of undistorted signal output which the tubes in question can supply, due to the fact that one of the prime reasons for using a power tube is to effect great volume without distortion. The following is a list of the tubes in which we are interested, together with some of their constants:

TABLE I

Type	Filament Voltage	Plate Voltage	Grid Voltage	Plate Current	Voltage Amp. Factor	Maximum Undistorted Output In Milli-Watts
UX-199	3.0	90.0	— 4.5	2.5	6.6	7.0
UX-201-A	5.0	90.0	— 4.5	2.5	8.0	15.0
		135.0	— 9.0	3.0	8.0	55.0
UX-120	3.0	135.0	—22.5	6.5	3.3	110.0
UX-112-A	5.0	135.0	— 9.0	7.0	8.0	120.0
		157.5	—10.5	9.5	8.0	195.0
UX-171-A	5.0	135.0	—27.0	16.0	3.0	330.0
		180.0	—40.5	20.0	3.0	700.0
UX-210	7.5	350.0	—27.0	16.0	8.0	925.0
		425.0	—35.0	18.0	8.0	1540.0
UX-245	2.5	250.0	—50.0	30-35	3.5	1600.0
UX-250	7.5	350.0	—63.0	45.0	3.8	2350.0
		450.0	—84.0	55.0	3.8	4650.0

LOW POWER AMPLIFIER

Figure 1 is the schematic diagram of a power amplifier, which produces good quality audio amplification and volume.

It is to be remembered that although the use of power tubes in an audio-frequency amplifier circuit is what produced the term "Power Amplifier" as used in connection with radio reception, the elements of the amplifier circuit must be of good quality and have the proper design to allow for good quality output signals.

In this particular amplifier the three different fundamental types of audio-frequency amplifier circuits are employed. The first stage is resistance coupled; the second stage is transformer coupled; and the third stage is resistance coupled, with an impedance leak across the grid filament terminals of the last amplifier tube.

Resistance coupled amplification possesses the inherent characteristics that all frequencies in the audio-frequency band in which we are interested in the course of the reception of radio broadcast signals, are amplified equally. The amplification is not as great as in the case of transformer coupled circuits. In the latter, voltage amplification is effected in the transformer itself, due to the step-up ratio between the primary and secondary windings. Whereas in the former the resistance coupling unit affords no inherent amplification. All the voltage step-up is attainable due to the amplification factor of the tube used.

Transformer coupled amplification produces the greatest step-up in signal voltage, but some audio-frequency interstage transformers show partiality to certain frequencies. While this might not be detected in the use of one transformer, if you use two stages of transformer coupling the chances are considerably greater. Unless you use transformers of extremely careful design and construction, which amplify the low frequency notes in the same proportion that the high frequency notes are amplified.

In the use of resistance coupling, you have a duplicate of the input circuit of a detector tube, (condenser in series with the grid and grid leak between grid and filament), with the exception that different constants are used and the frequency of the signals under consideration are different, e. g., in a resistance coupling unit the condenser has a value of the order of .05 mfd. as against .00025 mfd. in a detector circuit; the grid leak in a resistance coupling unit is usually a fraction of a megohm whereas in a detector circuit it is of the order of several megohms; in a resistance coupled unit such as we are considering we are concerned with audio-frequencies in the band between 50 and 5,000 cycles, whereas in the detector input circuit it is with radio-frequency currents that we are concerned.

Just as we get rectification in a detector circuit, so would we get rectification in a resistance coupled amplifier circuit, with subsequent distortion in the output signals, if we didn't keep the grid leak resistor of a low enough value so that electrons would leak off to the filament as fast as they collected on that plate of the coupling condenser connected to the grid terminal of the tube. This can be done without much trouble in the first stage of amplification, but in the last amplifier stage the grid swings through such a large potential difference that a great number of electrons are attracted to the grid of the tube when its potential is swinging through that half of its

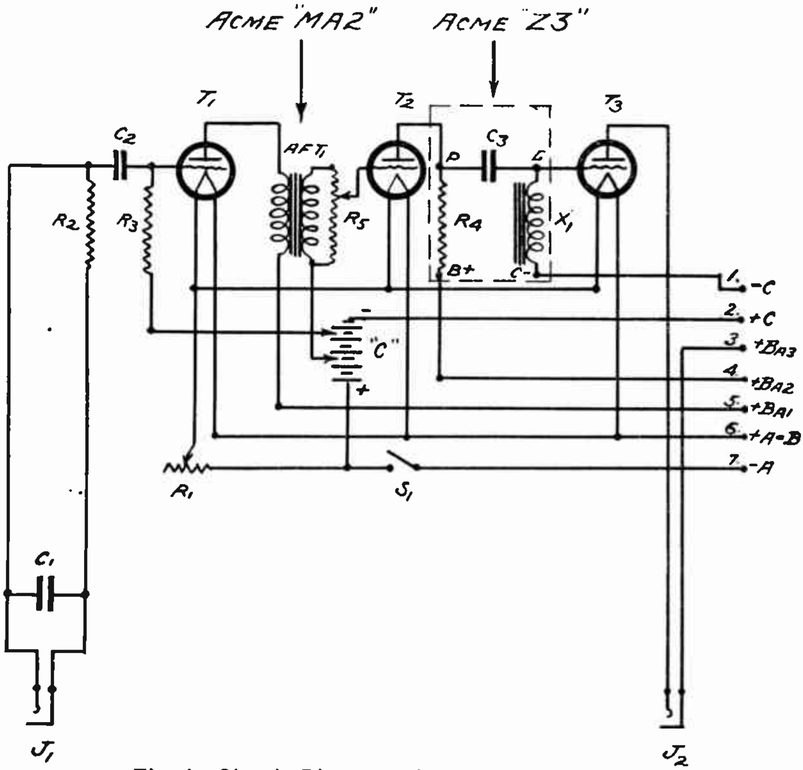

Fig. 1—Circuit Diagram of Low Power Amplifier.

cycle which is in the positive direction. Hence the value of grid leak must be made quite low or rectification will occur, and when the leak is decreased to that value which obviates the possibility of rectification, the value in question is usually so low that it greatly impairs the output volume.

What we want, then, in the grid circuit of the last stage amplifier, is a leak that will offer a low resistance to direct current flow, but a high resistance to alternating current flow. The impedance leak is the answer, hence its use in this circuit.

The following is a list of the apparatus used in this power amplifier together with the circuit constants:

AFT_1—Audio-frequency interstage transformer.
X_1—200 henry reactor.
C_1—.002 mfd. radio-frequency by-pass condenser.
C_2—.05 mfd. by-pass condenser.
C_3—.05 mfd. by-pass condenser.
R_1—6 ohm rheostat.
R_2—50,000 ohm coupling resistor.
R_3—50,000 ohm coupling resistor.
R_4—200,000 ohm resistor.

Fig. 2—Panel Arrangement of Amplifier.

R_5—500,000 ohm potentiometer.
T_1—UX-201-A.
T_2—UX-201-A.
T_3—UX-171-A.
3 —UX tube sockets.
J_1—Open circuit jack.
J_2—Open circuit jack.
S_1—Filament switch.

You will note that there are seven power supply terminals in this amplifier unit, which are numbered 1 to 7 on the schematic diagram of figure 1. The following is a list of the proper voltages to use:

No. 1—C for T_3 .... -19.5 volts.
No. 2—Positive terminal of external 19.5 volt "C" battery for T_3.

No. 3—"B" battery plus for T_3 . . . 135.0 volts.
No. 4—"B" battery plus for T_2 . . . 135.0 volts.
No. 5—"B" battery plus for T_1 . . . 90.0 volts.
No. 6—Positive 6 volt battery and negative "B" battery.
No. 7—Negative 6 volt battery.

There is a 7.5 volt "C" battery within the amplifier assembly which is designated as "C" on the diagram in figure 1. You will note that this 7.5 plus the external 19.5 volt battery gives a total bias of 27 volts on the grid of the last stage amplifier tube which has 135 volts on its plate. It is well to use a negative bias of -4.5 volts on the grid of T_1 and -1.5 volts on the grid of T_2.

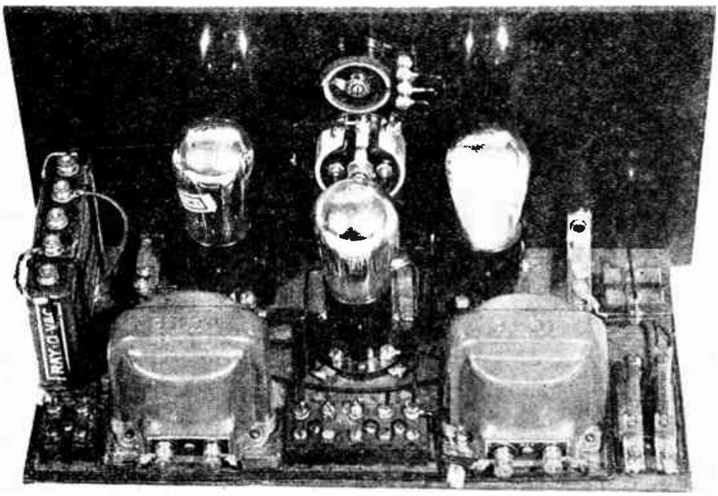

Fig. 3—Rear View of Amplifier.

If you want to push this amplifier a bit, you can increase the "B" supply for T_2 to 157.5 volts with a 3.0 volt bias on the grid of this tube, and raise the plate supply for T3 to 180 volts, putting a bias of 40.5 volts on the grid of this tube.

It is well to draw your attention to the fact that this power tube UX-171-A draws considerable plate current as compared with tubes of the UX-201-A type. For instance, with 135 volts on its plate and a 27 volt bias, this tube draws 16 milli-amps. of plate current, while with 180 volts on its plate and a 40.5 volt bias it draws 20 mils. In view of these facts, you can see that it is not wise to put more than 135 volts on the plate of this tube when you are using dry cell "B" batteries due to the rapidity with which they will be used up. However, if you have a "B" eliminator capable of supplying 180 volts, it is possible to use the higher voltage.

From a consideration of the facts contained in the preceding paragraph, and with the added knowledge that the standard loud-speaker should not have its field coil windings subjected to the flow of a direct current of greater than 10 milli-amps., you can see that when using the type of circuit shown in figure 1 with a UX-171-A in the last stage, it is not desirable to plug the loud-speaker right in the output jack of the last stage but rather, to couple the loud-speaker to the amplifier through the medium of an output transformer or a choke coil-condenser coupling unit.

Figure 2 is a front view of this amplifier. Figure 3 is a rear view, and figure 4 is a top view.

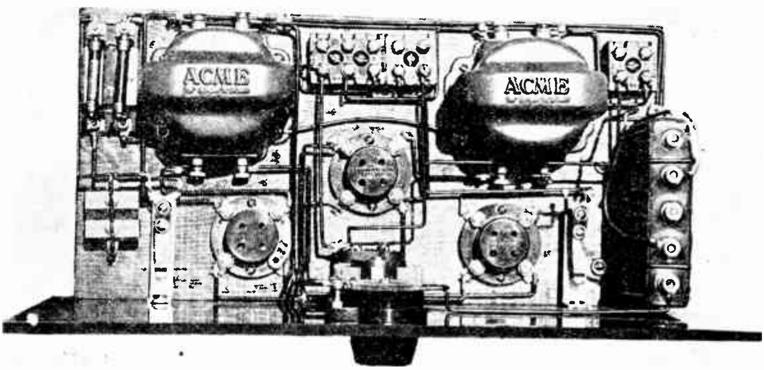

Fig. 4—Top View of Amplifier.

DOUBLE IMPEDANCE COUPLED AMPLIFIER

Figure 5 is the schematic diagram of an audio-frequency amplifier which uses two small power tubes. In this amplifier circuit there are two stages of impedance coupling, each employing the impedance leak, and one stage of transformer coupling.

In the previous discussion of a power amplifier, the point was brought up as to why resistance coupled amplifiers of the past had been modified, during the present era, by the application of the impedance leak, to prevent rectification with subsequent distortion. In the circuit now under discussion, two stages of impedance coupling have been also modified by the application of the desirable impedance leak.

In the amplifier, Figure 1, there are two stages of resistance coupled amplification, one of them modified, and one stage of transformer coupled amplification. In the "Double Impedance" amplifier there are two stages of impedance coupled amplification, both of them modified, and one stage of transformer coupled amplification.

Although Figure 5 gives quite a detailed idea of this type of amplifier, it might be well to list the component parts, as follows:

2—General Radio type 373 double impedance couplers.
1—General Radio type 285-D audio-frequency transformer.
1—General Radio type 387-A speaker filter.
1—General Radio type 410 rheostat, 6 ohms.
3—General Radio type 349, UX tube sockets.

SCHEMATIC DIAGRAM
FOR COMBINATION 2 STAGE DOUBLE IMPEDANCE COUPLED
AND 1 STAGE TRANSFORMER COUPLED AMPLIFIER WITH SPEAKER FILTER

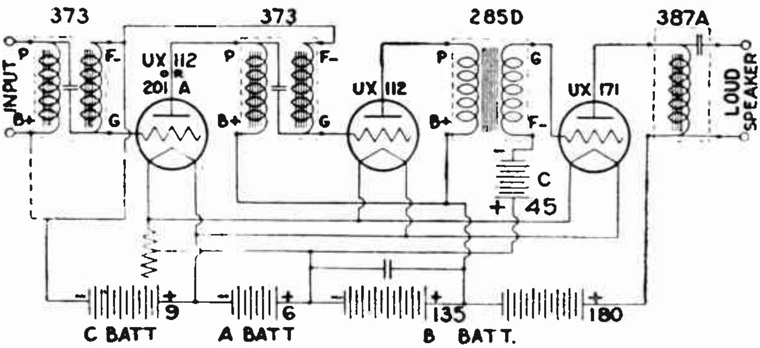

Fig. 5.

You will note that either a UX-201-A or a UX-112 can be used in the first stage; a UX-112 is used in the second stage; and a UX-171-A is used in the last stage, with a coupling unit between the amplifier output and the field coil windings of the loud-speaker.

Either an output filter, as it is termed here, or an output transformer is recommended for use wherever the direct current flow to the plate of the last stage amplifier tube is more than 10 milli-amperes. This is due to the fact that currents of greater value are quite apt to burn out the speaker field coil windings which are usually made of very fine wire. Also, the flow of this relatively high value of direct current through the field coil windings of the speaker is quite apt to demagnetize the permanent magnet in the field coil assembly, which will cause the speaker to decrease in sensitivity. The prime function of the output transformer, or the output filter, then, is to keep direct current of abnormal value out of the loud-speaker field coil windings.

ECONOMICAL HIGH POWER AMPLIFIER

We have termed this unit an "Economical High Power Amplifier," because the relative cost of the component parts for its construction is quite low.

The schematic diagram is shown in Figure 6 and the parts used in its construction, as well as the circuit constants, are given in the following list:

(1) —Power transformer.
One 450 volt plate winding.
Two 8 volt filament windings, one being center-tapped.
X_1—30 henry filter choke.
X_2—30 henry filter choke.
AFT_1—Audio-frequency transformer (2 to 1.)
AFT_2—Output transformer (1 to 1.)
C_1—750 volt, 2 mfd. filter condenser.
C_2—750 volt, 4 mfd. filter condenser.
C_3—750 volt, 6 mfd. filter condenser.
C_4—200 volt, 1 mfd. by-pass condenser.
C_5—200 volt, 1 mfd. by-pass condenser.
R_1—7 ohm rheostat.
R_2—7 ohm rheostat.
R_3—2,000 ohm variable resistor.
R_4—200 ohm potentiometer.
R_5—500,000 ohm potentiometer.
R_6—Heavy duty resistor, 20,000 ohms.
R_7—Heavy duty resistor, 4,500 ohms.
R_8—Heavy duty resistor, 7,500 ohms.
R_9—Heavy duty resistor, 9,000 ohms.
J_1—Open circuit jack.
J_2—Open circuit jack.
S_1—Filament switch.
—Overall size of amplifier, 21″x7″x10″ deep.

Considering the schematic diagram, you will note that 110 volts AC is supplied to the primary winding of the power transformer, through the single pole, single throw switch (S_1), which functions to turn the amplifier on or off, due to the fact that it supplies or removes the supply current to the plate and the filament of the power amplifier tube.

The high voltage secondary winding of the power transformer is the source of the AC which is to be rectified for application to the plate of the power amplifier tube. What we really do is to connect one side of this winding to the amplifier filament circuit, through the biasing resistance (R_3), and we connect the other end of this winding to the plate of the rectifier tube, through a rectifier tube (which only allows current to pass in one direction), through a filter circuit, and thence through the primary winding of an output transformer. The rectifier tube functions to change the AC to DC and the filter circuit functions to smooth out the ripple in the rectified AC.

The filament winding for the rectifier filament supply must be insulated for voltages of the order of 1.41x450, or, 635 volts due to the fact that the peak voltages at this point in the circuit are of the order of 635 volts, the rectifier filament winding being the source of the positive lead for the DC supply.

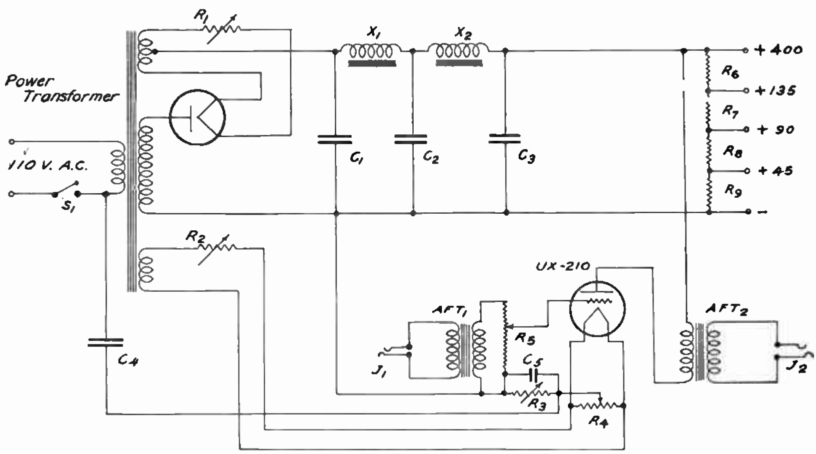

Fig. 6

Two 30 henry chokes are used in the filter circuit, together with 12 microfarads of capacity.

The filament of the power amplifier tube is energized from one of the low voltage windings on the power transformer. The filament current is limited to its normal value, 1.25 amps., by means of the 7 ohm rheostat (R_2).

The audio-frequency signal to be amplified is supplied to the primary winding of the input transformer through the medium of the jack (J_1). The secondary winding of this transformer is shunted by a 500,000 ohm potentiometer, the variable contact arm of which is connected to the grid terminal of the amplifier tube. Since maximum signal voltage is apparent across this 500,000 ohm resistor, as the movable contact arm is moved from the filament end of the resistor in question to the high voltage end, the signal voltage applied to the grid of the amplifier tube is varied through wide limits, thus affording a very convenient volume control.

The low side of the secondary winding of the input transformer is connected to the mid-point in the filament supply, through the 2,000 ohm biasing resistor (R_3). This resistor is shunted by an audio-frequency by-pass condenser (C_5) which increases the output volume and is a great aid to quality. The mid-point of the filament supply is effected through the medium of a 200 ohm potentiometer whose extremities are connected across the filament supply leads, it being possible to adjust the movable contact arm to the exact neutral in the filament supply.

It is desirable that the grid-return lead of the amplifier tube be brought to the electrical mid-point in the filament supply, due to the fact that this point remains at zero potential. In other words, there is no fluctuation in voltage at this point. For instance, let us consider the fluctuation in voltage at one end of the 200 ohm potentiometer that we have connected across the filament supply leads. The voltage at this point rises from zero to maximum in the positive direction, then decreases to zero, rises to its maximum negative value and again decreases to zero. This is called one cycle. If we move to a point, half way between the end of the resistor and the electrical mid-point of the coil, the voltage passes through the same cycle, but the peaks are now only half as high. Now, if we move to the center of the resistor we will find that there are no fluctuations in voltage.

If we brought the grid-return to one end of this potentiometer, an alternating e.m.f. would be applied to the grid of the amplifier tube, due to the fluctuations in filament supply voltage at the point in question. However, we can see how we would eliminate these fluctuations on the grid of the tube if we brought the grid-return to a point in the filament supply which was at zero potential.

You may wonder how it is possible to use pure A.C. on the filament of a power amplifier tube and not successfully on the filaments of the preceding D. C. tubes in a radio receiving system. The reason is that the power amplifier tube is the last tube in the system, and if you do create a slight hum by using A.C. on its filament, you have to worry only about the amplification effected by this tube itself. If A.C. were used on the filament of the D.C. tube preceding the power amplifier, the disturbance that it effected would be amplified through the medium of the amplification factor of this preceding tube, plus the amplification effected by the coupling transformer, as well as the amplification of the last amplifier tube. Thus, in the first case, you can see where the hum might not be appreciable. In the latter case, due to the greater degree of amplification, it is quite likely to be excessive.

The variable resistor (R_3) controls the bias on the grid of the tube by virtue of the plate current that flows through this resistor. To see this clearly, we had better trace the plate circuit of the power amplifier tube. We start at the source of the positive lead which is at the mid-point in the rectifier filament supply winding. We then pass through the two filter chokes (X_1 and X_2), through the primary winding of the output transformer AFT_2 to the plate of the power amplifier tube; through the interior of the tube in question, from plate to filament, to

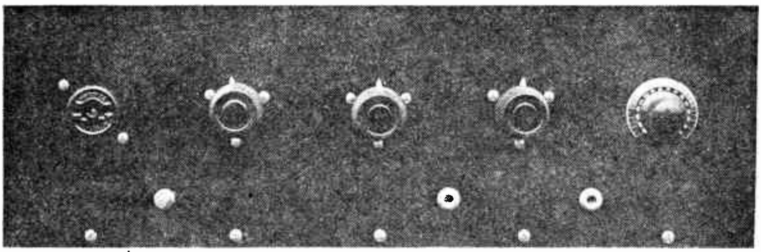

Fig. 7—Panel Arrangement of Power Amplifier.

the center point of the potentiometer (R_4), through the biasing resistance to the low side of the secondary winding of the signal input transformer, thence to the negative DC supply lead, through the high voltage secondary winding of the power transformer, to the plate of the rectifier tube, and through the interior of this tube, from plate to filament, and thence to the mid-point of the rectifier filament supply winding.

Bearing in mind the fact that we have just traced the path of the current flow through the plate circuit of the power amplifier tube, you will note that this current flowed through the biasing resistor in such a direction as to make the end nearest the filament positive and the end nearest the grid of the amplifier tube, negative. Thus the amount of bias applied on the grid of the amplifier tube depends upon the value of the resistor (R_3) and the amount of current flowing through this resistor. From a consideration of the foregoing facts, you can see how it is possible to vary the bias on the grid of the amplifier tube by changing the value of the effective resistance cut in the circuit at (R_3).

The output transformer AFT_2 is used to keep the high value of direct current flowing to the plate of the amplifier tube. out of the field coil windings of the loud-speaker. The normal amount of direct current to pass through the field coil windings of the standard loud-speaker is 10 milli-amperes. This applies to the better grade of speakers which use a very fine wire in their field coil construction. It is not advisable to pass more than 10 milli-amperes through the field coil windings of a loud-speaker due to the fact that you are liable either to burn out the delicate windings, or demagnetize the core on which the field coils are wound.

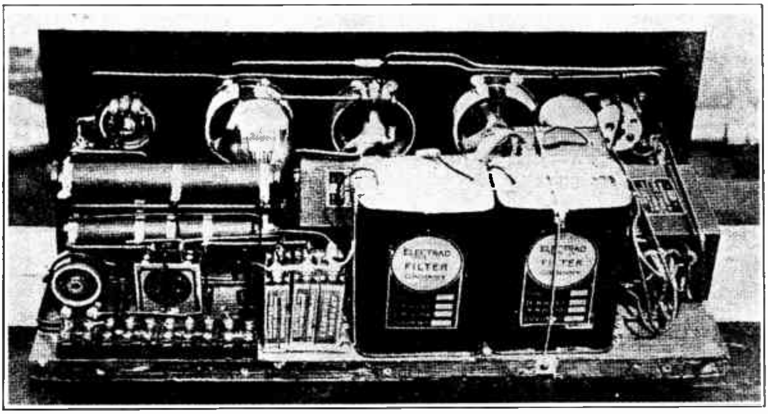

Fig. 8—Rear View of Power Amplifier.

Four resistors (R_6, R_7, R_8 and R_9) are connected in series across the rectifier output to afford "B" potential supply points of the proper value for the tubes in a radio receiver.

Figure 7 is a front view of the "Economical High Power Amplifier," and Figure 8 is a rear view of this unit.

HIGH POWER AMPLIFIER WITH FULL WAVE RECTIFIER SYSTEM

Figure 9 is a schematic diagram of a power amplifier which employs a full-wave rectifier system capable of supplying 500 volts D.C. to the plate of the power amplifier tube. The following is the list of parts and the circuit constants:

(1)—-200 watt power transformer.

One 110 volt primary winding.

One 1,500 volt secondary winding with a mid-tap. This high voltage secondary winding has taps which effect 550 volts on either side of the mid-tap, hence a 1,100 volt output.

One 10 volt rectifier filament winding center tapped.

One 10 volt amplifier filament winding center tapped.

AFT_1—Audio-frequency transformer. (2:1.)

AFT_2—Output transformer. (1:1.)

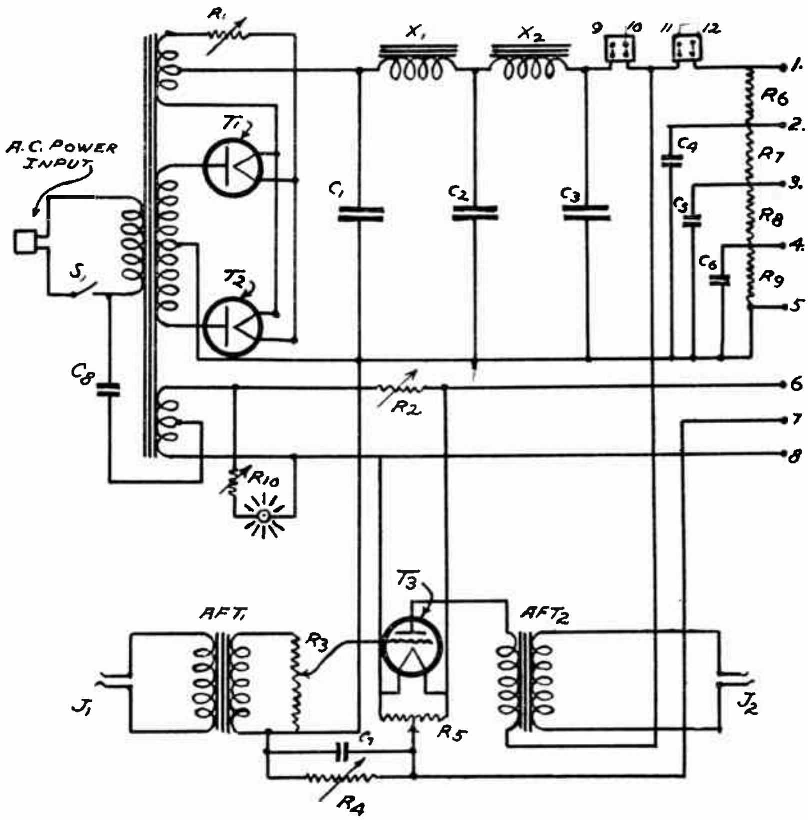

Fig. 9—Power-Amplifier Circuit and B-Eliminator with Full Wave Rectification.

X_1—30 henry choke.

X_2—30 henry choke.

C_1—1,000 volt, 2 mfd. filter condenser.

C_2—1,000 volt, 4 mfd. filter condenser.

C_3—1,000 volt, 6 mfd. filter condenser.

C_4—200 volt, 1 mfd. by-pass condenser.

C_5—200 volt, 1 mfd. by-pass condenser.

C_6—200 volt, 1 mfd. by-pass condenser.
C_7—200 volt, 1 mfd. by-pass condenser.
C_8—200 volt, 1 mfd. by-pass condenser.
R_1—2 ohm rheostat.
R_2—7 ohm rheostat.
R_3—500,000 ohm potentiometer.
R_4—2,000 ohm variable resistance.
R_5—400 ohm potentiometer.
R_6—11,500 ohm resistor.
R_7— 3,500 ohm resistor.
R_8— 1,500 ohm resistor.
R_9— 1,500 ohm resistor.
R_{10}—25 ohm variable resistor.
J_1—Open circuit jack.
J_2—Open circuit jack.
S_1—Filament switch.
3 —UX tube sockets.
T_1—UX-281 Rectifier tube.
T_2—UX-281 Rectifier tube.
T_3—UX-210 Radiotron.
8 —Bakelite binding posts.
—Overall dimensions of cabinet 20"x12"x9½".

From a consideration of the schematic wiring diagram shown in Figure 9 and the list of circuit constants and parts given above, there is probably not much question in your minds as to the fact that the amplifier in question is a real amplifier.

In this power amplifier unit, two UX-281 rectifier tubes are used for restifying both halves of the A.C. cycle. Each of these tubes is rated at 65 milli-amps. thus it is possible to draw 130 milli-amperes from this rectifier without overloading the tubes used. There are other limiting factors which also have a bearing in the amount of direct current drain allowable from this type of rectifier, such as, filter chokes, whose inductance varies with the amount of current passed through them (the greater the current flow the less the effective inductance of the choke.) In this case, the chokes specified have an inductance of about 30 henries each when passing 40 milli-amperes. If you should attempt to pass a current of the order of 100 milli-amperes through these chokes their effective inductance would go way down, and you would stand a pretty good chance of burning them out.

A little tell-tale lamp is connected across the amplifier filament supply, in series with a variable 25 ohm resistor, and is mounted in the front panel to indicate whether the amplifier is on or off. This is quite a practical idea.

A UX-210 tube is used for a power amplifier tube in this unit and is fed with signal energy through the medium of a low ratio, audio-frequency interstage transformer, AFT_1. The potentiometer method of volume control is used here, and the variable bias resistor is used to control the negative voltage on the amplifier grid. An artificial neutral is effected in the amplifier filament supply by means of the 400 ohm potentiometer R_5. An output transformer AFT_2 is used to keep the high value of direct current out of the loud-speaker field coil windings.

Fig. 10—Panel of Super-Power-Amplifier, Showing the Various Controls and Binding Posts.

Intermediate potentials for plate supply for a radio receiver are effected by means of the four fixed resistors connected across the 500 volt D.C. supply. These resistors allow for output voltages of the order of 135 volts at tap No. 2; 90 volts at tap No. 3; 45 volts at tap No. 4; remembering that we have 500 volts available at tap No. 1. The by-pass condensers (C_4, C_5, C_6) are connected between the different potential output taps to afford audio and radio-frequency by-pass paths in the case where an adjacent receiver is connected to these taps. If the receiver is located at some remote point, necessitating long leads between the potential output taps on the power amplifier unit and the radio set, it is quite obvious that the by-pass condensers must be at the radio receiver in that case. You will note in the diagram of the "Economical High Power Amplifier," Figure 6, no by-pass condensers were included across the output taps, due to the fact that they are superfluous in cases where the radio set is located at a distance from the amplifier, which is often the case. Hence, whether by-pass condensers are to be included in the power amplifier "B"-eliminator unit is strictly a question of installation conditions.

Three leads are also brought out, in this unit, from the extremities of the amplifier filament winding and the artificial

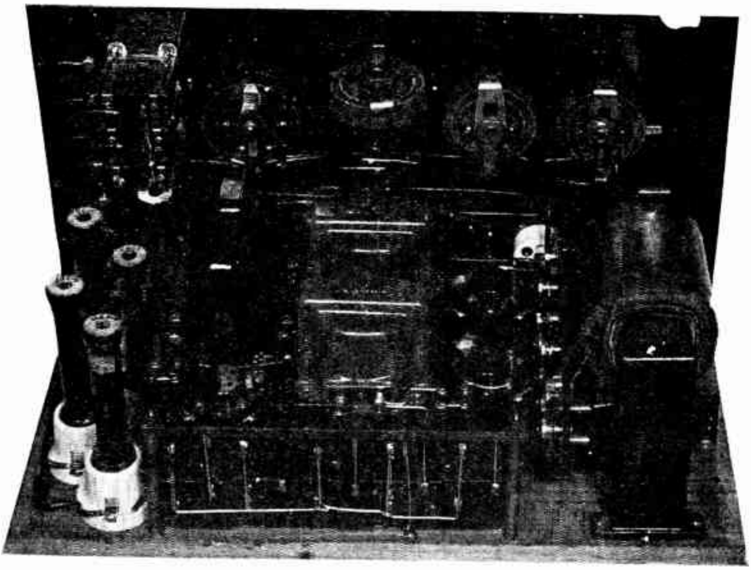

Fig. 11—Rear View of Amplifier.

mid-point, so that they are easily accessible in case it is desirable to feed filament heating energy to some other local unit.

Figure 10 is a front view of the amplifier. Figure 11 is a rear angle view of the amplifier, giving an idea of the arrangement of the component parts.

TWO STAGE AMPLIFIER

Figure 12 is the schematic diagram of a two stage power amplifier circuit which employs UX-171-A in the first stage, and a UX-210 in the second stage, the plates of these two power tubes being fed with direct current at high voltage from a half wave rectifier system, and the filament of the last amplifier tube (the UX-210) being fed with filament heating energy from a low voltage winding on the power transformer of the rectifier system, while the filament of the first stage amplifier tube is connected to a storage battery, or "A"-eliminator source of direct current supply.

The following is a list of parts used in the construction of the amplifier to be described herewith, and the circuit constants:

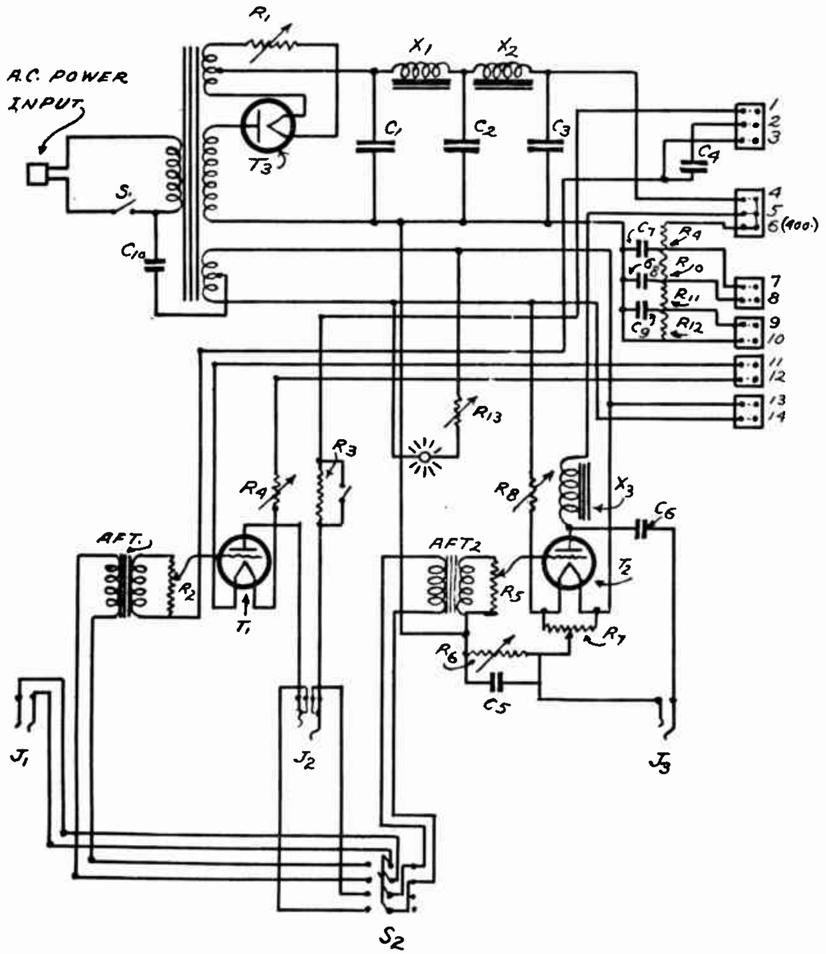

Fig. 12—Circuit Diagram of Two-Stage Power Amplifier and B-Eliminator.
*NOTE—The resistances to the right of condensers C7, C8 and C9 are R9, R10, R11 and R12.

(1)—Power Transformer.
One 110 volt primary winding.
One 450 volt secondary winding.
Two 8 volt secondaries with mid-taps.

X_1—60 henry choke coil.
X_2—60 henry choke coil.

X_3—60 henry choke coil.
AFT_1—First stage transformer.
AFT_2—Second stage transformer.
C_1—2 mfd., 750 volt filter condenser.
C_2—4 mfd., 750 volt filter condenser.
C_3—6 mfd., 750 volt filter condenser.
C_4—1 mfd., 200 volt by-pass condenser.
C_5—1 mfd., 200 volt by-pass condenser.
C_6—2 mfd., 750 volt blocking condenser.
C_7—1 mfd., 200 volt by-pass condenser.
C_8—1 mfd., 200 volt by-pass condenser.
C_9—1 mfd., 200 volt by-pass condenser.
C_{10}—1 mfd., 200 volt grounding condenser.
R_1—7 ohm rheostat.
R_2—500,000 ohm potentiometer.
R_3—10,000 ohm resistor, capacity 20 milliamps.
R_4—7 ohm rheostat.
R_5—500,000 ohm potentiometer.
R_6—2,000 ohm variable resistor.
R_7—100 ohm potentiometer.
R_8—7 ohm rheostat.
R_9—20,000 ohm heavy duty resistor.
R_{10}— 4,500 ohm heavy duty resistor.
R_{11}— 7,500 ohm heavy duty resistor.
R_{12}— 9,000 ohm heavy duty resistor.
R_{13}—25 ohm resistor.
J_1—Open circuit jack.
J_2—Double circuit jack.
J_3—Open circuit jack.
S_1—Filament switch.
S_2—Anti-capacity switch.
T_1—UX-171-A Radiotron.
T_2—UX-210 Radiotron.
T_3—UX-281 Rectron.
(3) —UX tube sockets.
(1) —Power input receptacle.
—Overall dimensions of cabinet, 20″x10″x12″.

In this particular type of amplifier equipment, the audio-frequency signal to be amplified is fed into the circuit at (J_1) by means of an ordinary radio plug. The terminals of (J_1) are connected to two of the poles of a four pole double throw switch, termed an "anti-capacity" switch. The function of this switch is to pass the input energy, either to the primary winding of the interstage transformer AFT_1, in which case the signals pass through two stages of amplification, or to the primary winding of the second interstage transformer AFT_2, in which case the signals only pass through the final amplifier stage.

A biasing resistor (R_6) is used to control the negative potential on the grid of T_2, hence the negative D.C. supply lead is connected to the low side of the secondary winding of AFT_2, rather than directly to the filament circuit of (T_2), which would be the procedure if a "C" battery were used instead of a biasing resistor. It is important that you shunt the biasing resistor with a by-pass condenser such as (C_5), to improve the quality and increase the output volume.

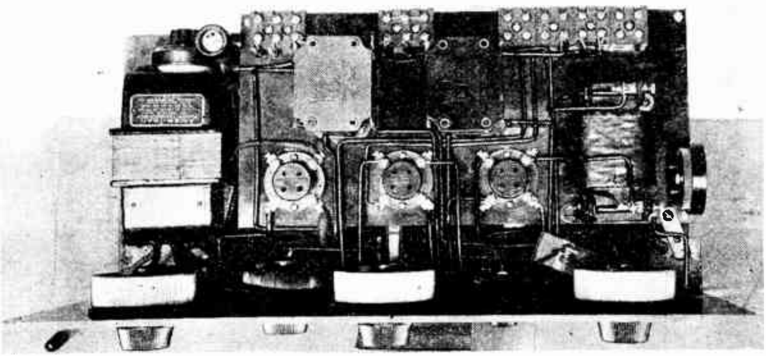

Fig. 13—Top View of Amplifier.

The filament of T_2 is heated from an A.C. source, namely, a low voltage secondary winding on the power transformer in the rectifier circuit. The leads from the secondary winding in question are brought out to terminals No. 13 and No. 14, to provide low voltage A.C. for any other device for which it is required.

Plate voltage is supplied to T_2 through the choke coil (X_3) which passes D.C. but chokes off the signal energy, the latter being by-passed through the condenser (C_6) and the field coil windings of the loud-speaker, by way of the output jack (J_3), to the filament circuit of T_2. The by-pass condenser (C_6) keeps direct current out of the field coil windings and offers very little impedance to the flow of audio-frequency signal current.

The entire design of this unit, as you will perceive, is along the lines of flexibility. Leads are brought out to terminals so that they can be connected in different ways. For instance, the filament of the first stage amplifier tube (T_1) can be connected to storage battery source of supply or it can be connected to a rectified source of supply, or still again, it can be connected to the same winding on the power transformer as the filament of T_2 by connecting terminals No. 11 and No. 12 to terminals No. 13 and No. 14.

A "C" battery or a biasing resistance can be used for biasing the first stage amplifier grid. External "B" batteries can be used on the plate of T_1 or plate current can be drawn from the output circuit of the high voltage rectifier for T_2. In fact, this type of amplifier affords you an opportunity to find out just what you can get away with and just what you can't get away with, at the present time, in the elimination of batteries from your audio-frequency amplifier system, as well as your radio receiver, which is connected ahead of your amplifier.

UX-245 PUSH-PULL AMPLIFIER AND PLATE SUPPLY

A power amplifier built around the Thordarson Power Compact is very easy to assemble since, through use of this compact, there are but few parts required for the complete assembly.

The Thordarson R-245 Power Compact is a specially designed power unit to supply plate, filament and grid voltages for a power amplifier using the 245 type power tubes in push-pull arrangement and also plate supply for the balance of the receiver.

This compact contains a high voltage supply of 350 volts (no load) each side of center and a 5 volt (center tapped) filament supply for a 280 type full-wave rectifier tube.

The 2.5 volt filament winding will supply two 245 type power tubes. It is tapped at the exact electrical center for the grid-return of the power tubes.

Two chokes with an inductance of 30 henries each are included in the compact. Chokes and high voltage winding have a capacity of 100 milliamperes. They are designed for 110 volt, 60 cycle alternating current and should never be used with any other power supply.

The voltage-divider Resistor supplies external voltages of 22½, 45, 90 and 135 volts when used with a receiver of normal drain. If heavier drain receivers are used, these voltages will drop somewhat but not beyond the point of practicable operation.

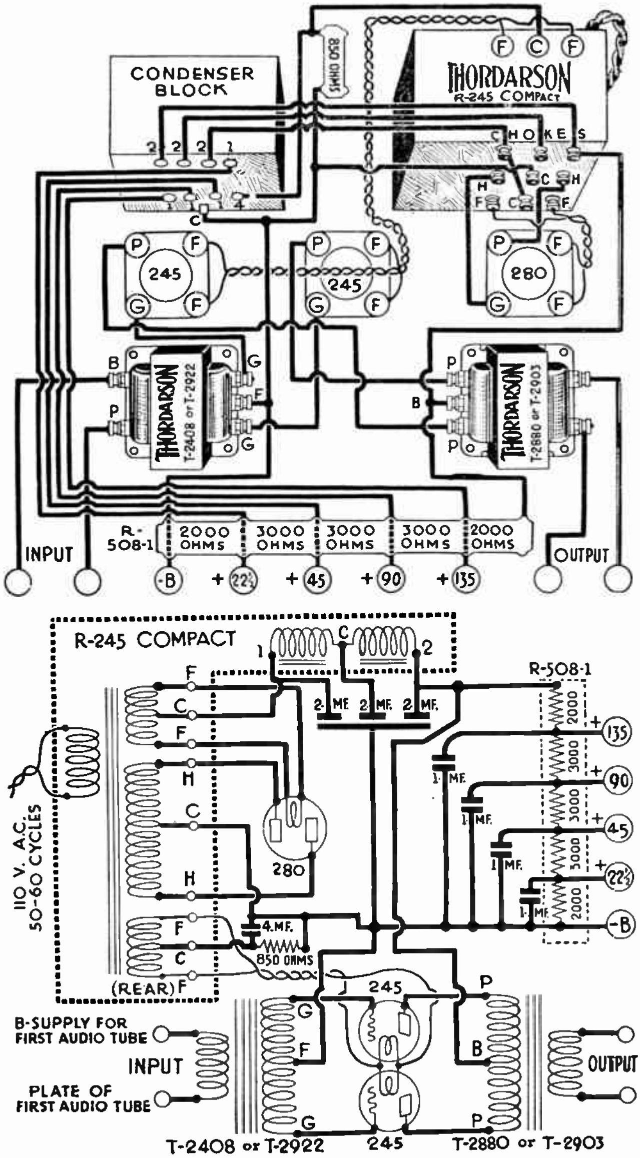

Fig. 14—Circuit Diagram of UX-245 Push-Pull Amplifier.

The voltage-divider also serves as a ballast to steady the voltages delivered to the receiver. It has a relatively low resistance with a high current carrying capacity and, when placed across the output of the filter circuit, serves as a ballast to compensate for variations in receiver current drain. Excellent regulation is thus secured.

In some cases, where comparatively large currents from the 45 volt tap are required, it is necessary to lower the value of the resistance between the 45 and the 90 volt taps. It is impossible to make the change in the divider itself but it may easily be accomplished merely by connecting a 10,000 or 15,000 ohm potentiometer with one side connected to the 45 volt tap, the other side connected to the 90 volt tap, the variable voltage being obtained from the binding post connected to the movable arm which is now the 45 volt tap. This arm is adjusted for desired results. In this case, the variable tap should be by-passed to B- with a 1 mfd. condenser.

In the event that the plate supply for the receiver is not taken from the amplifying unit, it is necessary nevertheless to see that the minus B of the amplifier is connected to the minus B of the receiver.

The plate terminal of the input push-pull transformer should be connected to the plate of the first audio-frequency tube, the second audio tube being removed when using this amplifier. The B terminal is connected to either the 90 volt terminal or the 135 volt terminal of the voltage-divider depending on which voltage is desired on the plate of the first audio tube.

Thordarson type T-2880 is used as an output transformer for a high impedance speaker (horn or cone.) If a dynamic speaker be used, the output transformer included with it should be changed for the Thordarson type T-2903 speaker coupling transformer. When this transformer is used, the output transformer in the dynamic speaker should be disconnected and the movable coil of the speaker connected directly to the output or secondary terminals of the T-2903. If high frequency cut-off is desired, two small fixed condensers, about .02 mfd. should be used across the plate winding or primary of the T-2903 transformer.

A condenser should be connected from each outer or plate terminal to the center or plus B terminal.

Because of the limited output of the rectifier tube, there is no provision for supplying the field of the dynamic speaker from the amplifier. The dynamic, if used, should either have a six volt field or a field operating direct from alternating current.

This assembly with the first audio tube in the set makes an excellent phonograph amplifier when used with a good electrical pick up. The pick up should be connected either by using the plug which is furnished with the pick up and plugging into the detector socket or by connecting across the primary of the first audio transformer with a single throw double pole switch. If an electric motor operates the turntable, the case of the motor should be grounded.

The following is a list of parts used for UX-245 Push-Pull Amplifier and Plate Supply.

1 Thordarson R-245 Compact.
1 Thordarson T-2922 Push-Pull Input Transformer.
1 Thordarson T-2880 Push-Pull Output Transformer (for High Impedance Speakers), or T-2903 Push-Pull Transformer (for Dynamic Speakers.)
1 Thordarson R-508-1 Resistance Unit (or Electrad type IT.)
1 R-245 Condenser Block (Dubilier PL 1429, Potter, Tobe, Acme, Aerovox.)
1 Fixed Resistance 850 ohms (Electrad type B 8.5, Ward-Leonard.)
3 UX Sockets
9 Binding Posts (2-Input, B-, +22, +45, +90, +135, 2-Output or Speaker.)
1 Pc. Bakelite 3″x11″x3/16″.
1 Wood Baseboard 1″x11″x14″.
Hardware, Solder, Wire.

Tubes Required:
2 UX-245 or CX-345 Amplifier Tubes.
1 UX-280 or CX-380 Rectifying Tube.

TWO STAGE AC AMPLIFIER WITH *UX-210 OR UX-250 TUBES IN PUSH-PULL

Figure 15 shows the schematic diagram of a two stage A.C. amplifier and power supply with UX-210 or UX-250 tubes push-pull in power stage for 110 volts 60 cycles A.C. The plates

Note: All AC filament leads must be twisted in with return and kept clear from plate and grid leads, otherwise excessive hum will result.

*This layout applies equally well for two UX-210 tubes push-pull if Hvs is reduced to 1,100 volts. Chokes may be reduced to 100 mills.

of the tubes are fed with direct current at high voltage from two UX-281 tubes full-wave rectifier system.

The following is a list of parts used in the construction of this power amplifier.

PT Power Transformer.
Pri Primary 110 volts, 60 cycles.
Hvs High voltage secondary 1,200 to 1,300 volts, 150 to 250 mills with center tap.
FS-1 Secondary 7.5 volts for two 250 tube filaments with center tap.
FS-2 Secondary 2.4 volts for 227 tube filament with center tap.
FS-3 Secondary 7.5 volts for two 281 tube filament with center tap.
X-1 Choke coil 30 henrys 150-200 mills.
X-2 Choke coil 30 henrys 150-200 mills.
C-1 Condenser, 2mf., 1,000 to 1,500 volts according to safety factor desired.
C-2 Condenser, 4 mf., 600 to 1,000 volts according to safety factor desired.
R Rectifier tubes two UX-281.
RV-1 Resistor, wire wound, 60,000 to 70,000 ohms, 25 mills with adjustable tap.
RV-2 Resistor, wire wound, 40,000 to 50,000 ohms, 50 mills with adjustable taps used only when desired for B & C supply for radio set (preferable to use separate supply for set.)
R-1 Resistor, 1,000 ohms, 200 mills.
R-2 Resistor, 10,000 ohms.
R-3 Resistor, 20,000 ohms.
R-4 Resistor, 2,000 ohms, 20 mills.
R-5 Resistor, 10,000 ohms.
R-6 Resistor, 250,000 ohms required only for AF-3c and AF-5c
R-7 Resistor, 250,000 ohms required only for AF-3c and AF-5c
R-8 Resistor, 20,000 ohms.
C-3 Condenser, 2 mf., 200 volts.
C-4 Condenser, 2 mf., 200 volts.
C-5 Condenser, 2 mf., 200 volts.
C-6 Condenser, 4 mf., 200 volts.

T-1 Audio transformer, AF-3, AF-4 or AF-5, from instructions.

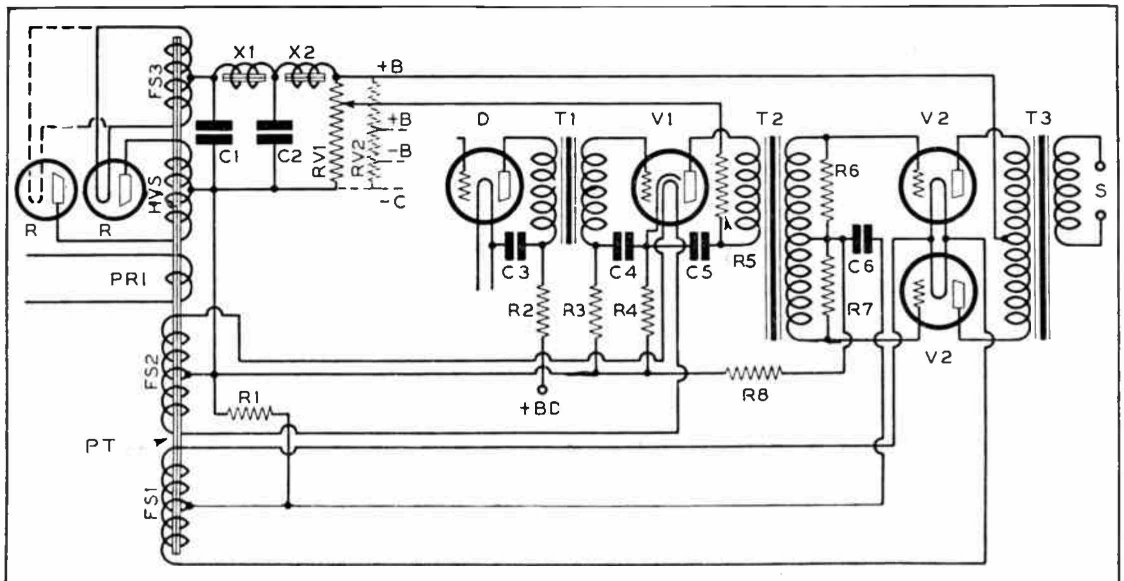

Fig. 15—Circuit Diagram of Two-Stage A. C. Amplifier and Power Supply With 210, 250 or 245 Tubes Push-Pull in Power Stage of 110 Volts, 60 Cycles A. C. (Courtesy Ferranti. Inc.)

T-2 Audio transformer, AF-3c, AF-4c, or AF-5c from instructions.

T-3 Output transformer, OP-8c for magnetic speakers, OP-4c or OP-4cc for dynamic speakers.
V-1 Tube UY-227.
V-2 Tube UX-250.

TWO STAGE AC AMPLIFIER WITH UX-245 TUBES IN PUSH-PULL

The same circuit arrangement can be used in building a two stage AC amplifier and power supply with UX-245 tubes push-pull in power stage for 110 volts, 60 cycles AC, as shown in Figure 15, except some of the apparatus must be changed. The following is a list of parts used in the construction of this amplifier:

PT Power Transformer.
Pri Primary 110 volts, 60 cycles.
Hvs High voltage secondary 750 volts 100-150 mills with center tap.
FS-1 Secondary 2.5 volts for UX-245 tube filament with center tap.
FS-2 Secondary 2.4 volts for UY-227 tube filament with center tap.
FS-3 Secondary 5 volts for UX-280 tube filament with center tap.
X-1 Choke coil 30 henrys 100-150 mills.
X-2 Choke coil 30 henrys 100-150 mills.
C-1 Condenser, 2 mf., 600 volts.
C-2 Condenser, 4 mf., 400 volts.
R Rectifier tube UX-280.
RV-1 Resistor, wire wound 30,000 to 35,000 ohms with adjustable tap.
RV-2 Resistor, wire wound 15,000 to 20,000 ohms with adjustable taps used only when desired for B and C supply for radio set (preferable to use separate supply for set.)
R-1 Resistor, 700 ohms, 100 mills.
V-1 Tube UY-227.
V-2 Tube UX-245.

All other components same as for UX-250 push-pull.

It is always preferable to build a power amplifier on a metal base which insures grounding all components. If a base of insulating material is used, all component cases, frames or cores should be connected to a common lead and joined to B negative. The negative must be connected to a good ground. Use gas pipe or water pipe where possible.

When amplifiers are built in accordance with diagram, Figure 15, if motor-boating or oscillations occur, a condenser of 4 mf. capacity should be connected across RV-1. It is desirable to add a 4 mf. condenser connected between the detector plus B tap at the resistor and the negative B if the power supply is designed to also supply B and C for a Radio set.

The various power amplifier units described in this text include some of the most modern and most efficient types of power equipment. It seems difficult to imagine a very great improvement over the equipment described in this text, but probably in the course of a few years we will have many modifications to consider.

TEST QUESTIONS

Number Your Answers 42 and add your **Student Number**

1. What is the chief reason for the poor quality of signals heard from many receiving sets?
2. Name 3 tubes that can be used as power amplifying tubes in a receiving set.
3. What is the disadvantage in using transformers for coupling the tubes in an amplifier?
4. Is it possible to cause distortion in a resistance coupled amplifier? If so, what is the cause?
5. Why is it best to use an output filter, or transformer, in the plate circuit of a power tube?
6. Draw a diagram of a high power amplifier, using a UX-210 tube, and show the method of obtaining the correct plate voltage for the receiver.
7. In figure 6 how is the power obtained for lighting the filament of the UX-210 tube?
8. What is the purpose of the variable resistance R_3 in Fig. 6?
9. What is the purpose of the resistors R_9, R_{10}, R_{11} and R_{12}, Figure 12?
10. Why is the condenser C_6, Figure 12 used?

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RADIO PROSPECTING

For several thousand years, men have been engaged in trying to locate valuable ore in the earth. In the olden days when kings wanted a new supply of valuable minerals for the temples, such as gold and silver, they sent their engineers and soldiers into far distant lands to bring it back. At that time, there was only one way of finding ores and mines. The engineers and soldiers would walk around until they chanced to see some precious mineral protruding out of the ground. Then, they had found a mine.

A great many changes have taken place since that day. but even today, in this century of steam engines, airplanes and Radio, the majority of individual prospectors are locating valuable ores and mines the old way. They merely walk around until they stumble over some piece of valuable ore.

Practically every great mine has been found in this way. Tonopah, the famous silver camp in Nevada, was discovered because a prospector's mule got away and kicked a chunk off a rock. The chunk proved to be silver ore. Cobalt, one of the richest of the Canadian mines, had a railway built right over the ore without anybody recognizing it. The blacksmith of the construction gang used a lump of silver ore for a spare anvil, thinking that it was ordinary rock. It was months afterwards before any one discovered that the railway builders had accidentally found a mine. The gold find at Weepah, Nevada, also was purely accidental. Two boys merely happened to see a badger's hole in the ground and noticed that near the entrance, small sparkling, shiny substances were being brought out by the badger.

So it has been for a great number of years that we have depended solely upon chance and accident in finding valuable ores and mines. However, during the past few years, we have been trying to bring into use some of the scientific instruments and methods which are used to advantage in other fields.

Electrical prospecting is not, contrary to what seems to be the popular belief, a new method. The various attempts to evolve a reliable means of locating ore bodies electrically cover a period of more than thirty years. In 1890, attempts were made to locate sulphides (a compound of sulphur and a metal or other elements) through the medium of conductivity, using a telegraphic receiver connected in series with a battery and wire brush. Contact was made in the earth, and the brush was moved over the surface. When touching sulphide, the brush would complete the circuit, causing a click in the receiver. As it could be used only on mineralized surfaces already exposed, the method was of little or no value.

Several years later, further attempts were made, using the Wheatstone Bridge, an instrument for measuring resistance. Here again, conductivity was the deciding factor, but indirectly, the conductivity between the two points on the earth's surface being calculated by first measuring the resistance. This method was also impracticable, due chiefly to the high resistance of the point of contact on the earth. As a result the resistance measurements were not truly indicative of the conductivity.

Another method which has been given considerable publicity employs the measuring or plotting of equi-potential lines (having equal power or influence). Direct current or a low frequency alternating current is allowed to flow between points, and the lines of equi-potential across the field are plotted by means of a galvanometer or telephone. The presence of an ore body causes these lines to warp or distort. Although this method has been successful to a degree, natural water layers, uneven moisture areas, and other substances in the soil are indications which can be misconstrued as indicating the presence of an ore body. On the other hand, failure of this method to indicate ore would not necessarily indicate barren ground. The oxidized condition existing above sulphide ore bodies forms an almost perfect insulator, an ore body thus insulated may cause indications similar to those caused by granite or other insulating materials. The low resistance of acid dikes to direct current or low frequency alternating current has been a source of annoyance also in trying to determine the presence of ore by this method.

Before going further into this subject we shall explain something about the various geological formations and the way that mineral deposits occur.

In very general terms, there are two kinds of such deposits, flat, layer-like deposits called "strata", and narrow pipe-like deposits called "veins". Coal is a good example of the first kind. A coal bed is just a layer of coal between layers of rock—like one black blanket between several gray or brown ones.

The vein deposits are different. They are cracks or holes in the rock, like cracks in a cement pavement, or like worm-holes in garden soil. Into these fissures in the rock, there have come up from deep down in the earth hot waters carrying in solution, gold, silver, or other minerals. These waters deposited, in the cracks and holes of the rocks, the minerals that they carried. This makes the vein. We find these veins (where they reach the surface of the ground) and explore into the interior of the earth, discovering the kinds of metal that they contain.

A good illustration of all this is an old-fashioned layer cake with a lot of icing in between the layers and none at all on the top. We can think of the icing as representing the minerals in the ground; the cake part represents the rock. A full layer of icing spread out evenly between two layers of cake will represent, for example, a strata or bed of coal. That is just the way the coal occurs, spread in between two layers of ordinary rock or other substance.

Now suppose that here and there in the cake there have been little cracks and holes. The icing will penetrate into these. If the cook has pressed down the layers of the cake as he put them together, the icing would be squeezed into such cracks or holes in the cake. This is a good illustration of a mineral vein. It is a thin piece or pipe of metal running through the unmineralized rock.

Now suppose that the cake, after it was made, had been jarred and cracked in a dozen places and squeezed out of shape. This is exactly what has happened to the rocks of the earth. Not that anything has fallen on the earth and smashed it, but the slow contraction of the globe, as a whole, has crushed and tilted and fractured the surface rock until layers that were once horizontal have been stood on end, until great breaks that the geologists call faults have cut across the whole earth's structure; in other words the original character of the rock and mineral deposits has been thoroughly obscured, even more thoroughly than the character of the cake and icing layers in the cake that has been squeezed out of shape.

So, the problem that confronts the geologists who try to do for the earth what we could have easily done by seeing the layers of the cake in the example above, is a very difficult problem indeed. The ground under his feet is so bent and twisted and broken that it is usually impossible to figure out in any detail what it was like in the beginning. The geologists know, perhaps, that there is mineral in these rocks somewhere. The question is, where? If he bores a hole down at random, he is as likely to miss the mineral deposit as he is to hit it; much more likely, in fact, for the mineral deposits occupy only a small fraction of the total volume of the rock.

The student can readily appreciate how valuable it would be if the geologists had some way of exploring the conditions underground without going to the extent of digging shafts, or boring holes, both of which are extremely expensive operations.

The methods described in this lesson are the result of efforts of various scientists to aid the geologists in locating valuable ore deposits without extensive drilling, and the accidental discovery by the prospector of these valuable mineral deposits.

The Equi-Potential Method

The fundamental principle of this method is, that an electric field is generated in the area to be investigated. By using a telephone receiver, a series of level lines is determined upon the surface, and by observing the disturbances in these level lines, it may be determined whether or not deep lying ores are present. If ore is present, the disturbances indicate the position and approximate extent of the ore.

To produce the necessary electric field in the area being investigated, a fixed primary circuit is employed, consisting of two poles or electrodes and two conductors connected to a source of current. In this method of ore detection, the electrodes are formed of long galvanized steel rope, which for convenience of handling, are divided into lengths of 50 meters. In order to produce good electrical contact with the ground, these ropes are fastened to steel spikes which are driven into the ground at regular distances. Electrodes of this type are called common linear poles or line electrodes. The conductors consist of ordinary insulated copper wires. The source of the current consists of a small hand or power driven generator, which produces a single phase alternating current with a maximum of 220 volts. To find the level lines, a movable secondary circuit, the so-called testing circuit, is employed, consisting of two iron rods with insulated handles, the so-called testing rods, connected with each other by insulated copper wires to which a telephone receiver is coupled. Usually, it is most convenient to use a telephone helmet with doube ear-pieces, which can be coupled in series or in parallel according to circumstances.

In order to set out a series of equi-potential lines, a pair of line electrodes 200 meters in length are usually employed, spiked down parallel to each other, and generally at about 200 meters apart. One end of each of these electrodes is connected by the insulated copper conductors to one of the poles of the generator, which is placed on one side some little distance beyond the ends of the electrodes in a position where it will not interfere with the observation.

If the field in between these two electrodes consists of material of uniform electrical conductivity, the equi-potential line lies parallel with the electrode in the intervening field. If, however, there is any marked irregularity in the electrical conductivity of the field, the equi-potential line will be distorted; and by plotting the equi-potential lines in this area, the distortion can readily be rendered visible.

The method employed is for the observer and an assistant to determine a series of equi-potential points, which are plotted by another assistant using a plane table; by joining these points, the equi-potential line can be drawn on the plan. The principal observer wears the telephone helmet and carries one of the searching rods, the other searching rod being carried by an assistant, who moves it about in obedience to the signals of the observer.

The observer first then drives a peg into the ground and the searching rod well into the ground beside it, then he signals his assistant to move the rod which the latter carries to a series of point lying in a line approximately perpendicular to the direction of the electrode, the distance between the two men varying from 3 to 10 meters. When the assistant has driven his rod into the ground at a point where the telephone is silent, the observer knows that both rods are on an equi-potential line. He then signals his assistant to put in a peg at that point. He next transfers his own searching rod to this peg, the assistant proceeds as before to get another point a few yards further along, until in this way, the whole area has been pegged out with a series of equi-potential points. The number of equi-potential lines thus determined may vary from 5 to 20 according to circumstances.

If the electrodes lie over bare rock, holes may be drilled and spikes clayed in. or a special device employed in order to obtain fair contact between the electrode and the ground. It is always advisable to drive the spike into the ground the same depth so as to obtain at all points the same electrical contact with the earth, this is especially important when the ground is very variable in character. When the ground is frozen, the contact between the electrodes and the earth becomes worse, but not so much so as to be a serious obstacle to the operation; the most serious difficulty is that of obtaining good contact between the searching rods and the ground, as it is very difficult to drive these into the frozen earth. The best plan, is to send a man ahead with a pointed steel rod with which he can make holes in the ground, to receive the ends of the searching rods, but the measurement will in any case proceed more slowly under these conditions.

As soon as the frost comes out of the ground, it is possible to measure at a maximum speed as soon as the surface is thawed to a depth of five centimeters.

Rain does not greatly affect the measurements; in districts where the moisture conditions present considerable variation, it is in fact possible to measure during, or immediately after, a rain.

By following the above procedure, a considerable area can be surveyed. In not too wooded or broken country, one sitting a day can be completed; in open, flat country, two or three settings can be completed in a day; in very wooded or broken ground, the rate of measurement can be reduced. By using electrodes a kilometer in length and a great distance between them a motor-driven generator and several observers, the rate of measurement can be increased considerably, but this is only possible in open and slightly undulating country. In other cases, when great speed is necessary, recourse must be had in the employment of several sets of apparatus. The method described is essentially a method of survey. In many cases, the results thereby obtained are so clear that no further measurements are necessary. In other cases, extra disturbances may arise so that it is necessary to carry out additional measurements. In very difficult cases, an attempt must be made to reproduce the occurrences on a small scale by laboratory experiment and by measurement on the laboratory scale to endeavor to obtain the information that will make it possible to verify the results obtained in the field. With the assistance of the above given supplementary means, which in any case needs a certain amount of experience on the part of the workers, it is understood that all precautions possible should be taken to avoid a misinterpretation of the indications obtained.

The Schlumberger Method

Professor Schlumberger describes the action of the passage of an electric current through minerals as follows: "Any mineral mass which possesses metallic electrical conductivity throughout a sufficient depth, and which lies underground in such a fashion that part of it lies above the water table, produces in the surrounding moist terrain, electrical currents observable by the differences of potential which they produce. This electrical action is probably due to the activity of the dissimilar waters of the oxidization and cementation zone when in contact with a metallic mass."

To detect with accuracy the presence of electrical currents in the earth, it is necessary that they be diverted to a measuring instrument by a contact that will not polarize when touching moist soil. Metal electrodes, even when gold plated are not suitable.

For his purpose, Professor Schlumberger devised an electrode made of a porous earthen cup cemented to the end of a copper tube, the tube and cup being filled with a saturated solution of copper sulphate containing an excess of copper sulphate crystals. The copper tube is slipped into a brass sleeve for convenience in the field, making the whole apparatus stand breast-high. The upper end of the sleeve is arranged to screw into the base of the potentiometer and galvanometer which are used for measuring electric currents. Two of the electrodes are connected by insulated wire about 200 ft. long, wound on two small reels arranged to clamp, one to each electrode. The path of the current is as follows: Ground, electrode, potentiometer and galvanometer, wire, electrode, ground.

The potentiometer and galvanometer are contained in a small aluminum case about 8 inches square and 2 inches deep. The galvanometer is sensitive to one milli-volt. It measures not only the strength, but also indicates the direction of the flow of the current.

The electrode bearing the potentiometer and galvanometer is carried by the operator and the other by an assistant. When prospecting, the following procedure is used:

A suitable distance between electrodes is chosen, say 25 or 50 ft. where two contacts are made, and the direction of the flow of the current is noted. The assistant's electrode is placed at the contact of the lowest potential, or contact towards which the current is flowing. The operator then feels in the direction of flow of current, makes contact, and again takes a reading. This is continued until a reversal of current direction is noted, whereupon the two then proceed to follow a line at right angles to the first, still going in the direction of lowest potential. This is repeated until the point of lowest potential in that region is found; that is, the point towards which the current seems to be flowing from all sides. The operator is now above the apex of the vein, and the next step is to discover the strike and shape of the ore body in question. This is done by tracing equi-potential curves above the center thus discovered, which is called the negative center.

An equi-potential curve is the line which joins all points which are the same potential difference from the center. That is, the distance from the center to the curve in question, which is always a closed curve, and will vary inversely as the resistance of the rock through which the current passes. The drop of potential is greater in a given distance for a resistance material than it is for a conducting material. Therefore in a resistance material, a given drop of potential will take place in less distance than it will in a conducting material.

It will be observed that the equi-potential curves in question will be elongated along the strike of the vein. They are in reality, the out-crop of equi-potential surfaces enclosing the vein beneath the surface. The equi-potential curves outline more or less regularly the horizontal projection of the ore body in question, and will be nearer the outside of the ore body than when lying in or traversing it. These equipotential curves are traced by placing the assistant's electrode in any convenient point near the center; the operator then feels about with his own electrode for that point which is at the same potential as the aide's; that is, the needle of the meter or galvanometer indicates no flow of current. The assistant then puts his electrode at that point. The operator then repeats the process and this is continued until the curve is closed, which should be within a five or ten foot area.

Further study may be made by determining the profiles of the electrical potential across the strike of the ore body. To do this, the aide places his electrode at a point 100 feet or more distant from the veins being studied, and the operator makes contact with the ground nearer the vein, the distance between him and the aide depending upon the probable size of the mass. Such distance may vary from 5 to 100 feet. He then measures the difference in potential between the two points, whereupon the aide moves closer, makes contact there, and the operator proceeds towards the ore body in a line at right angles to the strike, and then repeats the process. This is repeated until the ore body has been traversed. Since ore body is the source of the electric current, this activity is manifested by the shape and peak in the graph of the potentials where the profile crosses the vein. That is, the equi-potential curve may be likened to contour lines of the electrical field, and the profiles to the cross section thereon. A test is thus provided, as the profiles should indicate the same potentials as the point where they cross the same equi-potential curve.

Professor Schlumberger has also discovered that anthracite coal is not only a conductor, but apparently, also a generator, of electricity. From the results obtained by the use of this system, it would seem that metallic disseminations in a siliceous gangue (vein bearing silicia or quartz) cannot be prospected by this method, but the same minerals when deposited in a schist (layer-like formation) can easily be discovered.

The results of the experiments described warrant the conclusion that it is entirely possible for electrical prospecting to be applied in searching for silver cobalt veins of this type, where they are not covered by more than three or four feet of over-burden, and deeper if they are wider than the ones of only a few inches in thickness. Considerable expense in sluicing (to uncover by water under pressure) might thus be avoided.

The Chilson Method

The idea of electrically locating ore bodies was first conceived by Mr. D. G. Chilson, a mining engineer, in 1904. The discovery of large ore bodies where frequently the surface geology did not indicate the presence of ore furnished the incentive for his early experiments. These early experiments were made to determine the conductivity of various elements—earth, water, and other substances, and it was found that sulphides furnished the best conductors.

In 1909, Mr. Chilson turned to Radio, experimenting with some of the short waves, using the method now in use for directional telegraphic communication. During the following years, he spent considerable time in determining the audibility of signals from Radio stations, through readings taken in so-called "dead" spots in Alaska. Comparative conductivity tests on sulphides and soils proved the electrical continuity of sulphide ore bodies, contrary to the general contention of geologists that ore bodies and depth are not connected. By introducing currents of different electrical frequencies into sulphide ore bodies, it was found that by using a critical frequency, sulphide ore bodies could be followed regardless of other conductors such as earth, water, or other materials. The result obtained at that time proved accurate and established the practicability of the process. During the following five years, tests were made in California and in Arizona with good results. From 1920 to 1922, further experiments were carried on at the University of Arizona, and refinements and improvements were made which brought the process to its present state of perfection.

Briefly, the fundamental principle upon which the Chilson process operates is as follows: Contact is made upon sulphide ore having electrical continuity, with electrical energy of the proper frequency impressed upon same in such manner that all connecting ores will act in unison with the transmitter and as a part of the transmitter. A receiver, operating in proximity to the ores thus affected, will indicate their location, through the medium of the magnetic field caused by the ores acting as a part of the transmitter. It has proved possible with this method to locate sulphide ore bodies under favorable conditions to a depth of 2,000 ft. or more.

The frequency of the electrical impulse is the deciding factor in making this possible. Where the impulses vary from 300,000,000 impulses per second to 100,000 impulses per second, the waves created are very difficult to classify, because they are affected in the same manner as light, being reflected from metals, water, and hills. Impulses varying from 100,000 to 40,000 per second are affected only slightly, and while having the advantage of following metal conductors, they do not pass through the earth and water as readily as lower frequencies. These two groups are known as "Radio frequency." The range between 40,000 and 20,000 impulses have similar advantages and disadvantages. Between 20,000 and zero, or in other words, nearing a continuous flow of current, the disadvantage of the current flow taking place through wet material, rocks, and soil, makes the use of this group of frequencies impracticable. The range of frequencies between 40,000 and 20,000

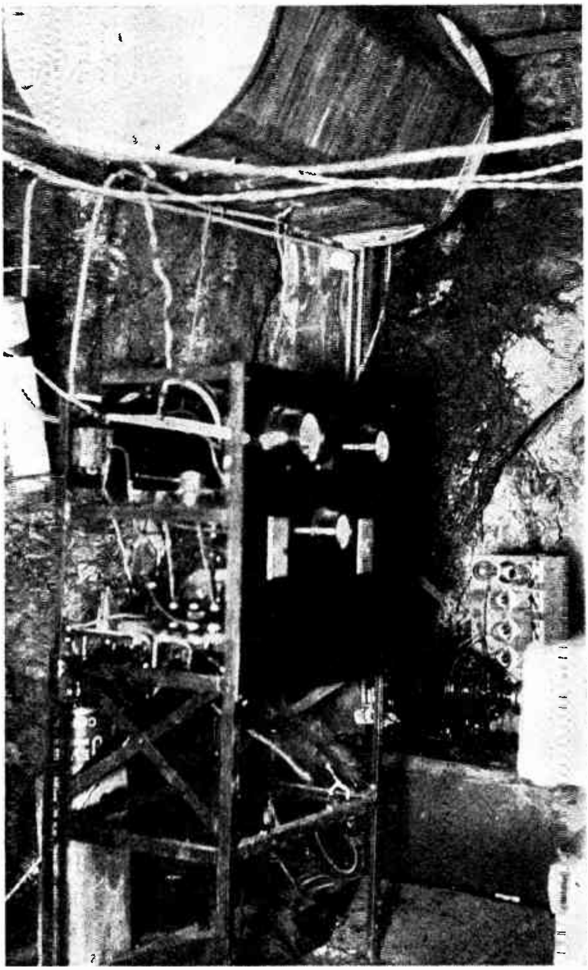

Fig. 1.—The Transmitter Installed Underground.

is the one generally used in this work. However, a higher frequency within the Radio band can be used to good advantage as a means to check the results obtained with the lower frequency.

The quality that an electric current possesses of oscillating within definite limits determined by the frequency of the current and conductivity of the body submerged within any substance, makes possible the location of any exact area of predetermined conductivity value. This action is similar to the action which takes place in a Radio antenna, which is highly insulated, so that high frequency oscillatory current may be used with minimum leakage. Inferior insulation might be used with lower frequencies and with some loss in efficiency. This could be likened unto the ground ore contact of the transmitter used in this work.

The apparatus used in this work consists of two units, a transmitter designed to radiate the proper current at the desired frequency, and a receiver to record the audibility of the signal. The transmitter is generally installed underground and contacts are made upon the sulphide. The receiver is specially designed, employing several stages of amplification. The receiver cabinet is suspended from a tripod, and the receiving coil is secured to the tripod in a swivel frame, so that it may be either swung in an arc, or horizontally. In taking readings, the receiver is set up so that the coil is in a vertical position. It is then swung in an arc until maximum signal audibility is reached—this gives the strike of the ore. Without changing the angle of the coil, it is dipped horizontally until maximum audibility is again reached. This gives the dip angle. After several set-ups taken in line, these dip angles are projected and the apex of the resultant triangle is the center of the magnetic field caused by the ore body acting as a part of the transmitter. When directly over an ore body, the dip angle is, of course, zero.

It is possible to cover as large an area as 30 or 40 square miles without moving the transmitter. This depends, of course, upon the characteristics of the particular field being surveyed. In mineralized ground, it is possible to make as many as 80 or more set-ups a day.

The Hertzian Wave System

Thus far, the systems described have been those using surface methods depending upon the conductivity or resistance of the ground and the out-cropping of the mineral. The Hertzian Wave System indicates the possibility of using Hertzian waves to penetrate the surface and indicate the presence of ore.

The Hertzian system of locating mines by Radio is based on the well-known phenomena of the penetrating resistance offered by good conductors to electric lines of force. As illustrated in Fig. 3, a Hertzian oscillator produces no phenomena of resonance because of the interposed grating shown in this figure. This grating is grounded as shown.

Let us assume that it is desirable to locate ore deposits in the side of a hill where out-crops of mineral have been found and also to determine how important these deposits are. It is necessary first to make some preliminary drifts to

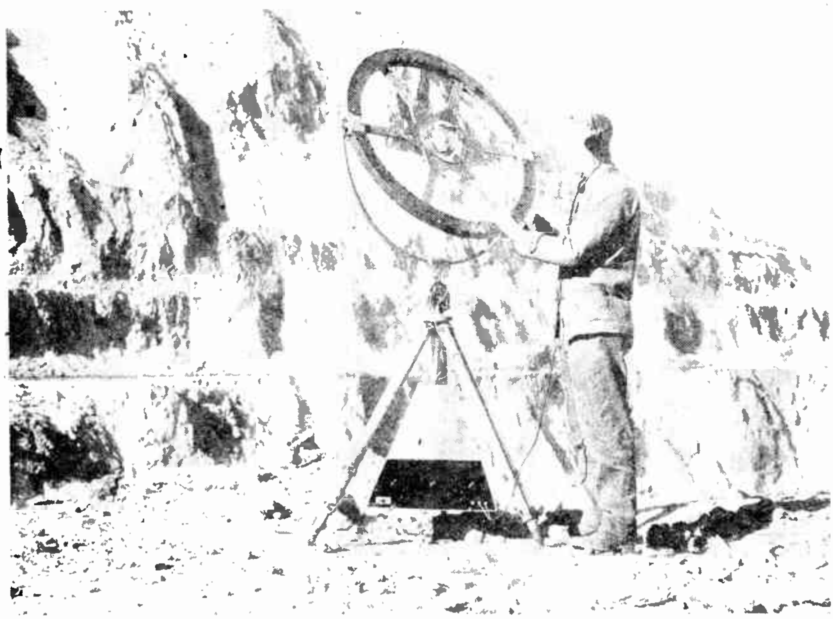

Fig. 2.—View of the Field Receiver, Showing the Operator Taking a Dip Reading.

determine the extent of the out-crop and shafts to determine its depth. Both of these operations may be avoided by using the apparatus for directional waves. In Fig. 4, the transmitter is located at the point T, and the detecting device or receiver is located at the point R. It is found that along the dash line T R, as indicated, no impediment exists to cut off the waves; but if the detector is moved from R to R_1, the telephone of the receiver is silent because the waves emitted from T meet the mineralized mass, which acts as a shield. If the receiver is placed in the next position, R_2, so that the line T R_2 passes below the mass, the telephones will produce a sound. The process is carried on by shifting the transmitter from T to T_1 while the detector remains at R_2; again, the waves are intercepted and the telephone becomes silent. The experiment is repeated, carrying the transmitter to T_2, and again, the telephone is silent.

By placing the transmitter and receiver successively in all directions, and, with the aid of plans and calculation, the existence and position of the mineral mass may be established. Of course this work should be preceded and accompanied by a complete study of the geological formation of the hill, and in this case, the Hertzian method will give a preliminary indication of the existence and location of the mineral mass. The study should be continued and completed by the means described above. For

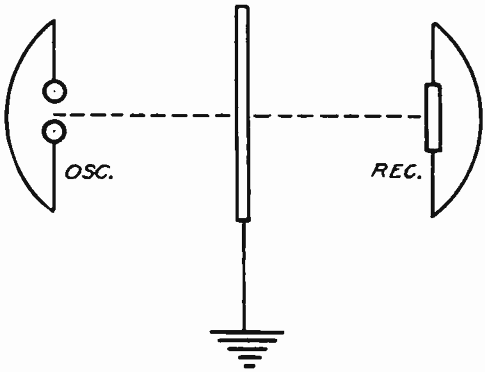

Fig. 3

instance, between the out-crop and the side of the hill to which the lower extremity of the vein seems nearest, the electrical resistance method may be applied. Then, between R and R_2, assuming that there is a covering of earth over the deposit, the silent zone system can be applied. When a well-organized series of experiments have been completed, sufficient data is available to make possible an intelligent attack on the problem of exploiting the deposits.

Let us now take up a case, that of examination from the interior of a working mine, and from the exterior, to determine the presence of a mineral zone whose existence is suspected. Figure 5 illustrates this case, which is that of a zinc mine containing calamine mixed with lead carbonate and hydroxide.

First, the transmitter is placed at the point T, and the receiver is placed in a drift at the bottom of the mine at the point R—the clear sound produced in the telephone shows that the line T R is clear of all mineral deposits. Leaving the receiver at the point R, the transmitter is carried down the hill to the point T_1; the transmitter remains in operation while it is being moved down from T to T_1, and the operator listening below, finds a rapid diminution of the sound. As the point T_1 is reached, the telephones become silent. This shows the presence, which we may assume has been suspected by other indications, of a new mineral zone; keeping the receiver at the point R, the transmitter is carried down the hill still further toward T_2. At a certain moment, the

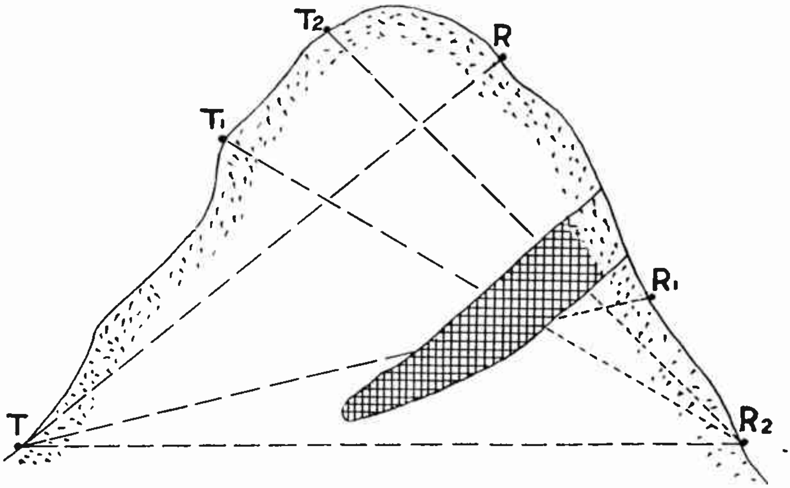

Fig. 4

sound which was lost is again heard, gradually becoming louder. Finally it is heard with full intensity, which indicates that on a given line, R T_2, the rock again is completely sterile.

At this point, the operators trace a profile of the ground explored, and then apply other tests. The transmitter is carried to the point T_4 at the end of a drift, and the receiver is placed first at R_1 and then at R_2, then the transmitter at T_1 and T_2. This gives four new lines. T_4 R_1 shows the end of the deposit; T_4 R_2 controls and confirms the preceding test; T_4 T_2 indicates the presence of the deposit higher up; T_1 T_4 indicates the sterility of the rock in this direction. Thus, the operators are able to complete the profile, acquiring an approximate section of the mineralized mass as discovered.

The work is continued afterwards on other sections of the deposit, so as to sketch with the greatest possible accuracy, the point of contact with barren rock surrounding it and its precise boundary. The data thus obtained is controlled and completed by experiments using the other systems. An interesting test is obtained by stretching a long wire on the left side of the hill, making good earth contacts at point T and T_1, measuring the resistance of the intervening soil. In the first case, the circuit being closed through sterile earth and the resistance was high. In the latter case the circuit closed through a portion of the ore bearing out-crop, the resistance was much lower. Such tests should be made over other portions of the hill to detect the presence of deposits which might be otherwise undiscovered. This data is useful when taken in connection with the Hertzian tests and serves to better establish the presence of ore bearing deposits.

Figure 6 shows another application of the Hertzian method. A shaft was dug below a mass of manganese ore, and reached a point where the mass thinned out and disappeared. The question then was to know whether there was a break in the deposit, or whether this was a definite end of the deposit, so as not to keep on pushing drifts without finding any more mineral.

The first investigation was carried on in the open by direct observation, and the result was negative over a large piece of territory to the right of the excavation. It was feared that due to the depth of the new body being searched, and the low power of the transmitter used, the results of the examination would not be positive, and it was decided to try the Hertzian method. The receiver was placed at R_1 at the extreme end of the third drift, and the transmitter was placed at T_2, near the entrance of the excavation. The operator placed at R_1, could determine exactly the lay of the deposit. No signals were heard as indicated by T_2 R_1. He then gave orders to the operator in charge of the transmitter to carry it to T_1, and found that on the new line, there was no mineral mass present as indicated by the line T_1 R_1.

The test was repeated, placing the transmitter at T, and with the same results as when the transmitter was placed at T_1. The receiver was then placed at R, and the discharge tested towards R. No signals were heard between T and R. The operator then took the receiver into the shaft below to its extreme end, R_2, and found that emissions from T were received, while those from T_1 were not. The experiments were then repeated, taking the transmitter a good distance to the right of T, and changing positions in the direction to the lines T_2, T_1, and T. It was found that the passage of the waves was not interfered with, therefore, there was no trace of mineral in the subterranean section explored.

In Fig. 7 is shown tests directed to discover a mass of ore, the probability of whose existence followed from the vicinity of other metal-bearing deposits in an active mine whose

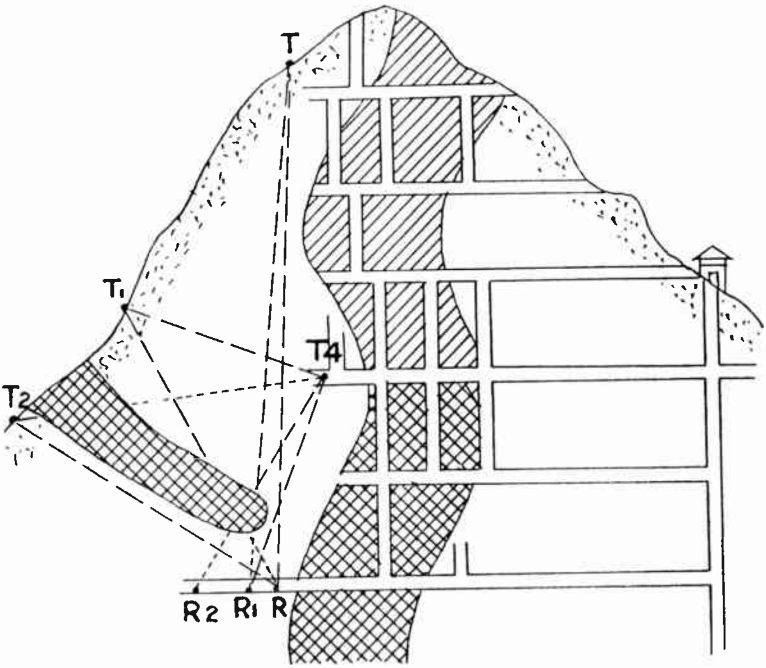

Fig. 5

plan is shown. The Hertzian transmitter was placed at T, and the first experiment consisted of placing the receiver at R_2, in order to be sure that the quality of the mineral of the known deposit was such as to make a screen along the way. Having determined this, the operator at R_2 moved along slowly, following the drift towards R_3, at which position, he began to catch the waves and thus established the line of contact of the bed being explored. Continuing to go on toward T, the operator employed a positive knowledge that all the region between the drift and the deposit was barren.

The operator then went to R_1 and followed along the drift between the same deposit, which was without mineral. Finally, the operator covered the whole gallery, which was dug in sterile ground in the direction of R_1, and having thus gotten to its end, found the sound had ceased, which proved that there was a new deposit in the line explored.

The apparatus used in the Hertzian system consists of a transmitter and a receiver. The transmitter is comprised of a direct current generator giving 320 volts potential. It may be a small dynamo apparatus on a wheeled platform, or a battery of small storage cells. Figure 8 shows this transmitter to be the usual Hartley type. The main characteristic of the apparatus is the absence of an aerial and any ground connec-

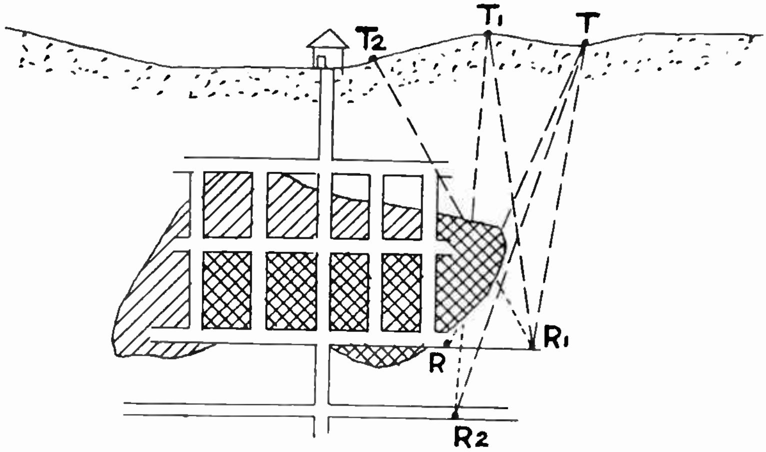

Fig. 6

tion, facilitating the disposition of the apparatus, giving it great mobility and making the exploration very easy. The radiating system consists of an inductance about 8 inches in diameter, wound around the box containing the vacuum tubes, which is mounted on a tripod so as to be turned about as desired. The direction of radiation of the waves can be produced in any desired direction. The whole transmitting set may be mounted on a small truck so as to make it easily transported either on the surface or in the drift, so that the work is made very easy.

The circuit diagram of the receiving apparatus is shown in Fig. 9. In this too, the inductance is wound around a box, which is carried by the operator, or it may be placed on a tripod, while the plate and filament batteries are held by the assistant.

The Hertzian system is far in advance of the first experiments which used a magnetic means, and those of Schlumberger with polarized electrodes. The main draw-back of all of the previous systems, was that each required too long a time to make the tests and determine the nature of the earth surveyed.

The Re-Radiation Process

The rapid development of Radio, and more especially of the apparatus used in Radio, such as the vacuum tube, during the past ten years, has led to the disclosure of a comparatively new phenomenon known as "re-radiation." This phenomenon borrowed from the Radio world and applied to

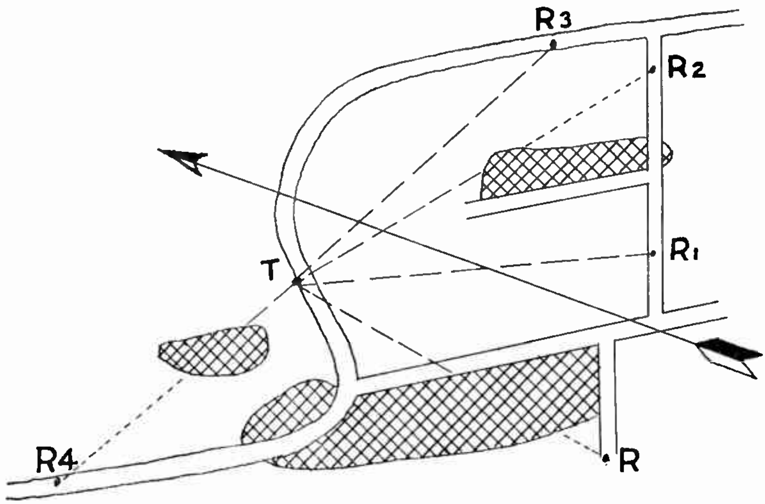

Fig. 7

the art of mining gives every assurance of opening up vast territories of mineralized ground, especially in areas hitherto not open to prospectors.

Re-radiation may be described as the occurrence of a secondary electromagnetic field about a conductor, which is located within a primary electromagnetic field of high frequency, and the unusual and outstanding characteristic of this phenomenon is the extent to which these secondary fields may be caused to reach out into space to comparatively great distances, from the secondary conductor about which they exist. Recognition of this phenomenon, together with an understanding of the many factors which control it, having enabled engineers to develop a means of locating unknown conductive bodies and more particularly, ore bodies which are electro-conductive.

While a complete understanding of the principles involved in the application of re-radiation to locate unknown conductors, requires a thorough understanding of high frequency electrical phenomena, the basic principles are easily grasped by those having an elementary understanding of electricity and Radio principles. These elementary principles will be outlined in the following paragraphs.

Referring to Fig. 10, there is represented in profile view, a vertical conductor, AB, and a vertical conductor, CD. The reader must imagine that alternating current of high fre-

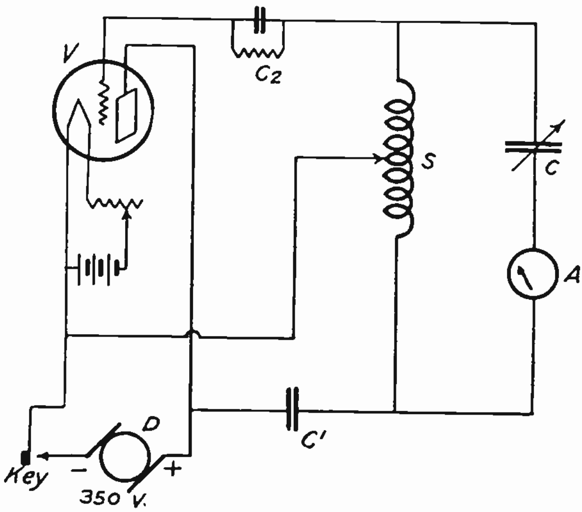

Fig. 8

quency is flowing in the conductor, AB, which, for convenience, will be called the primary conductor. As a result, there exists about this primary conductor, a high frequency electromagnetic field, called a primary field, the magnetic lines of force of which may be represented as circular lines similar to the lines H (center H), spreading out and contracting about the primary conductor, AB, as an axis. The lines of magnetic force H (center), have the ability to travel through space even if this space be filled with non-conductive material, and they further have the ability to cause an electric current to flow in any conductive material through which they might travel.

Therefore, when the lines of magnetic force, H (center), cross the conductor, CD, they cause a current to flow therein. This current is called a secondary current, and it is, of course, accompanied by its own electromagnetic field, for it is a well-known and commonly accepted fact that wherever there is a current flow, there will be an electromagnetic field surrounding the conductor and accompanying the flow of current therein. This latter electromagnetic field is called a secondary field, represented by the circular line H (to the right) of Fig. 10. There will be occasion to refer to it repeatedly throughout this discussion, for this system and process is built upon creating such a secondary field, causing it to extend to considerable distances, and then by means of this field, locating the secondary

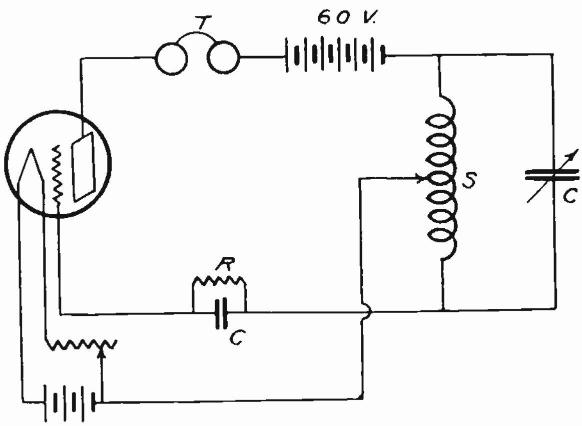

Fig. 9

conductor about which it exists. In Fig. 11, there is shown, drawn to a small scale, a plan view of the conditions pictured in Fig. 10.

All of the above phenomena are well-known to those versed in the art of high frequency electricity, but it has been generally thought that unless the secondary conductor, CD, (Fig. 10) was very close to the primary conductor, AB, and unless the secondary conductor be tuned to the frequency of the current flowing in the primary conductor, AB, just as a Radio set is tuned to the frequency of the broadcast station which one desires to hear, the secondary current flowing in CD, and its accompanying secondary field would be so small, that it would be useless to attempt to apply this phenomenon to any practical purpose.

However it has been found by those responsible for the development of this process that, the secondary field about the conductor, CD, can be made of sufficient intensity to actuate indicating devices at considerable distances away from the conductor, even if the secondary conductor be at some distance from the primary conductor, and furthermore, even if the secondary conductor is not tuned to the frequency of the primary field, under certain limiting conditions. The facts connected with causing the secondary field to extend to considerable distances and measurable intensities constitutes the phenomenon upon which this process is based.

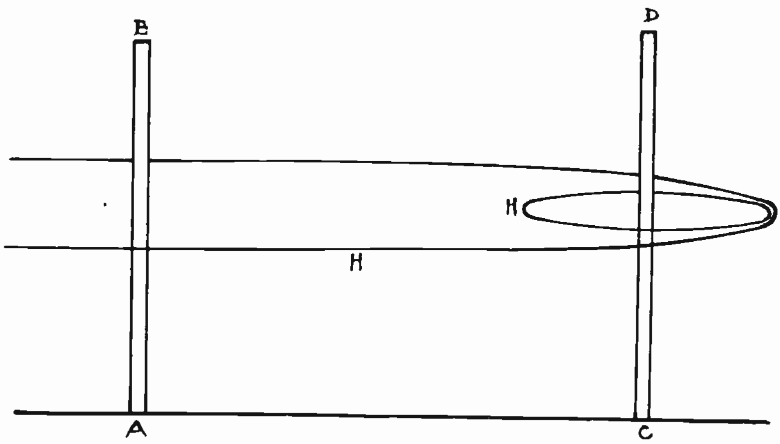

Fig. 10

The mere creation of an intense secondary field is in itself of no value unless a means be developed to utilize this secondary field to indicate its axis, which lies, of course, within the secondary conductor. (If the axis may be located, then the secondary conductor is located.) Here, a principle borrowed from the Radio world, and well-known in its particular application, was applied to this more complex problem of locating a secondary field within a primary field. The principle is that connected with the art of Radio direction finding where a direction finding coil is employed to indicate the direction towards the Radio transmitting station.

In Figure 12, there is represented in plan view, the axis of a primary conductor standing vertically at A, about which there exists a primary electromagnetic field, the magnetic lines of force of which may be represented as the general shape and position of the circular line, H. If a direction finding coil is placed anywhere within the effective area of this field and rotated about its vertical axis, it will indicate by its position of maximum signal intensity, a direction towards the axis of the primary field such as shown at G. If two or more such directions be obtained and plotted to an intersection, the location of the axis of the primary field will be determined. This is the principle connected with the use of a coil for direction finding, when in the presence of a single electromagnetic

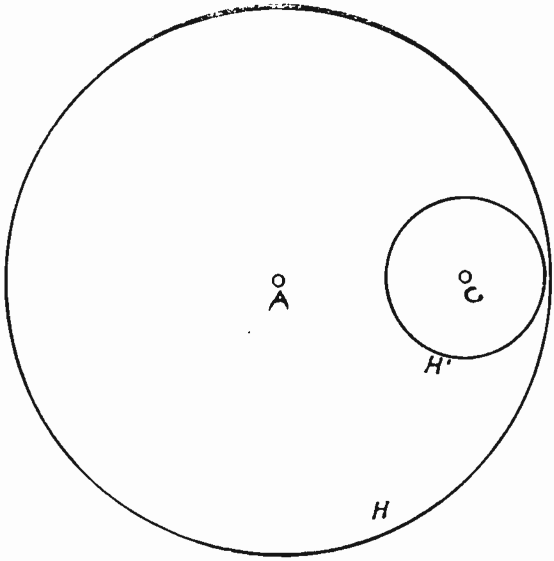

Fig. 11

field. It is well-known and generally employed in the Radio world.

In this method and process of locating ore and mines, the basic principle of the direction finding coil is employed in locating the axis of a secondary field, but the action of the coil becomes more complicated because if the coil is placed within the effective area of the secondary field, it will, of course, be within the effective area of the primary field and as a consequence, the direction finding coil will be acted upon simultaneously by two fields of identical frequency, whose axes do not coincide. This is an unusual application of the direction finding coil and it requires considerable study and work to determine just what sort of direction the coil would give under such a condition, and what the determining factors are for obtaining directions by means of which the secondary axis may be located. This is an interesting problem in itself but leads into highly technical subjects which need individual study and are too complicated to be included in this text.

The elementary principles governing the action of the coil when in the presence of two or more electromagnetic fields

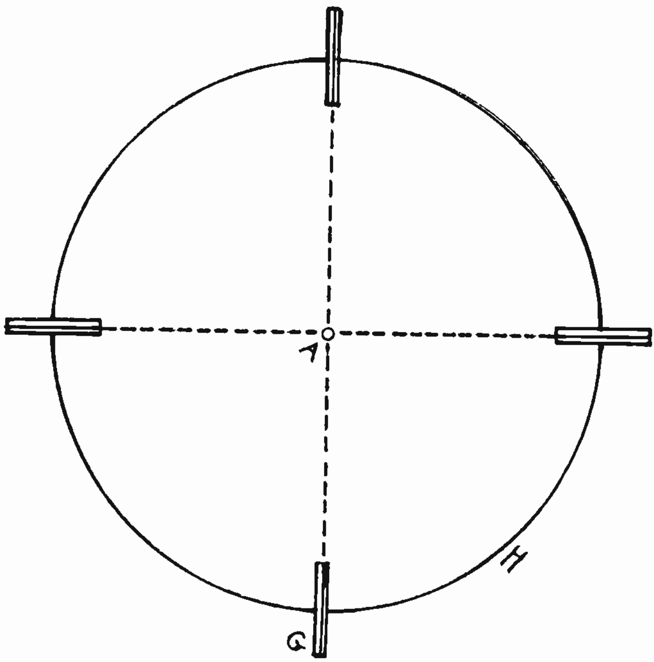

Fig. 12

of identical frequency are, however, easy to grasp. Referring again to Figure 12, if in any location such as G, the direction finding coil is rotated about a horizontal axis, the loudest signal will be obtained when the coil reaches a vertical position. In other words, the direction finding coil, when thus rotated about its horizontal axis, will normally indicate a vertical direction. Now referring to Figure 13, there is represented a profile view of the cross section of a secondary conductor, B, in a primary field, HH. The primary field, HH, has caused a current to flow in the secondary conductor, B, and as a result, there occurs the secondary field H^1. Suppose now that the coil is operated at various points along the line CD by revolving it about the horizontal axis. At points outside of the area of the secondary field H^1, the coil would indicate a vertical direction as at E, F, K, and L. At G, M, V, I and J, the coil would be acted upon by both the primary field, H, and the secondary field, H^1. At any one of these locations, as, for instance, at G, the primary field would tend to cause the coil to indicate a vertical direction along the line G, G^1, while the secondary field would tend to cause the coil to indicate a direction along the line GB, pointing to the axis of the secondary conductor. As a consequence, the coil would give a resultant direction such as is shown by the heavy line

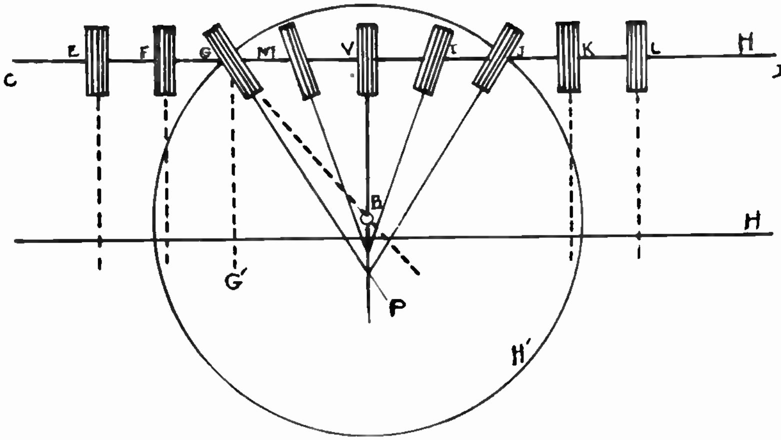

Fig. 13

GP. Similarly, at M, V, I, and J, other resultant directions would be obtained, all of which if plotted to scale as shown by the heavy lines would furnish a very good picture of the location of the axis of the secondary conductor, B.

These principles of re-radiation and of coil action when correctly applied furnish the basis of this method of locating ore bodies. The only requirements are that the ore body being sought must be conductive to high frequency electrical current, and that it must be of resonable length, the minimum length being dependent somewhat upon the depth. By using this method, it will be possible to determine the location of conductive ore bodies, both as to length and depth.

Electro-conductive ore bodies include practically all of the sulphide ores and some ores found in a native state. Ores occurring in a disseminated state are amenable to the process as well as those occurring in a massive condition. It is not possible to determine the character of the ore body located, no distinction being possible between iron, copper, lead or other sulphides. Nor will this process determine the width or the thickness of the ore body located. On the other hand, it will determine the location of all electro-conductive ore bodies down to depths of approximately 500 ft. in the area

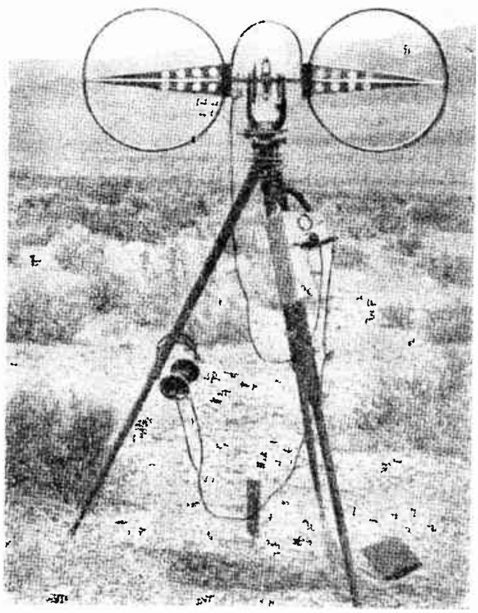

Fig. 14—Re-radiation Process Receiving Apparatus.

to which it is applied, regardless of the over-burden which may be present. It is not necessary that there be actual contact to a known ore body in the vicinity. The application of this process to territories covered with over-burden such as lava cap, or float, or where no ore out-crops occur, offers immense possibility in disclosing unknown mineralized areas.

Figure 14 shows a view of the receiving apparatus used in the Re-radiation process. The two loops are mounted so that they may be rotated easily. The transmitting apparatus is shown in Fig. 15.

With the use of this process, there should accompany as a follow-up, the application of core or diamond drilling, in order that an inexpensive determination of the character of the ore body, its value, width, and thickness may be determined.

It is apparent, that the ways and methods now available are far from perfect, and that this field of experimentation offers great opportunities to the man who is technically trained in Radio. Radio electrical surveying is in no sense destined

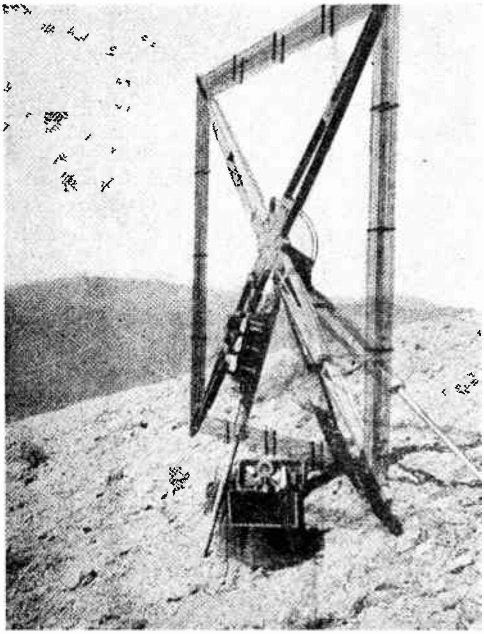

Fig. 15.—Re-radiation Process Transmitting Apparatus.

to render the professional mining engineer and geologist of minor importance in the mining world. On the contrary, the mining engineer and the man specially trained in Radio prospecting will work hand in hand in the future. Thus, by co-operating with each other, by interchanging of ideas, developing new methods and apparatus, it will be possible in the future to accurately locate valuable ores by scientific means solely, obviating the haphazard and chance methods employed in the past.

TEST QUESTIONS

Number Your Answers 43 and Add Your **Student Number**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

J. A. D.

1. Name the two general kinds of mineral deposits.

2. Name the methods of locating ore deposits mentioned in this lesson.

3. Describe the electrodes used in the Equi-potential method.

4. What is the purpose of the galvanometer used in the Schlumberger method?

5. What range of frequencies is generally used in the Chilson method of prospecting?

6. Draw a diagram and name the type of transmitter used in the Hertzian Wave System.

7. Draw a diagram of the receiver used in the Hertzian System.

8. What is re-radiation?

9. What causes a current to flow in the conductor CD, Fig. 10?

10. What is the greatest approximate depth that electro-conductive ores may be found by the re-radiation method?

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LESSON TEXT No. 44

SHORT WAVE BEAM TRANSMISSION

Originators of Radio Home Study Courses
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Washington, D. C.

Progress in industry depends very largely on the enterprise of deep thinking men, who are ahead of the times in their ideas.—SIR WILLIAM ELLIS.

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SHORT WAVE BEAM TRANSMISSION

Directional radio telegraphy is as old as the art itself. Hertz made use of reflectors at the transmitting as well as the receiving end, in order to augment the effect, and to prove that the electric wave which he had discovered, obeyed to a considerable degree, the ordinary optical laws of reflection.

As far back as 1895, when radio telegraphy was in its infancy, Senatore Marconi investigated to some extent, the practicability of the use of reflectors with the object of increasing the range of a radio station.

The discovery by Marconi of the great increase of range obtained by the use of longer waves, and the use of a ground connection with a vertical aerial, practically stopped development on directional lines for the time being. The demand of the time was for increased ranges; and as the first practical application of radio telegraphy, namely, working to and between ships, required the use of several different wavelengths, directional transmission was more of a handicap than an advantage. For this reason then, the development of directional transmission was dropped, and the need of the day, long wave transmission, received the major part of the development by the scientists and engineers at that time.

Before describing the essential features of the Beam system, it may be helpful to review, briefly, some of the more important factors of the present omni-directional long wave method of transmission which tend to limit its usefulness for long distance communication. By so doing, we shall be in a better position to appreciate the advantages offered by the Beam system.

By the ordinary method of omni-directional (all directions) radio transmission, electrical oscillations are generated in an aerial system from which the energy is radiated in the form of electrical waves which spread simultaneously in all directions. The energy which each wave or train of waves carries is thus dispersed more and more widely as the waves travel further from their source and only a very minute proportion of the total energy carried by each wave can be intercepted at the receiving point. It follows, naturally, that an immensely greater amount of energy must be radiated at the transmitting station than is required to operate the receiver, and that this disparity will get rapidly greater as the distance between the two communicating points is increased.

Apart from the question of ways and means of generating and controlling sufficient power to produce the required results at the receiving station, this characteristic introduces an entirely different problem when several transmitting stations are working simultaneously to different receiving points. Due to the fact that the radiations from each transmitter are spread indiscriminately in all directions, it becomes necessary to provide a means whereby each receiving station can pick out those signals coming from the desired source to the exclusion of all others. In practice, this is accomplished by allocating to each transmitter, a certain definite wavelength, and by tuning the circuit of the receiver to respond only to the wavelength of the particular transmitter from which it is intended to receive.

This power of selection is, however, limited. Due to the rapid interruption of the transmitted wave representing the character and spacing periods of the code, the carrier wave becomes broadened out into a series of slightly different wavelengths, with the result that each transmitter occupies not a single wavelength, but a band of wavelengths. According to the frequency of the code interruption, which in turn, is governed by the number of words per minute at which messages are transmitted, this wave-band will become wider or narrower.

At a speed of 100 words per minute, the variation in the frequency of the wave is approximately 50 cycles per second above and below the frequency of the carrier wave and, therefore, the width of the wave-band occupied by the transmission can be taken as 100 cycles. At 200 words per minute, the width will be double, and at 50 words per minute, the width will be half the figure given. Allowance must also be made for possible accidental variation in the length of the carrier wave radiated from the transmitter, due to the swinging of the aerial in a heavy wind, or to defects in the controlling and governing instrument of the transmitter. With a properly equipped installation, it should be sufficient to allow an additional variation of 200 cycles on this account. Altogether, a margin of about 400 cycles should be allowed between each wavelength allocated to a high power station for working at speeds up to 200 words per minute.

Translating these frequencies into terms of wavelengths, we find that if a station is allocated a wavelength of, say, 10,000 meters (30,000 cycles), it would actually occupy a band of about 130 meters, and for a wavelength of 30,000 meters (10,000 cycles) the band will be about 1,200 meters.

$$\frac{300{,}000{,}000}{29{,}800} = 10{,}065 \qquad \frac{300{,}000{,}000}{30{,}200} = 9{,}935 \qquad 10{,}065 - 9{,}935 = 130 \text{ Meters}$$

$$\frac{300{,}000{,}000}{9{,}800} = 30{,}600 \qquad \frac{300{,}000{,}000}{10{,}200} = 29{,}400 \qquad 30{,}600 - 29{,}400 = 1{,}200 \text{ Meters}$$

However, long wave high power stations do not normally exceed 100 words per minute, and it has been found in practice that they can work with a wavelength separation of 200 cycles.

With long wave omni-directional transmission, practical considerations, limit the band of wavelengths available for long distance telegraphy to waves between 10,000 and 30,000 meters. The lower wavelengths from 200 meters upwards are required for ship and aircraft services, for short distance point to point services for broadcasting, and for military and other governmental services. Waves above 30,000 meters are unsuitable because of the limitation in the speed of working and the much more severe atmospheric interference on these very long waves. Thus, the available waves on the long wave system are limited to some 100 bands of 200 cycles each.

The amount of power used by the omni-directional long wave transmitting station is also a limiting factor. One of the latest and largest of these long wave stations in the United States is located at Rocky Point, Long Island, and is operated by the Radio Corporation of America. Twelve antennas are used to communicate with various points in the world. Each antenna is supported on twelve 440 ft. steel towers, and the length of each antenna is in the neighborhood of 3 miles. From 200 to 400 kilowatts of power are used, and transmission is carried on at two frequencies, 17.15 and 18.22 kilocycles (17,500 and 16,465 meters). The British Post Office radio station at Rugby (England) has an antenna 800 ft. high supported on twelve masts, and uses about 500 kilowatts of power. The frequency used in transmission is 21.3 kilocycles (14,080 meters). Buenos Aires in Argentine, S. A., has an antenna about 680 ft. high supported on ten towers and uses about 800 kilowatts of power. The station normally works on a frequency of from 18.7 to 24.9 kilocycles (16,000 to 12,000 meters). Many other similar stations are operated in Germany, France, Italy and in other countries.

It has been found that in actual practice, the average speed obtained by the long wave stations is 20 words a minute for a daily average of 18 hours. This very slow average speed attained by long wavelength commercial radio stations is, of course, a decided disadvantage considering the competition of the cable companies and the speed of about 500 words a minute obtainable on the new type of cables now in use.

The Principles of the Short Wave Beam System

Having briefly reviewed the various factors and considerations which tend to restrict the wider use of the omni-directional system of long wave transmission, we may turn our attention to the possibilities offered by the new short wave Beam or reflector system.

It was explained in an earlier paragraph that with the present system of omni-directional transmission, the energy is radiated from the aerial in all directions and consequently, although only a very small amount of power is required at the receiving station to operate the receiving apparatus, an immense amount of energy must be generated at the transmitter to enable the necessary amount to be picked up by a far distant receiver.

If, by the use of a reflector, the whole energy of a transmitter is concentrated in a narrow angle of, say, 10 degrees, then provided that the distant receiving point lies within the arc of that angle, it is obvious that it will receive about 36 times more energy than it would if the same power were radiated uniformly throughout the 360 degrees of a circle. This result is illustrated graphically in Figure 1. Thus, all other things being equal, a 10 kilowatt station projecting its radiations in a narrow 10 degree beam becomes, so far as the distant receiver is concerned, the equivalent of a 360 kilowatt station radiating in all directions.

A similar reflecting system can be employed at the receiving station whereby energy can be drawn from a large area of the advancing wave front and concentrated on the receiver, thereby, still further increasing the total energy received.

Another important advantage is gained by using the system of short wave Beam transmission. As explained in an earlier paragraph, the number of long distance services which can be carried out using an omni-directional long wave transmission system are limited to the number of possible different wave-bands which can be accommodated within the

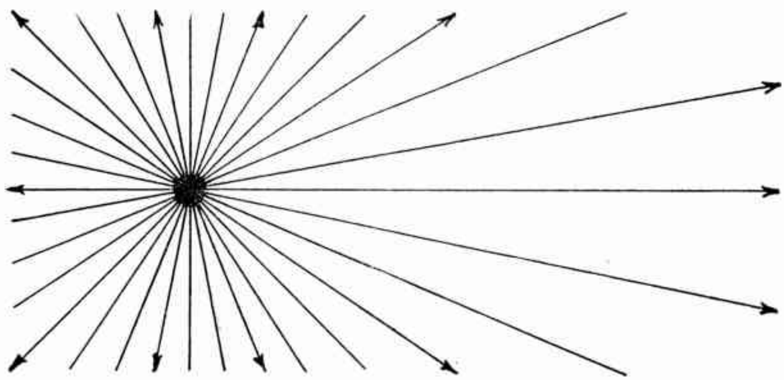

Fig. 1.—Graphic Representation of the Beam Principle.

range of wavelengths available for the purpose, because each transmitter must be allocated a different wave-band to enable it to work simultaneously with other stations. If the radiation of each transmitter is limited to an angle of 10 degrees, then obviously it would be possible for 36 stations, all transmitting from the same locality and all using exactly the same wavelength, to work simultaneously and quite independently of one another without causing any interference at the corresponding receiving station. Although in practice, the stations would not all be grouped in one locality, the principle holds good whether the transmitters are grouped together or scattered over the space of the world.

With short wave Beam transmission, a great many more working wave-bands are available than with the long wave.

For example, allowing as an outside figure a wave-band of 45 cycles which would suffice for facsimile telegraphy or simultaneous telegraphy with one or more high speed telegraph channels, approximately 700 stations could be worked on waves between 10 and 100 meters.

We must also take into consideration the effect of the reflectors at the receiving station in screening the receiver from radiations emanating from some source outside the arc of reception. Thus, with the Beam system of transmission and reception, the number of possible services which can be carried on simultaneously is many times the number of suitable wave bands which can be provided within the limit of the total wave range obtainable.

One of the principal advantages gained is that the speed in signalling is increased, due to the utilization of short waves. The larger antennae take an appreciable time to charge and discharge, while the smaller antennae take a much shorter time. There exists no theoretical reason why with a wavelength of 100 meters, the possible speed should not be 200 times as great as that obtainable with a wavelength of 20,000 meters which is approximately what some of the principal omnidirectional transmitting stations now use.

The greatest advantage of the short wave Beam transmission, however, is that the amount of power necessary to communicate between two specified points is relatively small compared to the amount of power used in the omni-directional long wave transmitter.

Early Developments of the Short Wave Beam Transmitter

There are, broadly, two general classes of directional aerial systems:

A. Those having the general characteristics and their directional power or polar curves nearly independent of their dimensions. The directional result is obtained by opposing the effecting of a number of aerials, or parts of an aerial with suitable phasing adjustment; the degree of opposition being a function of the direction. Systems of this class may be made small compared with the wavelength employed; for the purposes of position finding, and as receiving systems enabling interference to be eliminated from several directions, they have already been developed to a considerable degree. The simplest example of this class is the well-known "frame" or "loop" aerial. By employing a sufficient number of aerials the system may, theoretically, be given any desired sharpness of directional power without making the dimensions large; this can, however, only be done with a large sacrifice of receiving or radiating power.

B. Those having the general characteristics and their directional power or polar curves depending on their dimensions relative to the wavelength employed. In this class, the directional result is obtained by adding the effects of a number of aerials, or parts of an aerial, when working in the required direction. The underlying principle is that the effects, for the required direction, are integrated over a wide front in proportion to the wavelength. Such systems can, therefore, only have small dimensions when using short waves, and this fact makes their development difficult.

There are several examples of this second classification. Some of them are:

(1) Reflector systems in general.

(2) Systems composed of lines of aerials, at right angles to the working direction, correctly adjusted as regards phase. In this, may be included the Alexanderson long aerial with its feeders. Also, the multiple tuned type of antenna falls under this classification.

(3) The Beverage long, horizontal receiving aerial. This aerial and equivalent arrangement form a class by themselves, but have the characteristics that the directional power is a function of the dimensions.

The reflector system will be dealt with in this lesson text. Investigations were commenced by Senatore Marconi in Italy in 1916, with the idea of developing the use of very short waves, combined with reflectors, for certain war purposes. The waves used were 2 meters and 3 meters. Very little interference was experienced with the use of such short waves, except from the ignition system of motor cars and motor boats. At Senatore Marconi's suggestion, a coupled-circuit spark transmitter was developed, the primary having an air condenser and spark gap in compressed air. By this means, a moderate amount of energy was obtained, and the small spark gap in compressed air proved to have very low resistance.

The receiver used was a carefully picked crystal, while the reflectors employed were made of a number of strips of wires tuned to the wavelength, arranged on a cylindrical parabola with the aerial at the focus. The transmitting system was arranged so that it could be revolved and the effect studied at the receiver. It was assumed that the waves left the reflector as plane waves of uniform intensity, having a width equal to the aperture of the reflector, and the measured polar curves agreed very well indeed with the theoretical curves. Figure 2 shows the calculated curves for apertures of 1, 2, 3 and 5 wavelengths.

Reflectors having apertures up to five wavelengths were tested, and by the use of two reflectors with apertures of three and one-half wavelengths, one at the transmitter and one at the receiver, the working range was increased about three times.

Further experiments were continued during the year 1917. With an improved compressed air spark transmitter, a 3 meter wavelength and a reflector having an aperture of two wavelengths and a height of 1.5 wavelengths, a range of over 20 miles was obtained by a receiver without a receiving reflector. During these experiments, a phenomenon of wave propagation was discovered which up to that time had not been realized. This phenomenon was the very rapid increase in the strength of the electrical field with heights above the ground. The rate of increase appeared to be a fraction of the height divided by the wavelength, and while not very noticeable with waves of several hundred meters, it was very marked with waves of a few meters length. In the year 1919, experiments were commenced with a vacuum tube transmitter, with the idea of producing a directional telephone system. A wave of 15 meters was selected, which, while well within the capacity of the tube available, allowed a simple reflector to be used without too large a structure. After several trials, a single tube transmitter was developed taking about 200 watts with a 15 meter wave and giving 1 ampere in the center of a half wave aerial.

After all small practical difficulties were solved, very strong speech was obtained 20 miles away. The strength was such that shadows produced by the small hills and buildings were hardly noticeable, unless the stations were close behind them. The next point was to test the maximum range and, particularly, to find whether such waves would carry over the horizon, and whether there would then be a rapid falling off of the signal strength. During the test following, speech was received 70 nautical miles, and it was proved that there was no rapid loss of the strength after passing the horizontal line.

As a result of these early experiments, it was decided to test the range of a short wave reflector system, solely over land and where no large bodies of waters intervened between the transmitting and receiving station. A short wave reflector transmitter, using a 15 meter wavelength, was erected, and the tests were commenced in February, 1921, to a portable receiver on an automobile. Very good speech was received up to 66 miles, and fair speech at a slightly greater distance. A reflector receiving station was then erected 97 miles from the transmitter.

The transmitter consisted of two medium size power tubes working in parallel. The power delivered to the tubes

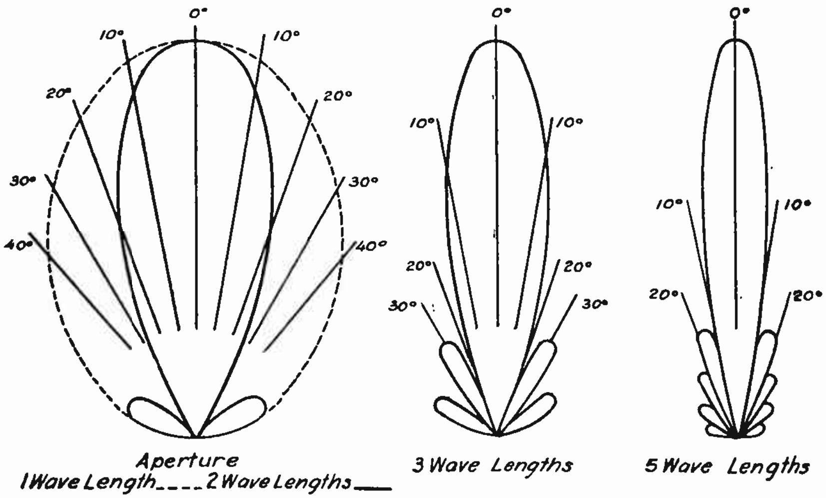

Fig. 2.—Illustrating How Width of Beam Depends on Aperture of Reflector.

was usually about 700 watts (4,000 volts, 175 milliamperes). The aerial wires were a little longer than half a wavelength, and the entire antenna system had a radiation resistance in the order of 90 ohms. The efficiency, input to tubes, to aerial power, was between 50 and 60 per cent, and about 300 watts were actually radiated. With the reflectors up at both ends, speech was very strong and of very good quality. It was usually strong enough to be just audible with a one-quarter to one-half ohm shunt resistance connected across the 60 ohm telephone receivers.

With both reflectors down, the speech was usually only just audible with no shunt resistance connected across the head telephones. Average measurements indicated that the energy received when both reflectors were up was about 200 times the energy received when not using the reflectors. Thus, to get the same strength without reflectors as with them, a 140 kilowatt tube transmitter of the same efficiency would be required. Local measurements of the polar curve taken near the station show that the electrical field in front of the reflector antenna was increased approximately four times by the use of the reflector, and that the same order of increase was obtained during reception. The increase of energy received, due to the use of a reflector at the transmitting and receiving antennae should, therefore ,be four squared times four squared, which equals 256 times.

It was at first thought that it was impossible to concentrate the waves radiated into a beam which would carry over a considerable distance. Some engineers believed that after the beam had been radiated into space, and had traveled for some distance, the concentration or beam effect would be lost; that the waves would gradually broaden, start going in all directions and, gradually, lose the directional or beam effect entirely. However, this theory was disproved by further tests, and in nearly all cases, the received signal was at least 200 times greater by the use of a reflector at the transmitter and receiver.

The U. S. Bureau of Standards Test

One of the most important problems of Radio communication is the interference between different transmitting stations. The Radio waves which are transmitting Radio telephone messages usually occupy a broader band of wavelengths than the waves which are transmitting Radio telegraph continuous wave code signals. There is a definite and not very large limit to the number of Radio telephone transmitting stations of any considerable power which can operate in a given locality without serious interference, employing the usual type of antennae and transmitting apparatus. In the past, commercial Radio communication has been almost entirely carried on by the use of wavelengths greater than 200 meters and non-directive antennae which radiated about equally well in every direction. On short wavelengths, a narrower band of wavelengths is required to transmit a given sound in Radio telephony than is required at long wavelengths.

At the present time, many Radio telephone transmitting stations are transmitting music and other entertainment broadcast for reception by a large number of receiving stations located in all directions from the transmitting station. For such broadcast transmission, directive antennae are not suitable, but the use of directional antennae for the reception of broadcast Radio telephone messages offers a means of reducing interference difficulties at a receiving station.

Directive antennae for transmission are, however, desirable for point to point communication; that is, communication from one transmitting station to one receiving station. Transoceanic and much of ship Radio traffic is practically all point to point communication. There are many cases in which communication is desired between points not easily accessible, so that Radio communication is the only practicable means. The use of directive transmission greatly reduces the interference which such communication ordinarily causes. There are some new kinds of point to point Radio communications which are now being developed, such as the transmission of photographs by Radio, and the remote control of mechanisms by Radio, all of which can advantageously be carried on by directive short wave transmission. The enormous increase in the use of Radio telegraphy and Radio telephony during the past few years has increased the demand for apparatus capable of being operated with a minimum of interference. Directive transmission should make possible such communication, with a minimum amount of power, as well as with the least interference.

It is also possible to use antennae of marked directional characteristics for reception, and thus to reduce interference in reception caused by undesired transmitting stations.

A serious difficulty in Radio communication is due to "strays," which are stray waves caused by atmospheric electrical disturbances. These disturbances are frequently so severe, particularly during the summer months, as to make satisfactory reception impossible. It is generally true that strays are less severe on short wavelengths than on long wavelengths, and at such short wavelengths as 10 meters, it has been found that strong strays are not ordinarily encountered. Strays of some kind come from a particular direction and can be practically eliminated by the use in reception of an antenna of marked directional characteristics. More serious difficulties are experienced from strays when a large antenna is used; a very small antenna is used for short wavelengths of 10 meters. For several reasons, therefore, a system of communication on 10 meters, which employs a directional antenna, greatly reduces the difficulties due to strays. The problem of the generation and directive radiation of waves of the order of 10 meters resolves itself into; (1) the development of a

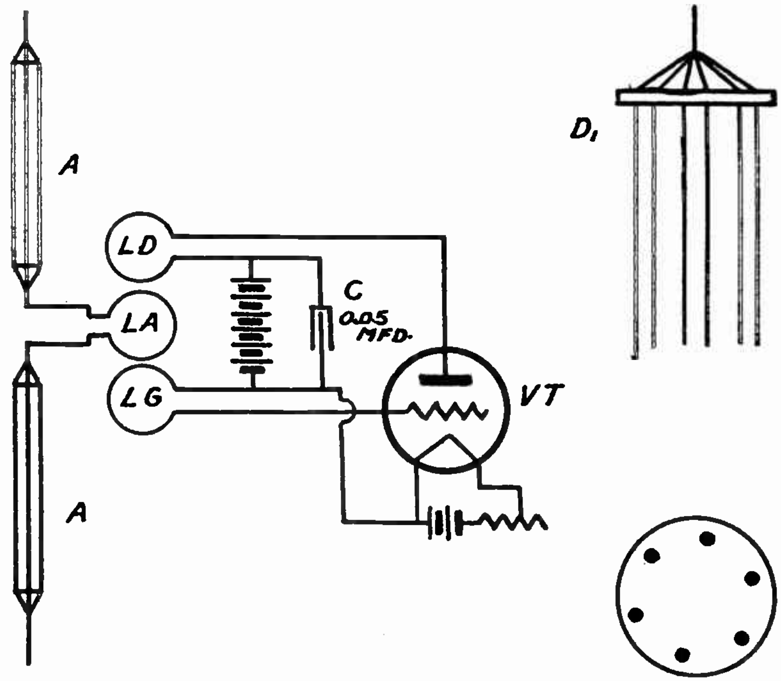

Fig. 3.—Experimental Beam Transmitter Circuit.

10 meter electron tube generator (of suitable power); (2) the development of an efficient directive reflecting system for Radio waves of this wavelength, and (3) the development of a 10 meter receiving apparatus.

A circuit diagram of a 10 meter Hartley type transmitter is shown in Figure 3. The plate coil LD consists of a single turn 17 centimeters in diameter for plate coupling, and the grid coil LG is a similar coil for grid coupling. The capacity between the elements of the tube, together with these coils, forms the oscillatory circuit. It is this internal capacity of the tube which largely determines the upper limit of the frequencies obtainable with a given tube.

The radiating system, (the antenna) shown at A in Figure 3, is coupled to the generating circuit by means of the coil LA, which is similar to the coils LD and LG. The antenna A consists of two sets of vertical wires. Each set consists of six parallel wires arranged in a circle, as shown at D_1 in Figure 3. These wires are spaced about 3 centimeters apart and are 1.8 meters in length.

The Reflecting System

There are several ways of obtaining directive transmission, but one of the most effective methods for short wavelengths consists of the use of a reflector of proper design in the form of a section of a parabolic cylinder. The wave from

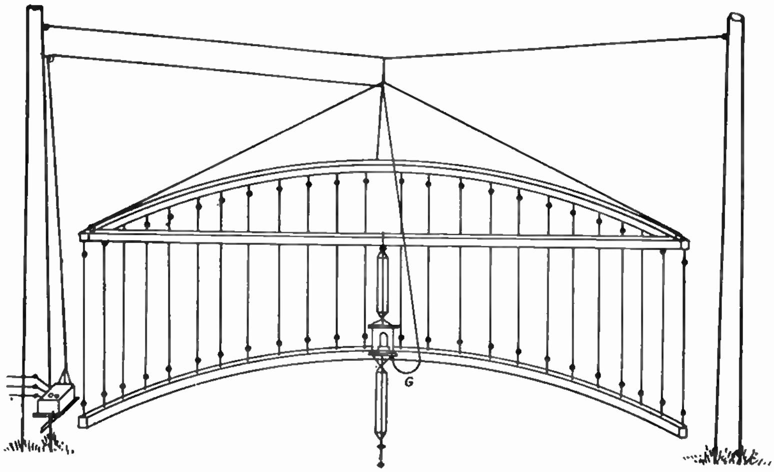

Fig. 4.—Illustrating Construction of Reflector.

this form of reflector is somewhat similar to a parallel beam of light which has passed through a slit in an opaque screen. From theoretical consideration for a parabolic cylinder having a line source situated in the focal axis, the reflected rays will all be parallel and will be parallel to the axis of the parabolic cylinder. This ideal result, however, is only approximated in practice.

Figure 4 illustrates the reflector used. It is in the shape of a segment of a parabolic cylinder and is made by suspending forty wires from a frame constructed in the form of a parabola. Each of these wires is tuned to 10 meters and spaced 30.47 centimeters (1 ft.) apart. The frame is suspended from a rope stretched between two poles, so that the reflector may be rotated through 360 degrees. The suspended wires are insulated from the frame and from each other. The focal distance was made one-quarter of a wavelength; that is, 2.5 meters (8 ft. 2.4 in.). With this distance determined, the parabolic frame may be constructed. It is important to have a frame of this shape in order to maintain the proper phase relation and to obtain maximum reflection. The reason for this will be made clear by reference to Figure 5, which may be considered a simplified plan view of Figure 4. The filament rheostat, the ammeters in the filament and plate supply circuits, and the plate and filament supply batteries are mounted on a small unit shown at the left in Figure 4.

In Figure 5, the 10 meter electron tube generator is shown at the focus "O" at a distance of one-fourth of a wavelength from the vertex E. The curve BEJ is parabolic. Each wire along BEJ reradiates the energy received from O by virtue of the fact that it is tuned to O. Since any distance ODN or OCM is equal to OE plus EO, it is evident that the reradiation from all the wires along BEJ will reach the aperture BJ in phase with each other. It is evident, therefore, that reinforcement takes place in the direction OP and interference in the direction EQ. Except for leakage, as shown at OK, practically all energy is reflected over a small angle in the direction of OP. By extending the parabola, as shown at A and L (increasing the aperture), this leakage is reduced, thus giving a narrower beam. The type of reflector illustrated was built for experimental use, and while it gives the dimensional values and electrical characteristics, the general mechanical design

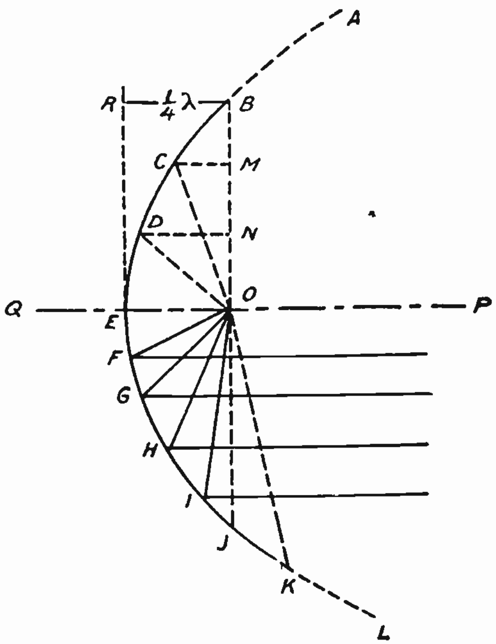

Fig. 5.—Showing How Phasing is Attained.

should be made more rugged for practical use and in permanent installations.

Figure 6 shows the schematic wiring diagram of the receiver used. An external heterodyne was employed so as to receive the continuous wave signals. However, a regenerative set of the usual design which would cause the detector tube of the receiving set to oscillate, may be used and thus eliminate the external heterodyne circuit. The antenna (A, La and A, Figure 6) used in picking up the energy of the receiving apparatus was a single wire tuned to the incoming wave frequency and coupled at the center by means of the coil, La, to the secondary coil, Lg, of the receiving set. The total length of this antenna wire including the single turn coil, La, was 4.37 meters (13 ft. 4 in.). The diameter of the single turn coil, La, was 30.48 centimeters (1 ft.). This antenna was made from

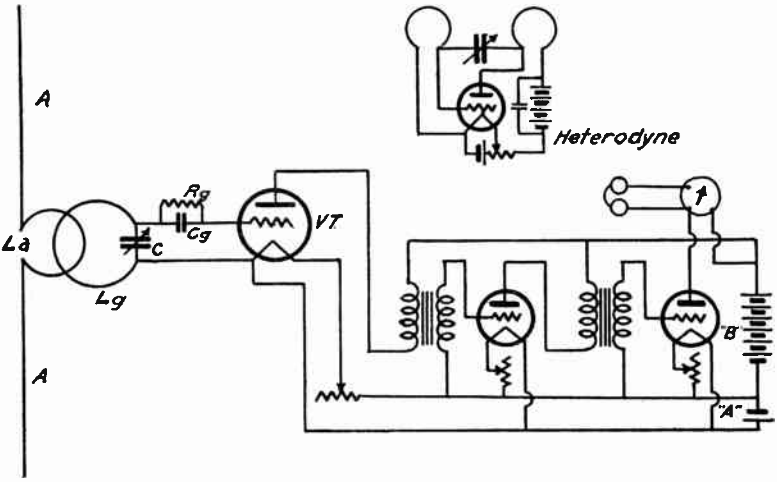

Fig. 6.—Schematic Wiring Diagram of the 10 Meter Receiver Used.

a single piece of No. 12 B and S gauge copper wire. The condenser, C (.0005 mfd.), grid leak (2 megohms), and condenser, Cg (.00025 mfd.), and the tube VT were mounted on the support with the secondary coil, Lg, in as close proximity to it as possible. Since this apparatus was attached to the frame supporting the coils La and Lg, it was suspended in the air with it when the signals were being received.

Figure 7 shows a view of the complete receiver ready for operation. No attempt was made to use a reflector system at the receiving end since the main problem was the radiation of a sufficiently narrow band or beam with as little leakage as possible. After all of the constructional details of the transmitter reflector system have been determined, it would be an easy matter to construct a reflector system for the receiver according to the dimensions of the reflector system at the transmitting

Fig. 7.—View of Complete Short Wave Receiver.

end. With the use of such a reflector system at the receiving end, the signal strength would be increased in proportion.

Results

A great many experiments were performed in order to determine the best possible type of reflector. From the results of these experiments, it was learned that the proper length of the reflecting wires must be determined while they are in position on the parabolic frame, as the capacity effect of the neighboring wires made necessary a slightly shorter length of wire for resonance than when they were oscillating. From the data obtained, it was determined that the correct length of the forty reflecting wires should be 4.39 meters (14 ft. 5 in.) and that they should be placed 30.48 centimeters (1 ft.) apart. With this arrangement, it was found that the beam was sufficiently narrow, and that very little radiation took place through the rear of the reflector.

The best results were obtained by increasing the aperture of the reflector to 1.5 wavelengths. In doing this, the parabolic frame was extended and ten tuned wires were suspended

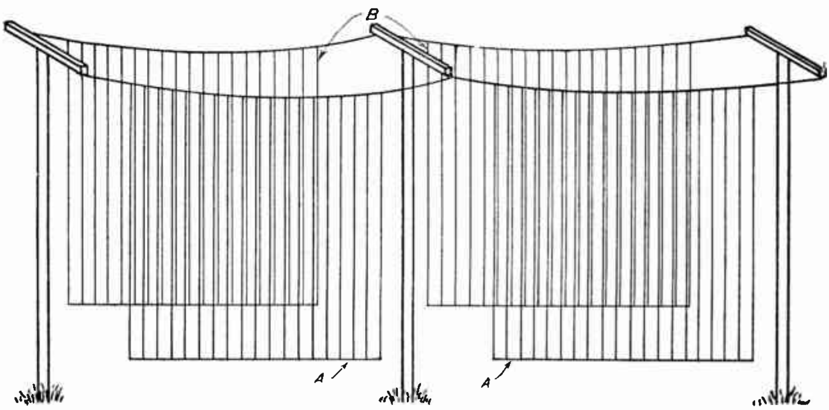

Fig. 8.—Simple Marconi Beam Antenna and Reflector.

1 ft. apart on each extension. This increased the number of reflecting wires from forty to sixty. All of the sixty reflecting wires were 14 ft. 5 in. long. It was determined that this type of reflector gave the best results. There was practically no leakage in the rear of the reflector, and the reflected wave was slightly narrower than with any of the other arrangements.

The results of these experiments prove that certain requirements must be met before efficient directive transmission can be obtained. These are: (1) The source of the wave to be reflected should be placed exactly at the focus; (2) the reflecting wires should be tuned to resonance with the source, and (3) the width of the reflected wave front is dependent upon the size of the aperture employed.

Further Developments of the Marconi Beam Antenna

During the years 1923 and 1924, the Marconi engineers conducted numerous experiments, which have an important bearing on the present type of installation. As a result of these experiments, an entirely different type of antenna was developed. It was determined that it was not necessary to have a parabolic shaped antenna and reflectors in order to concentrate the outgoing waves into a narrow beam. By properly spacing the reflector wires from the antenna wires, and by using a feeder system which maintained the same relative phase at every point of the antenna wire, a straight antenna could be used and the same results accomplished as when using the parabolic shaped antenna.

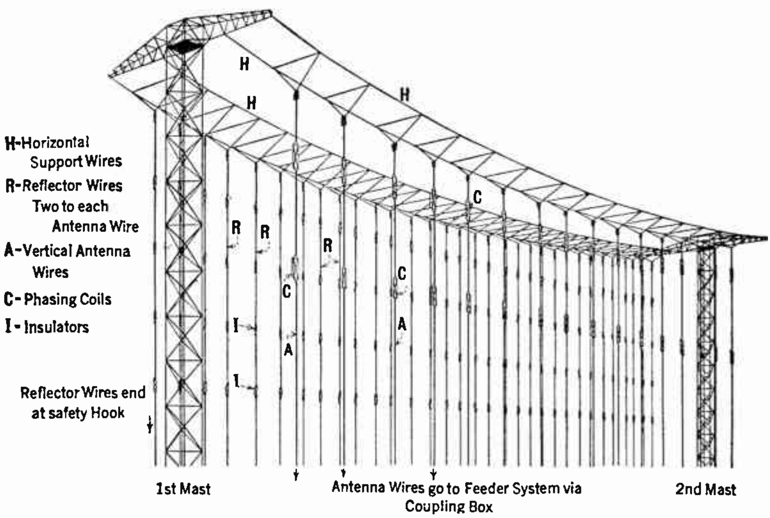

Fig. 9. Courtesy of Radio Broadcast.

Figure 8 illustrates this type of antenna. It approximates as nearly as practicable to a uniform current sheet in which the current is maintained in the same relative phase at every point. It is set up at right angles to the direction it is desired to work. The directional property or degree of concentration of radiated energy of such a current sheet is a function of its dimensions relative to the wavelength and its normal bi-directional. It can be made uni-directional by placing a second similar sheet which acts as a reflector parallel to the first and at the correct distance behind it.

Practically, the aerial consists of a number of vertical wires which may or may not be connected together by horizontal wires. The aerial is fed simultaneously at a number of feeding points by a special feeding system from the transmitter to insure that the phases in all the wires are the same.

A second system of wires placed parallel to the first and at one-quarter of a wavelength behind acts as the reflector and makes the system uni-directional. Figure 9 clearly illustrates the construction of such a system. Figure 10 illustrates the feeder system used. By maintaining the same distance from the transmitter to each antenna wire and in conjunction with the phasing coils, C, as shown in Figure 9, the same relative phase is maintained in all aerial wires. Herein lies the fundamental principle upon which this type of antenna functions.

The system of wires which constitutes the connecting link between the transmitter and the antenna is known as the

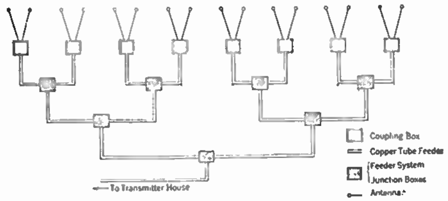

Fig. 10. Courtesy of Radio Broadcast.

feeder system. This system consists of two concentric copper tubes, air insulated from each other to avoid loss. The outer tube is grounded and carried on metal standards a short distance above the ground, while the inner tube carries the current to the antenna. In order to insure an equal amount of current for each of the separate antenna wires, the feeder system is so arranged that the distance which the current has to travel through the feeders is exactly the same for each individual wire in the entire antenna system. In order to prevent the presence of reflected waves in the feeder system which would cause trouble, equalization may be obtained by means of the coupling transformers located in each junction box. (See Figure 10.)

Figure 11 shows a view of part of the feeder system. The copper tubing which constitutes the line between the transmitter and the antenna system, together with one of the junction boxes, is shown in this picture. To the left, may be seen one of the antenna coupling boxes to which two of the antenna down leads are taken. The wooden structures seen dotted about the field in the background are the automatic counterweights which provide a certain amount of slack to the antenna wires when necessary.

The receiving aerial and reflector system have the same general construction as the transmitter. If required, either may be arranged to serve as the transmitter or receiver.

The calculated directional effect of aerials of different widths is indicated below:

Width of aerial in wavelengths	1	4	20
Approximate horizontal angle within which practically all the energy is confined....	180°	30°	6°

The approximate energy magnification, due to the concentration of the energy by the directional effect when using this type of antenna is shown in the table below, which gives the comparative energy available on the receivers, compared with what would be available from an ordinary vertical antenna radiating the same amount of energy.

Type of Aerial.	Approximate Magnification with Similar Aerials at Transmitter and Receiver.
Simple vertical aerial one-eighth wavelength high or less	1
Beam aerial half wavelength high, three wavelengths wide, plus reflector	350
Beam aerial one wavelength high, three wavelengths wide, plus reflector	900
Beam aerial one wavelength high, five wavelengths wide, plus reflector	2500
Beam aerial one wavelength high, twelve wavelengths wide, plus reflector	14000

There are some general laws governing the beam antenna system just described, which may be stated as follows:

(1) The ratio of the loss by radiation to the loss by ohmic resistance and, therefore, the efficiency, remains constant for all sizes of the aerial at the same frequency. The efficiency of the Marconi System is very high and can be easily of the order of 80 per cent.

(2) The natural decrement of the aerial is very high and remains constant whatever the extension, as the ratio of the inductance to the resistance of the aerial remains the same.

(3) The greatest magnification for a given area of aerial and, therefore, for a given cost, is obtained by having equal areas at the transmitter and receiver. Thus, an aerial of 20 square wavelengths at the transmitter or the receiver gives a magnification of 200, but if divided into two aerials at the transmitter and receiver, each of 10 square wavelengths, it gives a magnification of 10,000.

A Short Wave Beam Station

The first beam service to be open for commercial purposes was between England and Canada. This recalls the fact that Senatore Marconi's earliest long distance experiments were conducted between these two countries in December, 1901,

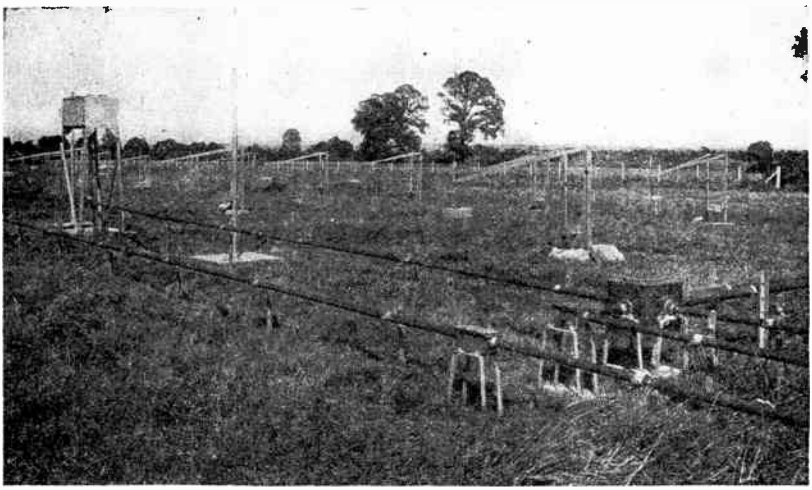

Fig. 11.

and the establishment of the first trans-Atlantic wireless service was between Clifden, Ireland, and Glace Bay, Canada, in the year 1907.

During the preliminary tests, before the stations were open for public service, speeds of 1,250 letters per minute in each direction, equal to 2,500 letters per minute over the whole circuit, were accomplished and the stations were worked without an error for hours on end. Counting every hour of a 7 day test, the average speed of signalling was 650 letters per minute in each direction, or 1,300 letters per minute over the complete circuit.

The Canadian transmitting station is situated about 2 miles south of the city of Drummondville, Quebec, and the receiving station at Yamachiche, about 30 miles north of Drummondville. Figure 12 shows an interior view of the power apparatus room, showing some of the motor-generators used and the main switchboard for controlling the output from the various motor-generators. These furnish the various D. C. voltages for the transmitter, and the A. C. voltages and frequencies required by the rectifiers. Power is obtained from the hydro-electric system of a local power company at 48,000 volts, three phase, and is stepped down to 550 volts, three

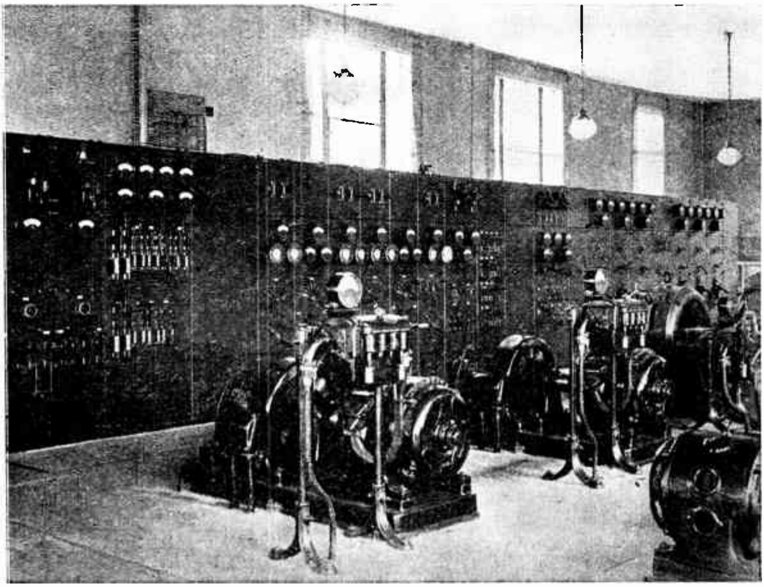

Fig. 12.—View of the Drummondville Transmitting Station, showing Motor, Generators and Switchboard.

phase, at an outdoor substation just outside the transmitting building. This 550 volts, three phase supply, operates the motors of the various motor-generator sets, the generators of these motor-generator sets furnishing low voltage D. C. for the filament lighting of the transmitter, D. C. for charging the master oscillator storage battery, 110 volts D. C. for the exciter and control circuit, 300 cycle single phase A. C. for the main rectifier and 1,000 cycle single phase A. C. for the master oscillator rectifier.

Figure 13 shows a rectifier for furnishing the main 10,000 volts anode D. C. supply to the transmitter and also a separate small rectifier for furnishing anode supply to the master oscillator. Two sets of each of the aforementioned rectifiers are shown. These rectifiers are situated in the apparatus room and furnish D. C. for the filament, 1,000 cycle A. C. single phase for the master oscillator rectifier, and 300 cycle A. C. single phase for the main rectifier.

The D. C. for filament, controls, etc., direct from the switchboard and the high tension direct current from the rectifiers are carried by cables to the transmitter in the transmitting room, shown in Figure 14.

The transmitter consists of the four panels shown in the background and the local controls are contained on and under

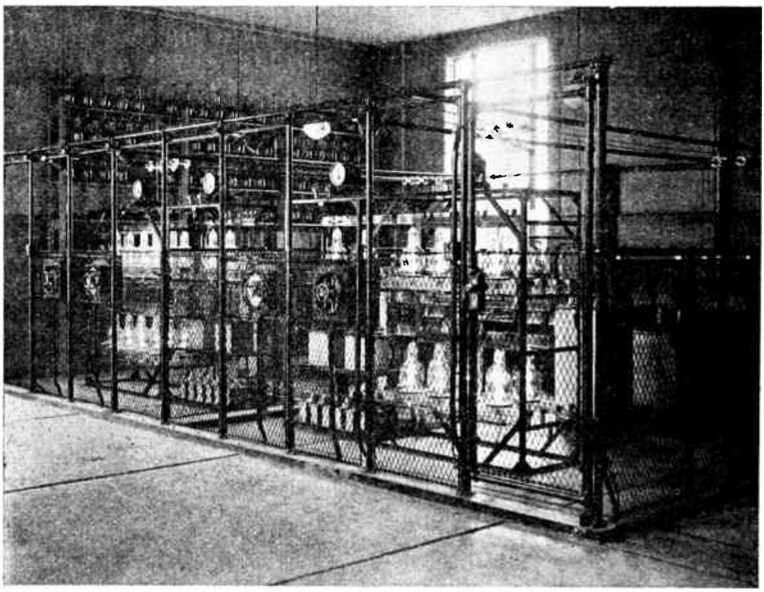

Fig. 13—View of Rectifiers.

the tables in the foreground. The panel on the extreme right carries two oil cooled tubes which are so connected and operated by the keying system that they act as absorbers of energy during the period of no signals. This panel operates in the same manner as the modulator panel on a Radio telephone set, and its inclusion in this installation enables a steady load to be maintained upon the power supply apparatus whether signalling is going on or not, thus avoiding any fluctuations which might arise from varying loads.

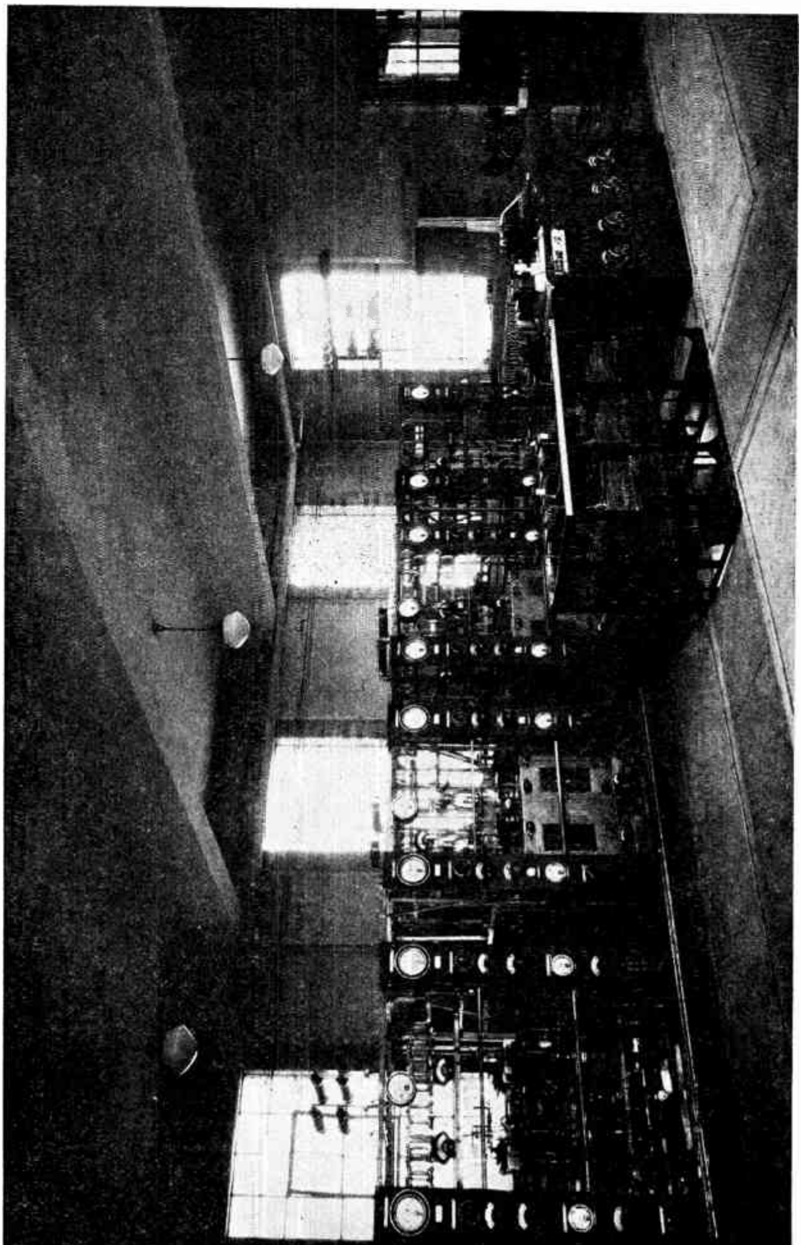

Fig. 14.—Transmitter Room at the Drummondville Station.

The second panel from the right contains the master oscillator and first amplifier in the screened compartment in the lower portion, and the second amplifier on exposed circuit immediately above it. The third panel from the right is simi-

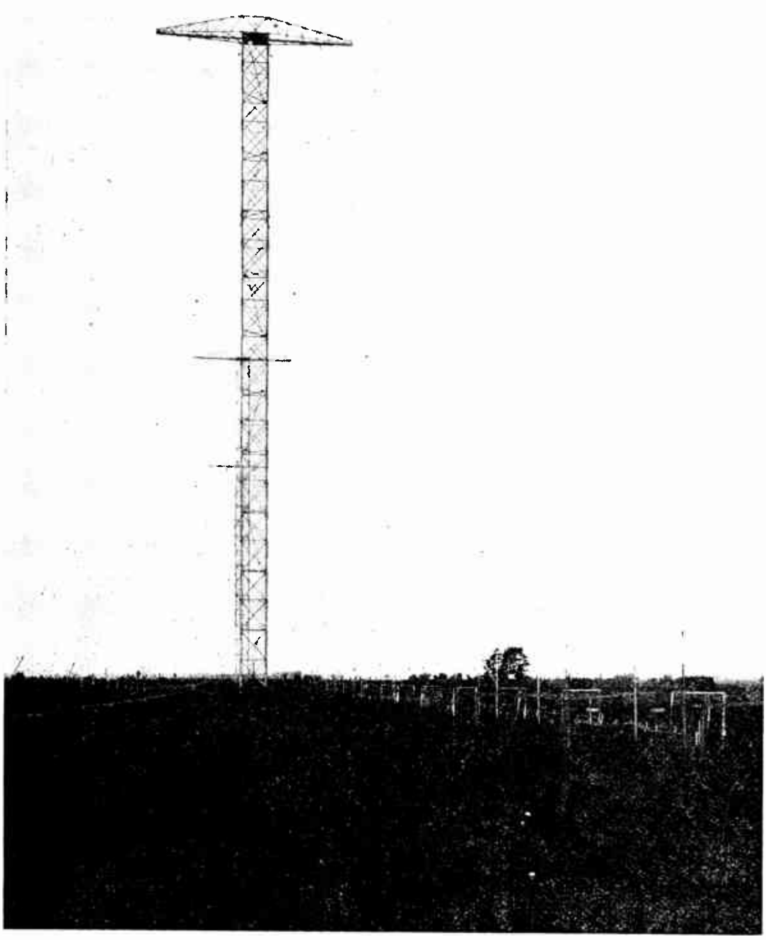

Fig. 15.—View of Antenna and Reflector System.

lar to the second from the right excepting that it is tuned to a different wavelength. The panel fourth from the right, or extreme left, is the third amplifier which operates directly on the aerial through the feeder system. This panel is arranged so that it may be tuned to the wavelength of either of the middle two panels, depending upon which wavelength is being used. When in operation, one of these center panels is not in use.

Air-cooled vacuum tubes are used for the master oscillator and the No. 1 and No. 2 amplifiers. Oil-cooled tubes are used in the main amplifier No. 3. The circuits of No. 2 and No. 3 amplifiers each use two tubes in a balanced circuit arrangement.

The keying relays on the absorber panel are operated direct from Montreal by wired radio.

The high frequency output from the transmitter is conveyed through the back of the building to a feeder system or special transmission line supported close to the ground. The feeder system consists of concentric copper tubing, the inner tube being insulated from the outer throughout the whole of its length by means of porcelain insulators. The outer tube is directly supported by angle irons and straps and is always directly grounded.

The feeder system is continued for over 1,000 ft. to a point near the aerial system and on the center line of it, and is there branched and sub-divided by special distribution boxes so as to obtain the required number of outlets for the various aerial wires. All these branches are symmetrical and balanced so that the actual physical length of conductor between any aerial wire and the first junction box of the feeder is exactly the same. At each point where the feeder is sub-divided, impedances are introduced so that the load impedance at any junction point is always equal to the surge impedance of the feeder. These precautions insure that all the aerial wires are radiating energy in phase and that loss by reflection on the feeder system is at a minimum.

The aerial and reflector system is shown in Figure 15. The complete aerial consists of a number of independent wires supported in a flat vertical plane by means of horizontal stays or cross arms. There are sixteen antenna wires and thirty-two reflector wires between each tower. The antenna wires are shown to the right of the towers in Figure 15, and the reflector wires are to the left. Each aerial wire consists of a long single wire with several special inductance coils in series, these coils being used for phasing purposes. Their action is such that the several exposed lengths of aerial wire are radiating energy in phase one with the other.

The vertical plane of aerial and reflector wires extends horizontally a distance of two spaces of the mast line. Provision is made for the use of two wavelengths on the trans-Atlantic circuit and there are, therefore, five masts which allow two spaces to be utilized on each wavelength. On the Australian circuit, one wavelength is provided for and there are, therefore, three masts. The distance between the masts, which also constitutes the width of each space is 650 feet. The height of the mast on the trans-Atlantic circuit is approximately 300 feet to the cross-arm, and on the Australian circuit, approximately 250 feet to the cross-arm. The mast line is laid out so that it lies perpendicular to the great circle (shortest distance be-

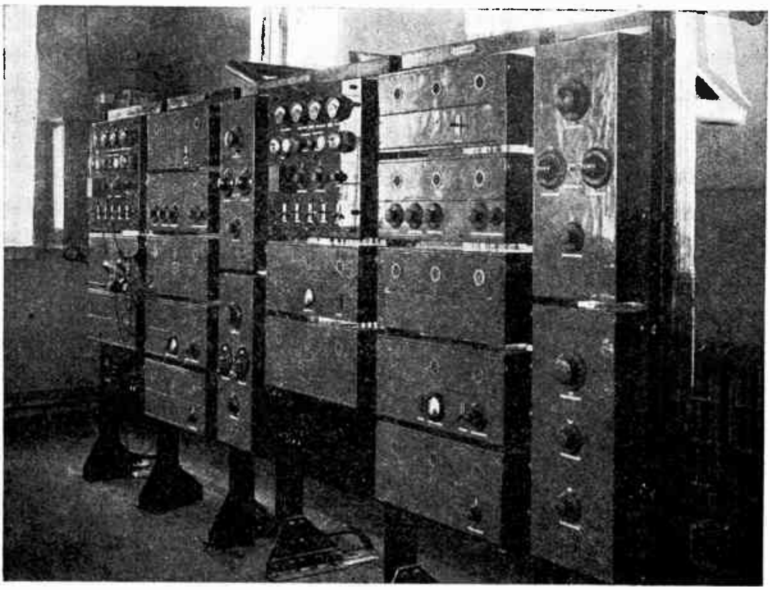

Fig. 16.—Panel Arrangement of Receiving Equipment.

tween two points on the surface of a sphere) between the transmitting and receiving stations.

The reflector wires shown on the left of the figure are suspended from the left-hand end of the cross-arm of the masts. The plane of the reflector wires is one-quarter wavelength behind the plane of the aerial wires and it is on that side of the aerial remote from the direction it is desired to transmit. These reflector wires consist of independent lengths insulated from each other and from the ground, and have no physical connection with the aerial or feeder system, acting simply as radiators in space. Energy transmitted backwards from the aerial wires excites the reflector wires and the combination of this excitation and the one-quarter wavelength spacing produces polarization of energy in a forward direction. The foot of each aerial and reflector wire is steadied by a balanced weight and a lever arrangement which permits the aerial to rise or fall with changes in wind pressure and temperature but which anchors the lower point in the horizontal plane. This anchoring arrangement is shown in Figure 15 at the lower end of each of the aerial and reflector wires.

At the Yamachiche receiving station, the aerial system, consisting of reflector wires, aerial wires and feeder system, is identical with that of the transmitting station. Two wavelengths, occupying two spaces, each on a mast line, are provided for the trans-Atlantic service and one wavelength occupying two spaces on a mast line is provided for the Australian circuit. As in the case of the transmitting station, the mast line is laid out perpendicular to the great circle between the transmitting and receiving stations, the reflector being on that side of the aerial remote from the transmitting station. Received energy at several million cycles per second is collected in phase by all the aerial wires, each of which delivers the energy so collected to the feeder system, and the total carried by the main feeder to the receiving station and equipment.

The panel arrangement of the receiving equipment is shown in Figure 16. There are two separate receiving systems shown, each receiver comprising 3 vertical panels, one unit being for use on the Australian circuit and the other on the trans-Atlantic circuit.

The copper tubes comprising the feeder can be seen just above the panel and behind the right hand upper corner where they make the right angle bend into the receiver. Each unit embodies special circuits, amplifiers, and filters, whereby the energy is received from the feeder at several million cycles per second and is delivered to the land line through the switch on one of the lower panels at a much lower frequency. The signals are conveyed to Montreal by wired radio at this frequency, where they are rectified, amplified and made to operate automatic recording devices. The system of heterodyning employed at the receiving station is quite unique in that it employs two heterodyning systems, or what is practically the equivalent of two Superheterodynes in series. The energy from the feeder system is fed to the first detector through a very loosely coupled tuned unit. The loose coupling is resorted to in order to cut out interference and reduce the pick-up of static and other noises. The first detector is coupled with an oscillator which changes the wave of approximately 26 meters wavelength over to a wavelength of about 1,600 meters. The signal then goes through a three stage amplifier at this frequency and is again detected. At this point, another heterodyne oscillator is provided and the wavelength changed from 1,600 meters to approximately 10,000 meters. Again, it is amplified through 3 stages and again detected. This second heterodyne may be tuned to an audible note so that the operator may listen in and tune the signals as received through the first part of the receiver. Each stage of amplification is of the push-pull type in order to provide distortionless amplification throughout. The output works through a bridge system which insures the signal strength to be practically the same, no matter what the strength of the incoming signal.

TEST QUESTIONS

Number Your Answers 44 and add your **Student Number**

1. Name two advantages of short wave beam transmission over long wave omni-directional transmission.
2. What is the approximate power used by the omni-directional long wave transmitting stations?
3. What wavelengths were used by Marconi in his experiments with beam transmission in the year 1916?
4. Draw a diagram of a 10 meter Hartley beam transmitter.
5. Describe the antenna used with the transmitter whose diagram is shown in Fig. 3.
6. Give a brief description of the reflector shown in Fig. 4.
7. Draw a diagram of a 10 meter receiver used for receiving signals from a beam transmitter.
8. What is the size of coil La, Fig. 6?
9. What is the approximate efficiency of the Marconi beam antenna described in this lesson?
10. How are the tubes in the main amplifier of the set shown in Fig. 14 cooled?

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(Second Edition)

AIRCRAFT RADIO TRANSMITTERS AND RECEIVERS

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> "We learn wisdom from failure much more than from success. We often discover what will do by finding out what will not do; and probably he who never made a mistake never made a discovery."—*Samuel Smiles.*

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

AIRCRAFT RADIO TRANSMITTERS AND RECEIVERS

After a period of rapid growth, aviation today has reached a state where its successful commercial application is as much concerned with development of essential accessories as with improvements in the aircraft itself. Thus one of the greatest needs of commercial air transportation at the present time is the provision of simple and accurate means of navigation and of safety in landing under unfavorable flying conditions with poor visibility.

The importance of radio communication to aircraft is apparent; its value has been proved not only in many years of application in our military services but also by foreign every-day commercial use, as well as on a number of more or less spectacular long-distance flights. If existing radio possibilities have not been realized or taken advantage of on some otherwise well-prepared flights, this has been due in many cases to lack of information on aircraft radio by the flight organization; in some cases, the operating or installation personnel has not been sufficiently competent, or the equipment has been unsuitable.

It is surprising how little is known about the special problems and developments of aircraft radio even among professional radio engineers. It is impossible within the scope of this text to more than touch upon the various requirements and conditions encountered in this large special field, but it is hoped that this lesson will result in giving students a better understanding of this important application of radio.

Radio Equipment for Dirigibles

Conditions on aircraft demand that most radio equipment carried be of highly specialized design, both electrically and mechanically, in order to meet the severe requirements imposed. Dirigibles, or airships, so-called lighter-than-air craft, beyond imposing space and weight restrictions on the equipment are relatively free from the detrimental conditions found on heavier-than-air planes; in fact, the height of the radiating system above the energy-absorbing ground

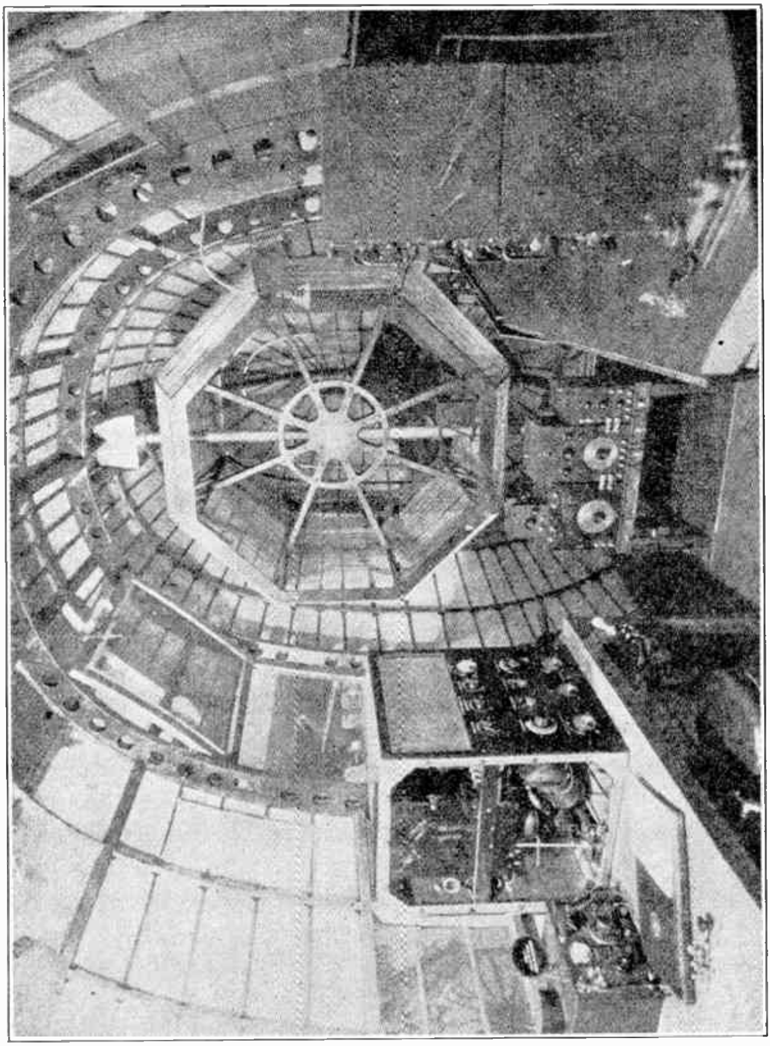

Fig. 1—Looking aft in radio room, USS Shenandoah

together with the effective low-resistance counterpoise offered by the all-metal framework give the large rigid dirigibles advantages not found on ground or shipboard installations making possible communication over great distances with radio equipment of necessarily restricted power and weight.

Figure 1 shows a typical installation in a large airship, the rear portion of the radio room in the late USS *Shenandoah.* In order to provide a relatively unshielded location for the radio compass shown in the center of the picture, the radio room was of wood and fabric construction and in this respect differed from the metal framework construction of the remainder of the ship including the control room ahead. Being a part of the forward "car" or gondola, the radio room was well removed from the propelling motors located in the enclosed power plant, making it free from noise and vibration as well as from electrical disturbances in flight. To the right in the picture are shown the intermediate and low-frequency receivers, while the small high-frequency receiver with removable coils is shown at the extreme left. Adjoining this is seen the high-frequency 50-watt transmitter, and under the table at the left are shown the flameproof switch boxes for the transmitters. The main intermediate frequency transmitter employing six 50-watt tubes is not shown in the picture, being to the left and ahead of the receiver. It provided for transmission either by plain or modulated C. W. or by voice, with a dependable telegraph range in excess of 500 miles. Power supply for both transmitters was from a dynamotor operated from storage batteries, which in turn were kept charged by means of a gasoline-driven charging generator operated intermittently. Undue noise was avoided by enclosing the power supply equipment and batteries in a small separate compartment between the radio room and the control room.

The west coast cruise of the *Shenandoah* in the fall of 1924 gave an opportunity to test the possibilities of high-frequency aircraft equipment. Despite the crude receivers of those days, two-way communication between the dirigible and the Naval Research Laboratory was accomplished night after night on the entire trip, the Laboratory employing a 54-meter transmitter with about 500 watts in the antenna, and the *Shenandoah* transmitting on 90 meters with 50 watts output. The USS *Canopus* reported instances of good night reception of the *Shenandoah's* signals at Guam while the airship was flying in the vicinity of Seattle, 5,000 miles away.

Our present rigid dirigible, the USS *Los Angeles*, is equipped with a German Telefunken intermediate-frequency transmitter of 200 watts antenna input, and a high-frequency 50-watt crystal-controlled transmitter operating on 3475 and 8012 kc.; either of these transmitters has a daylight range of approximately 500 miles. In addition, the *Los Angeles* is equipped with a rotating coil radio compass, a German plug-in coil universal receiver, and a high-frequency receiver. Radio operating conditions on these dirigibles have been found very advantageous. In addition to the trailing-wire antenna employed, a short fixed antenna is provided which is especially valuable for communication with the ground crew in landing operations.

General Flight Conditions Affecting Radio

As previously mentioned, in view of the favorable radiation conditions in flight good results are usually attained by use of a single trailing wire antenna, against the metal structure and bonding of the plane as a counterpoise; this gives a good effective height with relatively little absorption loss. Stranded phosphor bronze or copperclad steel wire is generally employed, carrying a total weight of from two to five pounds at the end. To reduce the possibility of accidental loss and to make possible ready renewal of an antenna in flight, tubular antenna weights together with a large diameter fairlead (metal tubing) to make them completely retractable are often used.

Space and weight restrictions imposed on all aircraft radio equipment are usually severe and can be met only by skilful design; all equipment should be readily accessible for inspection and maintenance and must be constructed to withstand continued vibration and landing shocks without breakage. Equipment is generally supported on cushions of sponge rubber or on spring suspensions, or is hung in place by a suspension of rubber exerciser cord, also known as "Bunge" cord. Too resilient a suspension also, however, is unsuitable as it may allow the equipment to bounce around and suffer severe shocks from striking an adjacent object during a bumpy landing.

A precaution which is necessary for efficient radio operation and which is also desirable for general safety reasons is the proper bonding of aircraft. By this is meant a thorough electrical interconnection of all metallic parts of the plane or airship, with permissible exception only of such isolated parts as actually are well-insulated from the main metal structure. Bonding is effected by means of copper straps or wires with particular attention to clean and durable connections. The purpose of bonding is three-fold: First, it reduces fire hazard by preventing sparking between adjacent metallic parts. In the absence of bonding such sparks may occur as the result of charges of atmospheric electricity or from voltages induced by radio transmission. Obviously, especial care must be exercised to bond all fuel tanks and feed pipes with

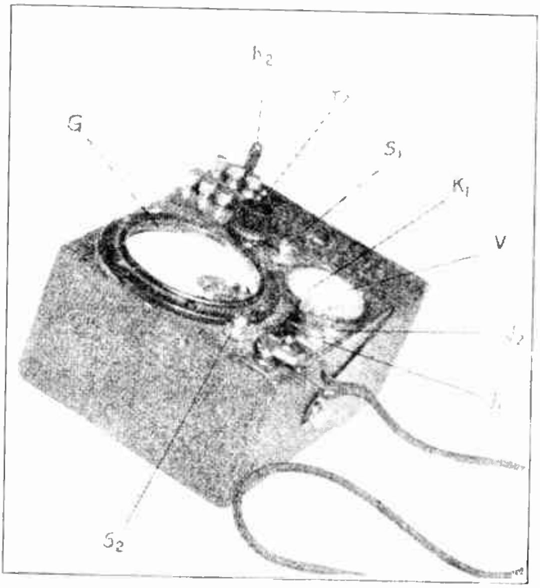

Fig. 2—Visual signal intensity meter

adjacent metal work. In hydrogen-filled dirigibles, bonding of all metal parts in the vicinity of the gas cells or envelope is a safety precaution of the greatest importance.

A second advantage of bonding is the resulting increase of effective counterpoise area for radio transmission, and reduction of the radio-frequency resistance. Thirdly, absence of bonding may cause many electrical disturbances in radio reception, resulting from intermittent slapping or rubbing together of separate conductors in the field of the antenna-counterpoise system. To avoid such noises particular attention should be paid to control wires; it is modern practice to run such cables through casing and guides which are either well-grounded or well-insulated and to cover one or both cables with insulating sleeves at points where they cross and may slap together in flight.

Aircraft Radio Receiver Problems

There are many conditions adversely affecting radio reception in flight; these are only recently being overcome to a satisfactory degree, by specialized design and installation precautions. One of the worst obstacles is the great noise produced by the motor, usually accompanied by noise from the propeller and whistling of exposed wires. These noises, which are naturally more pronounced in open planes, can be partly excluded by well-fitting radio helmets with pads or rubber

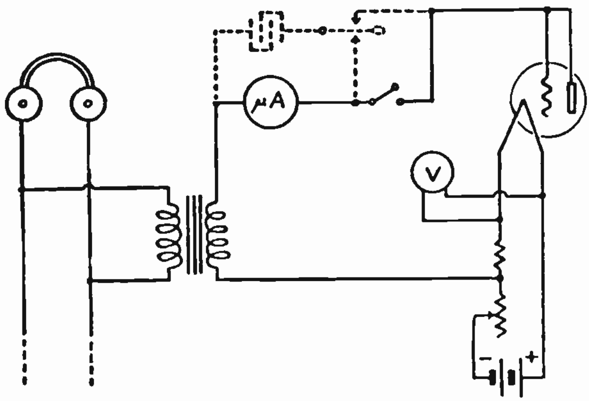

Fig. 3—Schematic circuit diagram of visual intensity meter

cups surrounding the ear pieces; nevertheless, a very strong signal is generally required in order to be heard in flight. Radio disturbances produced by the motor spark plugs and leads often interfere seriously with reception and can be entirely avoided only by careful and systematic electrical shielding and bonding of the entire ignition system.

In studying the strength of signals and ignition disturbances encountered with various receivers, the Naval Research Laboratory in 1926 developed a small portable visual intensity meter, shown in Fig. 2. As seen in the schematic diagram of Fig. 3, the signal voltage is measured by deflection of a microammeter connected in series with a receiving tube employed as rectifier and coupled across the telephones by means of a small step-down transformer. In dotted lines is shown an integrating attachment consisting of a 4 mfd high-grade paper condenser with a charge and discharge key; telegraph signals or other weak or irregular disturbances may be averaged by charging this condenser through the rectifying tube during a given length of time and then reading the discharge kick through the microammeter. With the aid of this intensity meter it

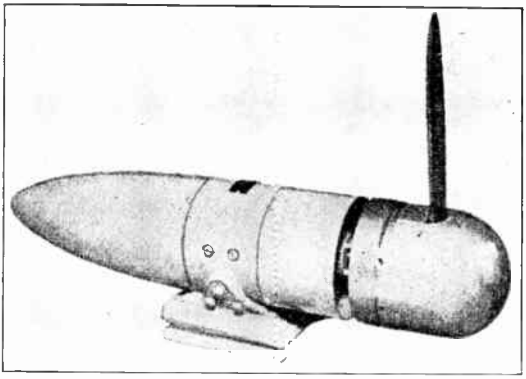

Fig. 4—Wind-driven radio generator with self-regulating propeller

has been found that signal strengths giving approximately 1.5 to 2.0 volts across the headphones are ordinarily required for satisfactory reception in flight.

Serious microphone noises may be set up by the vibration of tube elements or condenser plates, and often require special design and suspension. Special non-microphonic tubes with

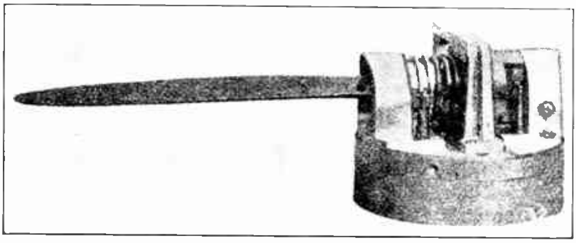

Fig. 5—Mechanism of self-regulating propeller

rigid elements have recently been developed for aircraft use. Audio tuning by peaked transformers or trap circuits is at times of value in reducing disturbances in telegraph reception, but obviously is unsuitable for radio telephony. Series condensers in the antenna or ground connection should be avoided or shunted by a choke or resistance leak in order to prevent sparking from accumulated static charges. The plate batteries are often self-contained in the receiver to save space; recently both Naval and commercial aircraft receivers have been successfully operated without batteries, by deriving their voltages from the wind-driven generator which furnishes power to the transmitter.

Transmitter Design Considerations

Aircraft radio transmitters must be of very compact, yet durable and accessible construction, and as in the case of the receiving equipment, wiring connections should have a certain resilience and be mechanically anchored so as not to loosen up or break at soldered joints under continued vibration. Intricate adjustments should generally be avoided in order to enable effective operation by untrained personnel. High-voltage circuits should be well protected against accidental short circuits under vibration, and safety precautions should be taken to minimize danger to the operator while doing any necessary work on the transmitter under confined flight conditions.

It is especially desirable in closed planes to guard against danger of fire by encasing all sparking switch contacts in flame-proof boxes, to prevent igniting any gasoline fumes which may be present. As an added precaution against fire, insulating materials throughout should be of highest grade and properly employed, with particular attention to avoid chafing under vibration. In radio telephony some disturbances in transmission may be encountered from flight noises, but these have been considerably minimized by special anti-noise microphones which are sensitive to voice but exclude or balance out other sounds.

The power supply for the transmitter radio generator may be derived directly from the airplane motor by gearing, or indirectly by fan drive in the airstream, or from a storage battery through a suitable dynamotor. The latter method will readily furnish full power on the ground or water as well as in flight, but permits operation in flight for a limited time only, unless the battery is kept charged by another generator, such as has been done on many Army installations. The wind-driven generator with self-regulating fan gives the most flexible installation and will furnish power as long as the plane is in flight; if suitably installed in the propeller slipstream, the wind-driven generator can also be made to turn up on the ground, for testing or for emergency communication.

Figure 4 shows a streamlined radio generator of several hundred watts output, supplying filament and plate voltages, and driven by a self-regulating air propeller. In Fig. 5 is shown the centrifugal governing mechanism which regulates the pitch of the counterbalanced single blade to keep the speed of rotation constant. Figure 6 shows a 12-volt, 15-ampere generator mounted on an air-cooled engine; notice the ventilating stack for cooling the generator. Figure 7 shows a somewhat similar generator with its mounting flange, and the box

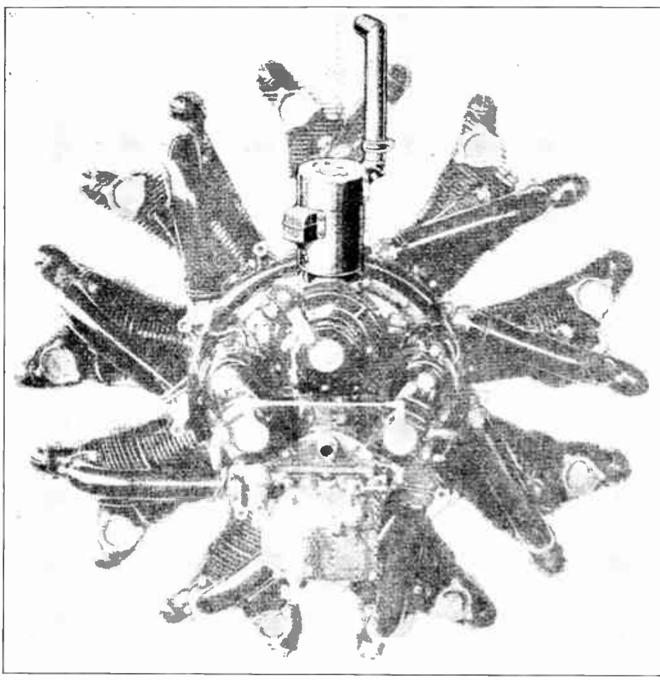

Fig. 6—Generator geared to Pratt and Whitney "Wasp" engine

containing a vibrating voltage regulator as well as a battery cut-out. Such generators, for radio purposes, are provided with separate commutators for plate and filament voltages and are now manufactured by several concerns.

A type of current supply especially suitable for emergency use is the hand-driven radio generator shown in Fig. 8. This device, of British make, furnishes up to 50 watts of combined electrical energy for plate and filament supply; it has beefound that one man is not able to exceed this power for any length of time, and in view of this fact, such hand-driven generators lend themselves especially to high-frequency emergency transmitters, which may despite their low power reach out over great distances.

In another part of this text is described a high-frequency transmitter which effectively uses dry batteries as power source.

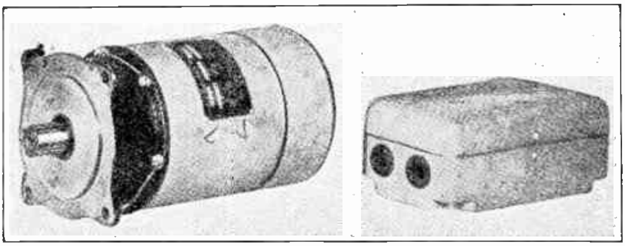

Fig. 7—Eclipse engine mounting generator with voltage regulator

COMPARISON OF RADIO TELEPHONY WITH RADIO TELEGRAPHY.

Because of its convenience and in view of personnel limitations, it is likely that radio telephony will continue to be employed extensively for many classes of aircraft communication, up to distances of 100 miles or more. Where accuracy of communication, simplicity of equipment, or distance range

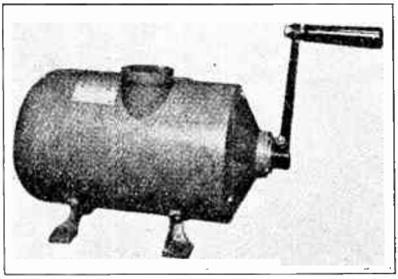

Fig. 8—Hand-driven radio generator, with automatic contactor

without excessive power are requirements, however, radio telegraphy offers advantages, provided suitable operating personnel is available. In Fig. 9 are shown curves, based on average American and foreign practice, which compare the average frequency communication range with antenna power and total installation weight, for radio telegraph and radio telephone equipment.

Practice has shown that for a given antenna power and under average conditions, well-modulated radio telephony will carry approximately one-third the distance obtainable with radio telegraphy, while the weight for a telephonic installation is 15 to 20 per cent greater and correspondingly more complicated. Under adverse conditions of communication and with insufficient ignition shielding, radio telephony is impaired to a greater extent than telegraphy, while under especially favorable conditions a better ratio may be obtainable than shown by the curve. As a rule, radio telephone equipment is arranged to provide radio telegraph transmission at will by a simple switch-over arrangement. It must be borne in mind, however, that

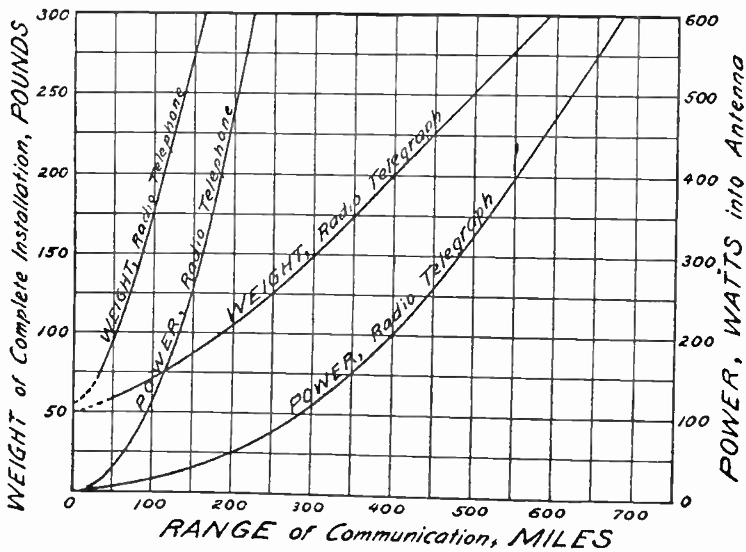

Fig. 9—Weight-Power-Range Curve for typical air-craft radio installation for frequencies between 250 and 1,000 kilocycles

equipment designed solely for radio telegraphy is not only much simpler in construction, but the tubes and circuits may be safely loaded to a greater extent in view of the intermittent keying in place of a continuous carrier and modulation current.

Some Expeditionary Installations

Long-range telegraphic equipment in its simplest form and of lightest weight is required for many expeditionary and long-distance flights. Where such flights are over long stretches of water an intermediate frequency without skip-dis-

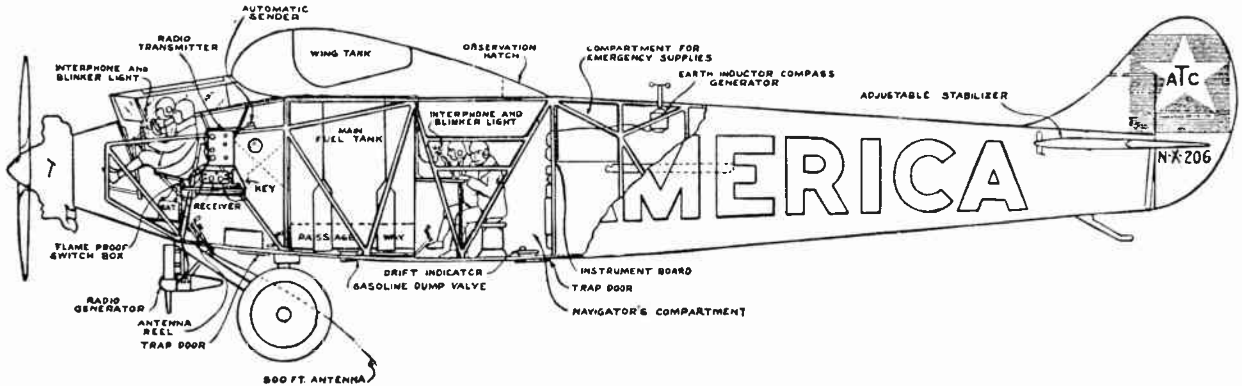

Fig. 10—Interior arrangement of Byrd's airplane America

tance and near the ship calling wave has obvious advantages. A typical installation of this sort was carried on Commander Byrd's flight across the Atlantic, in his airplane *America* as shown in Fig. 10. The equipment was patterned after installations which had proved their value on Naval scouting planes, but modified in several respects for the sake of lightness, simplicity, and dependability, with the result that it functioned without failure during the entire forty-one hours that the plane was in the air.

The wind-driven radio generator shown in Fig. 17 was a standard Navy type delivering 500 watts at 200 volts, 400 cycles, with the fan adjusted to 4,000 r.p.m. Its location under the

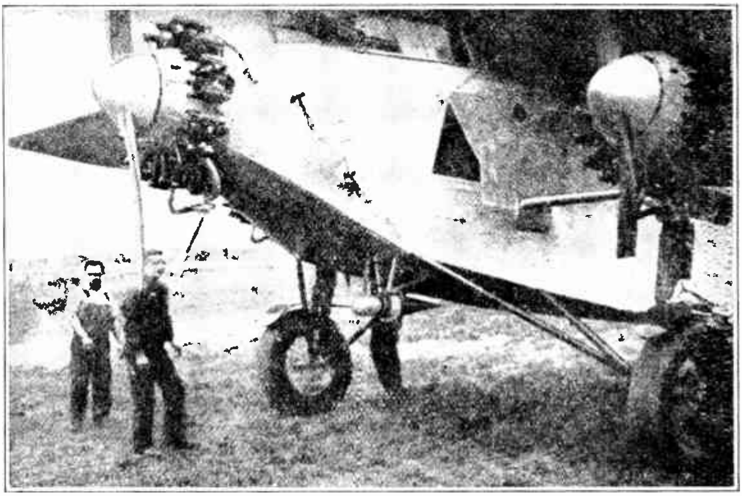

Fig. 11—Forward portion of airplane America

fuselage and near the landing wheels was prompted by necessity but exposed the fan to possible danger from flying stones and mud particles during take-off, and from swinging antenna weights while reeling in. Figure 12 shows the receiver with self-contained plate battery which employed four tubes, namely, one-stage of tuned neutralized r.f. amplification followed by a regenerative detector and two stages of audio amplification; a tuning range from 200 to 800 kc. was provided. Audio tuning of variable pitch could be switched across the detector output if desired, and microphonic tube noises were reduced by acoustic damping with sponge rubber, sound shielding with lead foil, and damped flexible tube supports. Figure 13 shows the front panel

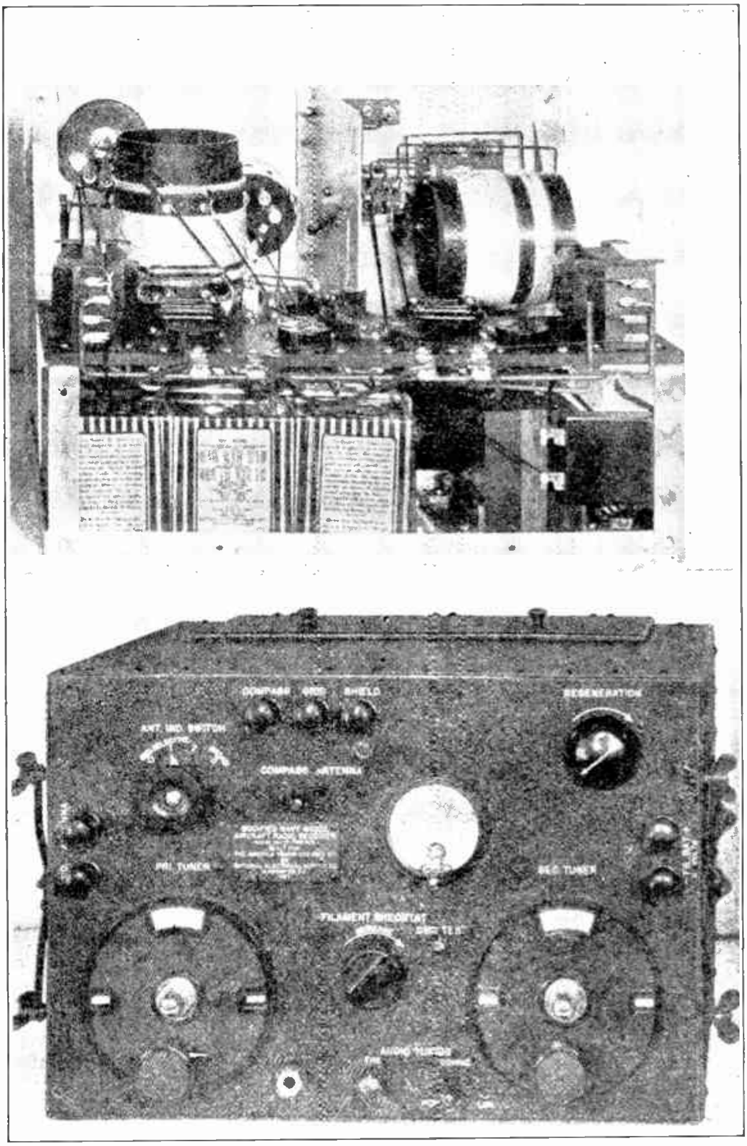

Fig. 12—Radio receiver used on Byrd's Trans-atlantic flight

of the transmitter, which employed two 50-watt tubes, type UX-211 and delivered approximately 150 watts to the antenna. A full-wave self-rectifying circuit was employed with a transformer giving a plate voltage of about 1,500 on either side of the center tap. An antenna variometer permitted tuning to either a 690-meter working wave or a 600-meter calling and emergency wave, resonance to either being indicated by one of two small fixed wavemeter circuits with glow lamps, located in the upper portion of the panel.

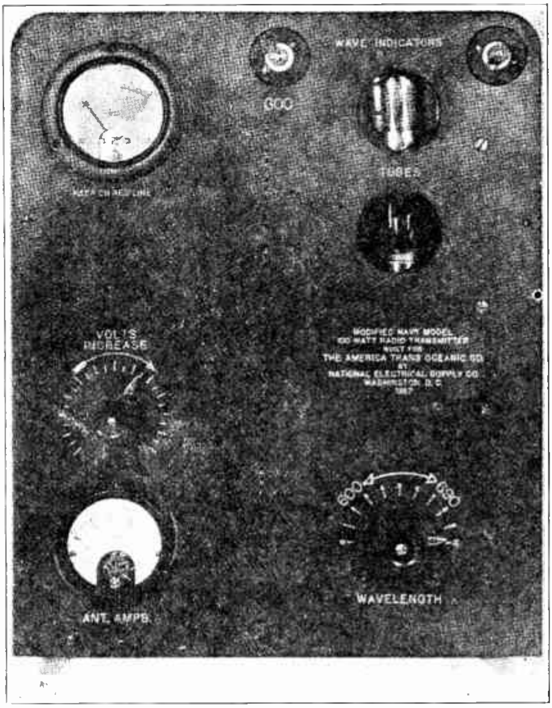

Fig. 13—150 watt transmitter of airplane America, front view

A device which proved of great value on this flight, was a wind-driven automatic code disk which continuously repeated the *America's* call letters WTW at times when the operator was engaged with non-radio duties; by this means stations and ships within range were able to keep track of and take bearings on the *America's* signals at all times and were kept on the alert for any messages and communications.

Figure 14 shows an installation somewhat similar to

Byrd's in the airplane *Old Glory,* which in the summer of 1927 met disaster on an attempted New York to Rome flight.

A totally different transmitter suitable for long-distance flights is shown in Fig. 15; this set, developed by the Westinghouse Company for the Radio Corporation gave excellent results on its test flights in Commander Davis' and Lieut. Wooster's ill-fated *American Legion.* The transmitter was operated from a storage battery and dynamotor and provided for ap-

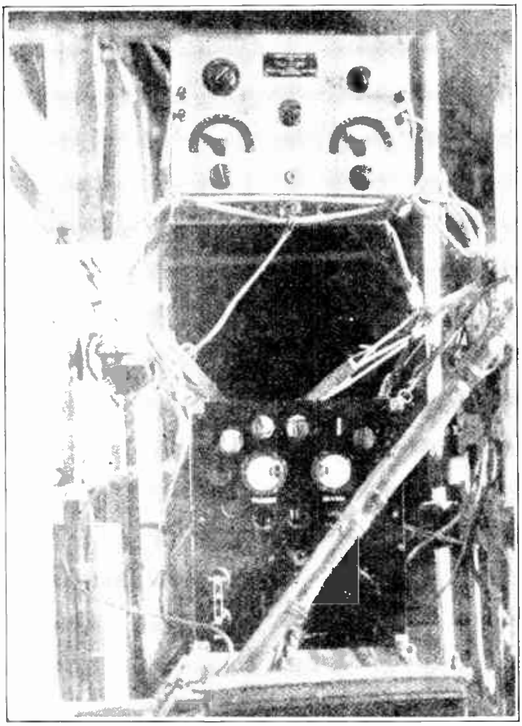

Fig. 14—Radio installation on airplane Old Glory, front view

proximately fifty watts CW output on either 45 meters or 600 meters; the 45-meter wave was crystal-controlled, while in the 600-meter position the transmitter was self-oscillating. A dependable transmitter of this type in the hands of a competent operator will give effective long-distance communication on high-frequency, while providing for contact with commercial ship and shore stations on the 600-meter wave. Another advantage of this wave length combination is the possibility of bridging with the 600-meter transmission any fading or skip zone likely to arise at moderate distances with the short wave.

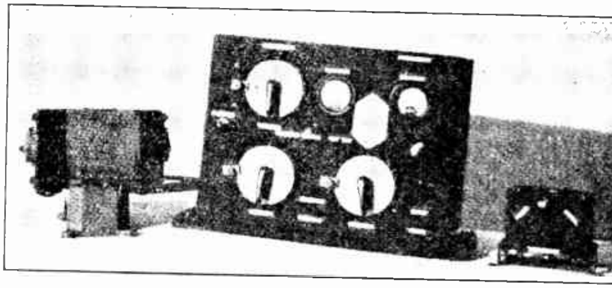

Fig. 15—Combined 600- and 45- meter transmitter built for airplane American Legion

The schematic wiring diagram of the receiver installed on "American Legion" airplane is shown in Fig 16.

Emergency Radio Equipment

For possible use in case of a forced landing, a completely waterproof and self-contained emergency transmitter was de-

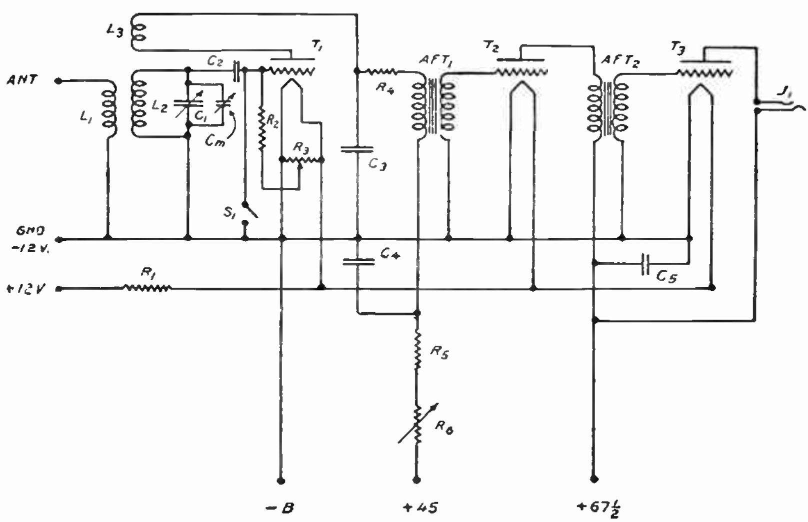

Fig. 16—Schematic wiring diagram of the receiver installed on American Legion airplane

vised for Byrd's *America*, and so constructed that if required; it could be operated from one of the inflated life rafts. Transmitters such as these were also carried by several other trans-atlantic flight contestants. This set, shown in Fig. 17, employed a spark coil operated from internally contained flashlight batteries which sufficed for several hours' telegraph operation; projecting waterproof leads made possible external connection to any other available battery. The small groundplate shown was to be dropped into the water, while a 300-foot length of wire held aloft by a kite served as antenna. A radiation meter mounted behind a waterproof window indicated antenna current and resonance; and tight inductive coupling with a fixed primary circuit tuned to 600 meters was employed. In tests, fair signals were still obtained from this

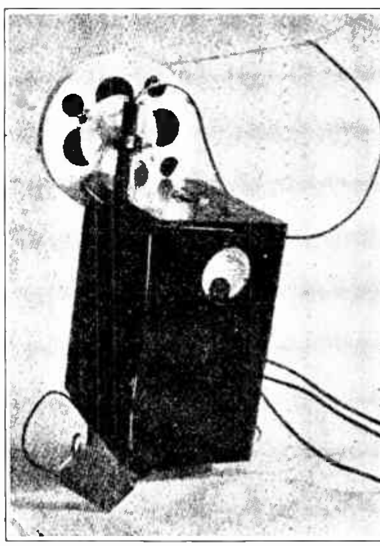

Fig. 17—Waterproof self-contained emergency spark coil transmitter

transmitter at 25 miles distance. A standard Navy kite for carrying aloft an emergency antenna is sometimes used: such kites are provided in two sizes of 6 and 7½ feet height, for strong and light winds, respectively.

Naval flying boats on the water employ for radio communication either a kite antenna or a fixed antenna supported by the wings and the tail structure. Power for the main transmitter may be obtained from a wind-driven generator in the slip stream of an operating propeller; hand-driven generators in conjunction with high-frequency transmitters have also been employed for emergency operation, but in several instances have proved objectionable due to fatigue of personnel and the required departure from the plane's regular working frequency.

Some foreign airplanes are provided with balloons in place of antenna kites for emergency operation, and carry

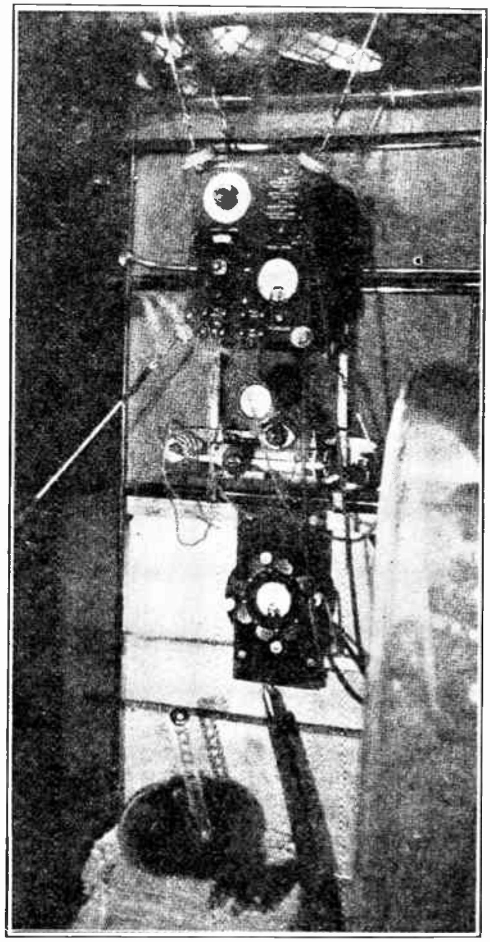

Fig. 18—High frequency radio transmitter installation in Fokker monoplane, Wilkins-Detroit Arctic Expedition, 1926

small bottles of compressed hydrogen for inflation purposes. Small gasoline engines for emergency power have also been used to some extent, and are being experimented with in this country.

Great distance possibilities in low-power transmission from airplanes were established by the Naval Research Laboratory in flight tests during 1924, and with the co-operation of a large number of radio amateurs were confirmed during the summer of 1925, when a number of distance tests were made in flight with a simple crystal-controlled telegraph transmitter operating on waves as short as 22 meters; the extremely thin crystals operated with an impressed plate voltage of about 250 volts, and gave an antenna input from one to two watts with two 201-A type receiving tubes connected in

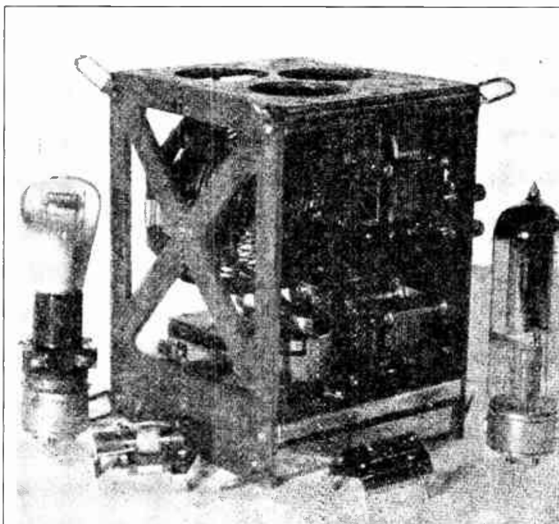

Fig. 19—Rear view of Byrd's high frequency transmitter

parallel. With this low power, 25-meter flight tests conducted near mid-day were heard as far as Unity, Saskatchewan, a distance of 1,800 miles, and were reported also by a number of other stations beyond a thousand mile radius; this wave, however, showed a decided skip zone inside of 500 miles. A 40-meter wave, employed alternately with the higher frequency, showed less than 800 miles range but had no skip zone, although at close range fading was often pronounced and reception especially poor when the plane flew at low altitude. Reception of high-frequencies in flight was found to be greatly hampered by ignition disturbance as well as vibration detuning and microphonic noises, but has since been accomplished effectively with suitably installed receivers of improved design.

When Captain George H. Wilkins conferred with the Navy Dept. in December, 1925, regarding suitable airplane equipment for his proposed North Pole flight to be attempted the following spring, the value of high-frequencies for his purpose became apparent, and at his request a suitable airplane transmitter of very low weight was designed and constructed. This set, installed in Wilkins' single-motored Fokker plane, is shown in Fig. 18; an antenna input between 10 and 20 watts was obtained from a 50-watt Western Electric tube, with 400 volts on the plate, at crystal frequencies of approximately

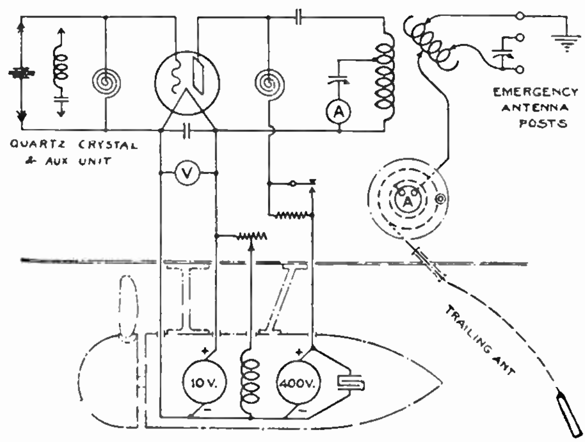

Fig. 20—Schematic diagram of crystal controlled high frequency aircraft transmitter

5,000 and 7,000 kc. At Commander Byrd's request identical apparatus was constructed for his North Pole flight.

After two seasons' flight use, in 1927, Wilkins was finally forced to abandon this set on the polar ice with his damaged plane; after notifying the world of his forced landing, he and his pilot, Eielson, had a month's struggle back to the mainland. He left behind with the set an Evershed hand generator which he had employed with good success. Figure 19 shows the back of the Byrd-Wilkins set, with spare crystal and emergency self-oscillation unit, as well as emergency adapter and 7½-watt tube for easier cranking in hand operation. The schematic diagram of the set is shown in Fig. 20; for ground operation, in place of the quarter or three-quarter wave trailing wire a simple fixed antenna could be improvised and tuned by means of a variable condenser connected in series or parallel with the antenna and counterpoise.

In view of the excellent results obtained in point-to-point communication by Wilkins and others with portable high-frequency, battery-operated transmitting equipment of very low

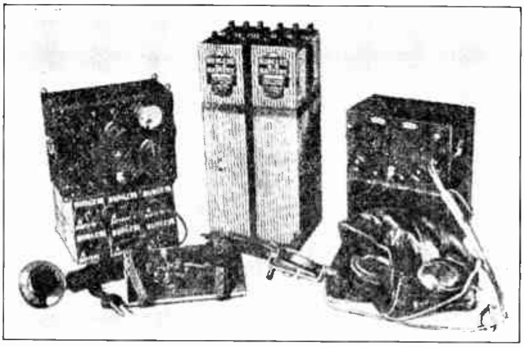

Fig. 21--Burgess experimental aircraft set

power, the Burgess Battery Company undertook a series of flight tests which resulted in the development of some extremely compact experimental aircraft radio equipment of interesting performance, shown in Fig. 21. Figure 22 is an inside view of the little transmitter which employs one 201-A

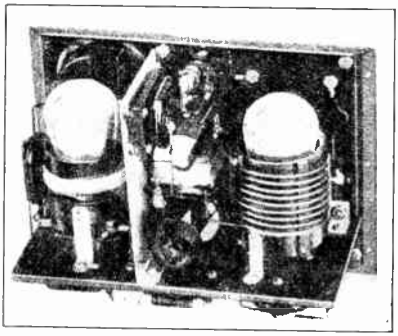

Fig. 22—Rear view of interior, Burgess airplane transmitter

tube, shown at the left, as master oscillator, and a similar tube as balanced power amplifier. With 350 volts on the amplifier and 180 volts on the master oscillator plate, an antenna input of about 4 watts is reported; the master oscillator may be speech modulated by means of an absorption loop shown just beneath the white inductance winding. Installed in a Travel Airplane as shown in Fig. 23, experimental two-way communication with amateurs was accomplished on 79 meters up to 500 miles, and on 40 meters the plane's signals

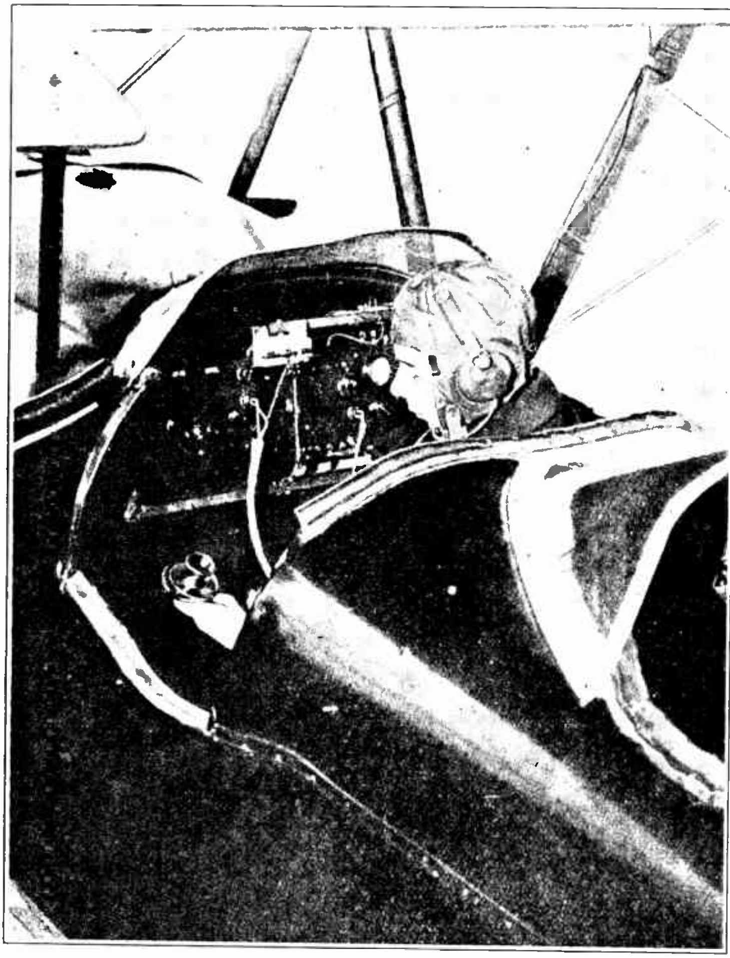

Fig. 23—Burgess radio equipped installation in travel airplane

were reported up to a distance of 725 miles. Further contemplated tests with equipment of this type are looked forward to with great interest to determine its possibilities in certain commercial applications. There is no question that for expeditionary purposes and uses requiring extreme portability, high frequencies offer great possibilities which in aircraft communication so far have only just begun to be realized. When the *Spirit of Dallas* went into a tail spin and disappeared into the Pacific Ocean last year, her SOS, transmitted on a 33-meter wave with a simple 50-watt set, was heard in New York City and beyond, as far as Italy. Extremely interesting results in high-frequency air plane experiments have also been obtained in Germany.

An elaborate installation of Naval intermediate and high-frequency equipment is shown in Fig. 24, installed in the

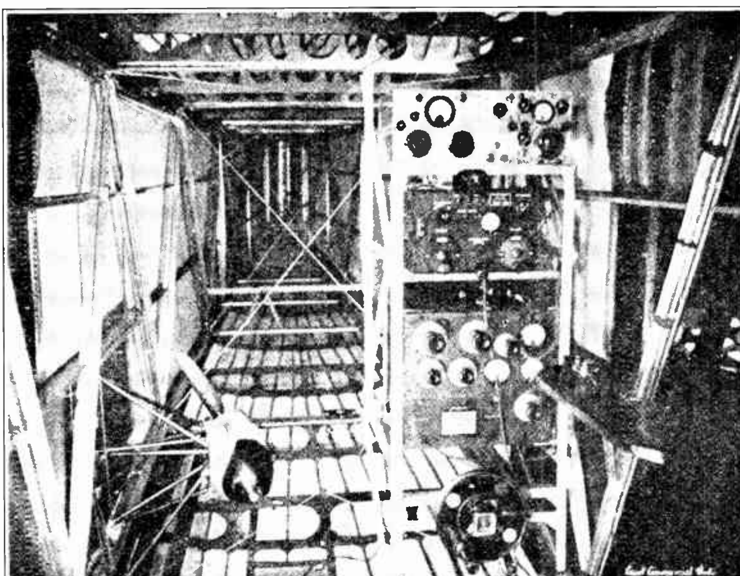

Fig. 24—Radio installation in Sikorsky S-37 for Fonck's Trans-atlantic flight, 1927

Sikorsky S-37. Of especial interest is the retractible swinging generator mounted at the left, which enables withdrawal of the generator from the airstream for inspection purposes. It also reduces wind resistance when radio is not employed. Uppermost on the apparatus rack is shown a high-frequency 10-watt transmitter-receiver built for emergency communication. Below this is a standard intermediate-frequency aircraft receiver, and at the bottom is mounted a standard aircraft transmitter; this transmitter develops about 150 watts into the trailing wire antenna, at intermediate frequencies, employing 400-

cycle, self-rectified ACW. The transatlantic flight proposed in this plane was indefinitely postponed, so that no opportunity was had thoroughly to test the attractive installation.

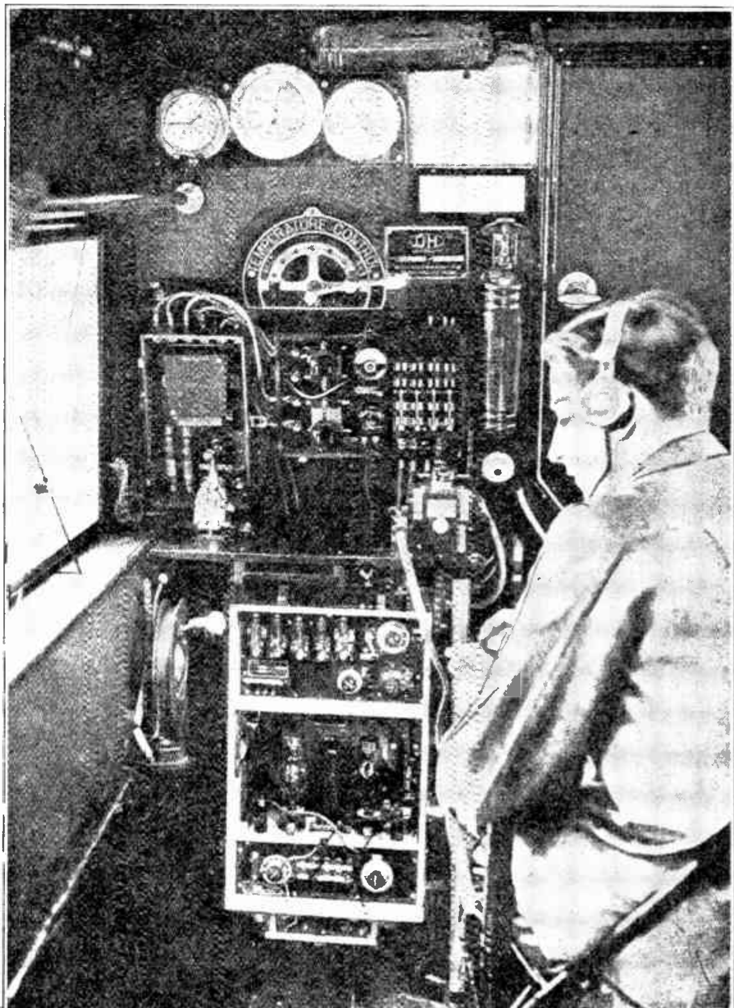

Fig. 25—Marconi type AD-6 radio installation in British D.H. 66 Hercules passenger airliner

Commercial Aircraft Radio Equipment

In Europe there have existed for many years commercial lines of aircraft radio apparatus, the most prominent of which have been developed by the British Marconi Company; their most widely used set, type AD-6, installed in a large British passenger plane on the England-Egypt-India air route, is shown in Fig. 44. The transmitter is rated at 150 watts tube input, and has a transmitting range between 100 and 200 miles, both telegraphy and telephony being provided. The upper portion of the cabinet is occupied by a 5-tube receiver, employing two stages of radio-frequency amplification. An interesting feature of this equipment is provision for full remote control by means of mechanical Bowden cable attachments, so that the equipment may be placed out of the way and operated from the pilot's cockpit.

The Radio Corporation of America has recently placed on the market commercial aircraft radio equipment of three different sizes, giving output ratings of 10, 100, and 300 watts.

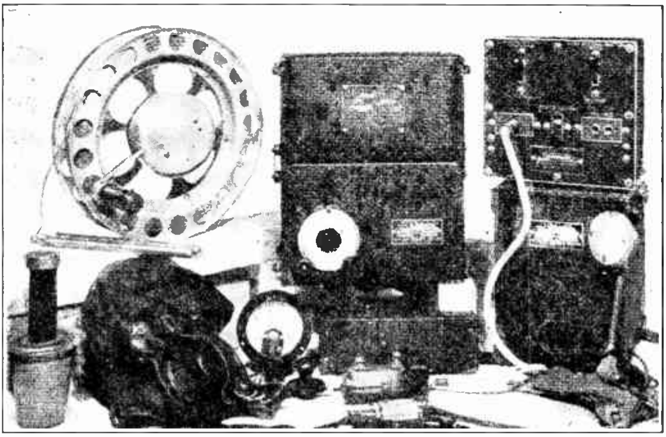

Fig. 26—10-watt R.C.A. aircraft radio equipment, model ET-3652

Both telephone and telegraph communication is provided, in the frequency band between 2,250 and 2,750 kc. Power supply both for transmitters and receivers is furnished by wind-driven generators, and trailing wire antennas of about 100 feet in length are employed. Figure 26 shows the components of the 10-watt equipment, except the receiver; the combined weight of the 10-watt equipment is 86½ lbs.

The 100-watt set, model ET3653, is designed to cover up to 300 miles by CW telegraph and up to 75 miles or more by telephony; the total weight of this equipment is 133 lbs. A 5-tube receiver with interchangeable coils is a part of this equipment.

The components of the 300-watt equipment model ET-3654, are shown in Figs. 27 and 28. The combined weight of this equipment is 202 lbs., and the range is given as 500 miles for CW and 200 for voice communication. Eight 50-watt tubes model UV-211 are used in the transmitter. The receiver contains five tubes, and is similar to the one employed with the 10-watt equipment. Both the 100- and the 300-watt installations provide for interphone communication between the radio operator and the pilot; in addition, the 300-watt equipment may be operated at will by the pilot by means of an auxiliary remote control unit, shown with the receiver in Fig. 28.

Separate equipment for merely receiving purposes has been developed for commercial airplanes wishing to avail

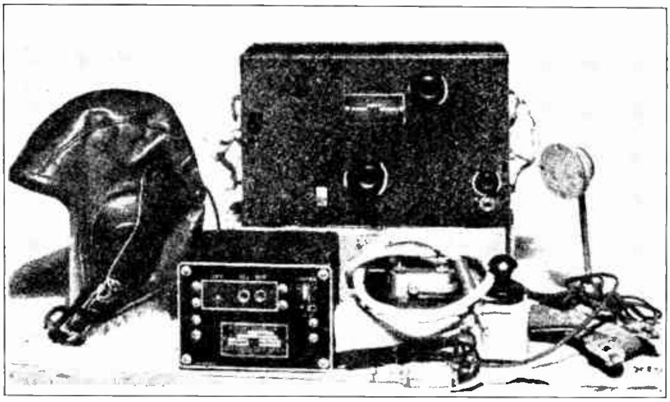

Fig. 27—300-watt R.C.A. equipment, model ET-3654, showing receiver and auxiliaries

themselves of the weather broadcast and directional beacon service being established on our airways. Frequencies around 300 kc. are employed for these uses.

Radio Aids for our Airways

In accordance with the provision of the Air Commerce Act our national airways and air mail routes are rapidly being provided with adequate radio aids. Among the ground facilities which are being installed under the supervision of the Airways Division, Bureau of Lighthouses, are Radio Stations for intercommunication between airports, ground radio stations for communications with aircraft, directional radio beacons, and low-power marker beacons.

Radio Used on Transcontinental Air Transport Planes and Ground

The transmitting circuit used on these planes is a standard one with master oscillator and power amplifier. It is a combination telephone and telegraph arrangement, able to transmit either keyed continuous waves or voice. It uses four tubes, three of the UV-211 type and one UX-210.

Power is derived from a light-weight dynamotor driven by the plane's 12 volt landing light battery. It supplies the low voltages necessary for Radiotron filaments as well as the plate current supply of 1,000 volts.

The receiving set consists of three stages of tuned screen grid radio frequency amplification, with a detector and two

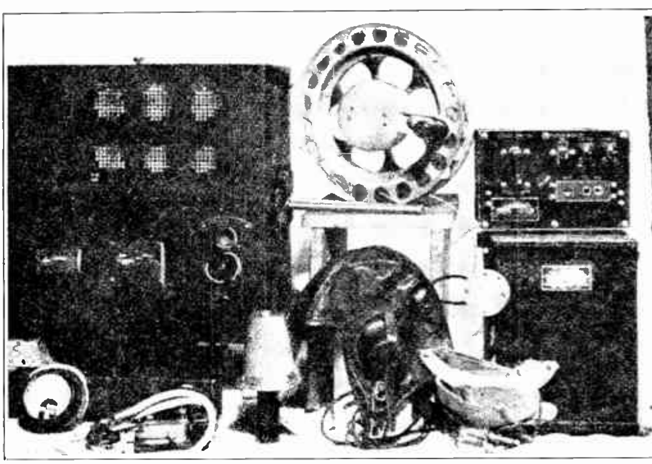

Fig. 28—300-watt R.C.A. equipment, model ET-3654, transmitter and related components

stages of resistance-coupled audio-frequency amplification, with output transformer. A power tube is used in the last audio stage. Resistance-coupling rather than transformer-coupling is used in order to obtain the audio characteristics necessary for beacon reception, whenever beacons may be desirable. The tube equipment consists of three UX-222 tubes, two of the UX-240 type and one UX-171A.

Power is drawn off the plane's lighting battery for the receiving tube filaments, while B and C voltages are derived from dry batteries.

One extremely interesting phase of this apparatus is that it is remotely controlled. Another is the ease with which portions of it can be removed for servicing; the receiver, for instance, can be taken completely out of the ship by loosening four wing nuts and uncoupling the flexible control shaft.

The weight of the transmitting and receiving apparatus is as follows: Entire receiving equipment including batteries, filter, headphones, battery box and controls, 56 lbs. 9 ozs.

Transmitter, including dynamotor and all accessories, power box, control box, microphones, keys, antenna-ammeter, and antenna reel, 87 lbs.

The ground installations are 2 kw. combined telephone and telegraph stations and those the company is installing are designed for easy modification whenever it is desired to establish radio beacon service along this route.

There is no doubt but that with the provision of adequate ground facilities a great impetus will be given to the equipment of a large portion of our commercial airfleet with modern and efficient types of aircraft radio apparatus, with inevitable gains in the dependability and safety of air transportation.

TEST QUESTIONS

Number your answers 15-2 and add your student number

1. What is the daylight range of the transmitter installed on the dirigible USS Los Angeles?
2. Why is aircraft radio equipment supported on cushions of sponge rubber or on spring suspension?
3. Why are proper bonding connections necessary on aircraft?
4. When no batteries are used with a receiver, how do they obtain their power supply?
5. How are flight noises and other disturbances overcome in radio telephone transmission?
6. What is the advantage of using radio telegraphy equipment over radio telephony on aircraft?
7. What is the advantage of using a wind-driven automatic code device?
8. Name the apparatus used for emergency in case of a forced landing.
9. How are emergency antennas carried aloft?
10. Draw a circuit diagram of a crystal controlled high frequency aircraft transmitter.

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NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

TELEVISION

For some years past we have become accustomed to "listening in" by radio to audible sounds produced at some distant point, which may be anywhere up to several thousands of miles away. How long will it be before we are able also to "see in" by radio, and thus witness scenes and events at places similarly distant from us? In view of the vast progress recently made in this direction, it will not now be very long before this comes to pass.

The moving picture has been developed within the last twenty years or so, till today it is a highly efficient and marvelous means of entertainment. Its appeal is to the eye, also the ear. We see and hear on the screen great actors. Many inventors have been working for years to make this possible.

Radio broadcasting as we know it today, is one sided. We can hear a great man speak, but we cannot see his gestures and facial expressions. It is the province of Television to overcome this disability. By combining television with ordinary broadcasting, we shall, in the near future, not only hear the performance of a play, but also see the actors, the scenery, the entire stage.

REPRODUCTION OF SIGHT

That is the function of television. It must not be confused with telephotography, which is something totally different. Telephotography, or phototelegraphy as it is sometimes called, means the telegraphic transmission of a single "still" picture from one place to another.

In Webster's dictionary, television is confused with phototelegraphy, and if such an authority is in confusion, there is no wonder that the public—even the technical section of it—does not possess clear ideas on the subject. It needs no apology, therefore, to commence an article on television with an attempt to define exactly what television is, and for an authoritative statement, we cannot do better than quote the British patent office, whose business it is to define and catalogue such terms.

In the patent office library, we find classed, under the heading "Television," "Apparatus for transmitting instantaneously to a distance images of views, scenes or objects by telegraphy (either wire or wireless)." In other words, Television means seeing at a distance by telegraphy.

HISTORY OF DEVELOPMENT

Both phototelegraphy and television are no new ideas. The latter is but a development of the former; and the inspirations for both date back to the year 1873, when May, one of Willoughby Graham's assistants, communicated to the Society of Telegraph Engineers the details of his discovery of the photo-electric properties of selenium.

It was not long before this discovery led to the construction of selenium cells by Siemens, Graham, Bell and others. These, as all the world knows, are devices for transforming light impulses into electrical impulses; and the idea soon occurred to a number of investigators that they might be utilized to give to the eye what telephony had given to the ear, and render it possible to see by telegraph.

Ayrton, Perry, Senlee and several others actually described systems which were to accomplish this; and nearly fifty years ago, it was confidently predicted that in a very short time, it would be possible for us to see one another over the telephone line!

These optimistic inventors had, however, entirely over-rated the capabilities of selenium to respond to the immense speed of signaling involved; and their predictions came to naught, as far as practical results were concerned. Considerable progress was made, however, in phototelegraphy, for time is a secondary consideration in the transmission of a single still picture, and the various other problems in connection with this accomplishment are considerably easier.

At the present time, many investigators in various countries have demonstrated their ability to transmit and receive still pictures, either by wire or radio; among whom may be mentioned C. Francis Jenkins in the United States, Thornton Baker in England, Fournier and Belin in France, and Dr. Korn in Germany. Also worthy of mention is the more recent achievement of Captain Ranger of the R. C. A., who succeeded in sending a photographic copy of a check from London to New York in 25 minutes.

Phototelegraphy, therefore, is not only a definitely accomplished fact; it is also a commercial proposition. Television, however, has not made anything like such progress; for only a few actual demonstrations of "seeing at a distance" have been given.

SOME PROBLEMS OF TELEVISION

Most of the systems in use for transmitting still pictures make use of the cylinder method; in which the picture to be transmitted is transferred to a film, which is wrapped around a cylinder of glass. As this cylinder is rotated, a spot of light is caused to cover the film from end to end in a series of finely separated lines. The intensity of the light which passes through the film depends upon the latter's density at different points; and the varying light beam, after passing through the film, is focused upon a light-sensitive cell, of one type or another. This cell transforms the light variations into electric-current variations, which are sent over a wire or by radio to the distant receiver.

At the receiving end, the process is reversed, the incoming current variations being caused to vary a source of light which is focused upon a photographic film wrapped around a rotating cylinder. This film becomes covered with fine lines of varying density, which, when developed in the usual manner, make up the complete picture.

Obviously, this system is inapplicable to television, for a scene, or even the image of it, cannot be wrapped around a cylinder. Some means, therefore, had to be found which would enable a picture to be transmitted directly from a flat surface. This can be done by moving the light beam instead of the picture. By rotating a suitably designed and arranged series of prisms between a fixed light source, and a fixed flat-surface picture, the beam of light is made to traverse the picture from side to side, moving slowly across it as it does so, so that ultimately the entire surface is covered.

This, very roughly, is the operating principle of television apparatus, but only as applied to the transmission of a single picture or image.

From the transmission of a single picture from a flat surface to television is a far cry, however; and, to understand something of the tremendous obstacles to be overcome, let us consider the moving picture. When witnessing a movie performance, we think we see a smoothly flowing animated scene. Actually, we are looking at 16 separate and distinct pictures every second, but, owing to the persistence of human vision, we do not receive this impression from the sense of sight. The one and only similarity between the movies and television is that, in both cases, the scenes are projected upon a screen. In order to make television a success, it is necessary to transmit and receive something like 16 complete pictures per second, in order to give the witness an impression of life-like movement.

BELL LABORATORIES SYSTEM

Described as one of the greatest triumphs in the history of communication methods, the television process of the American Telephone and Telegraph Company is the product of many minds working together in the Bell laboratories in New York under the guidance of Dr. Herbert E. Ives. Despite the elaborateness of the apparatus, television depends essentially upon the fact that a film of potassium metal in a vacuum tube can be made to give a small electric current when light shines on it. This is in the photo-electric cell. The method of its use in the new process is quite different from previous attempts to attain the same result. In other methods, the subject, whose visage is to be transmitted, is flooded with brilliant light and a lens picks up the illumination and focusses it on a small photo-electric cell. In the new method, by the idea of Dr. Frank Gray, the subject is illuminated with a tiny moving spot of light, which is picked up by a battery of large photo-electric cells—the largest yet made. The result is the most successful transmission of the actual view of the human face that has yet been achieved.

As seen on the small receiving screen, the scene looks like a halftone two inches high, printed in the pink sheet edition of a daily paper, except it has come to life. Most newspapers print photographs in what is known as a halftone—small dots spaced 50 to 60 to the inch and blended by eye into a continuous picture —a process, incidentally, which was the invention many years ago of Frederic E. Ives, the father of Dr. Herbert E. Ives, who is immediately responsible for the new process.

In the television receiver, the picture is also made up of 50 eye-blended rows of light and dark, which appear pink because the light in which they are painted comes from glowing neon gas—a rare element found in the atmosphere. Like its relatives —helium, argon, krypton and xenon—the neon used in the receiving lamp is peculiar because it will not combine with any

Fig. 1—Examining one of the giant photo-electric cells, which serve as eyes in television.

other chemical substance. When two metallic electrodes are sealed into a glass tube from which all air has been exhausted, but which contains a little neon, and an electric current is passed through the tube, the gas glows with a pinkish light. Unlike the ordinary electric lamp with a filament of tungsten, which continues to glow for an instant after the current has been disconnected, the neon light goes on and off as instantaneously as the current itself.

To television a speaker's face from Washington to New York, for example, the light starts from the carbons of an automatic arc lamp. In front of the lamp is a disc with 50 holes around its edge in a spiral, each hole a little nearer the center than the one before it. A lens projects an image of the holes out into space, just as the lens of a movie machine projects an image of the moving film to the screen, but in the television device, the screen is the subject's face.

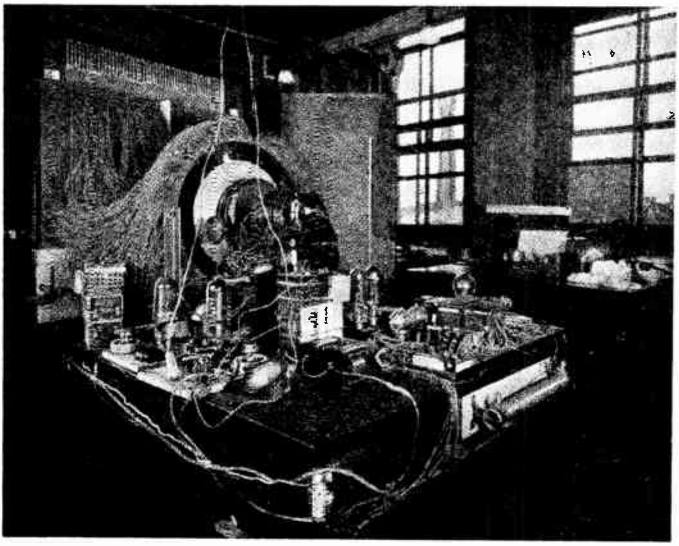


Fig. 2—Rear view of the large grid showing current distributor, its control equipment and preliminary form of the high voltage high-frequency equipment for exciting the successive areas of the neon tube.

And just as the movie film travels through the machine so fast that the single pictures are not seen, but are combined together by the eye into a continuous picture, so does the rapidly moving disc, containing the holes, move so rapidly that the 50 holes, each a little lower than the one before it, sweep across the facial screen in less than a fifteenth of a second. The person being televisioned has this light spot swept over him 17.5 times a second. To a person standing beside the subject, his face seems to be illuminated by a slightly flickering but single area light. The single holes, or even the rows of holes, are not seen separately. Outside of the light from the arc, shining through the holes in the disc, the subject is in semi-darkness. In front of him are three photo-electric cells, the eyes of television. They turn the light into electricity. The production of these cells itself is a triumph accomplished by Dr. Ives. They are the largest that have yet been constructed. When the moving finger of light, a fiftieth of an inch in diameter, sweeps across the face, it encounters the light-colored flesh; light is reflected to the sen-

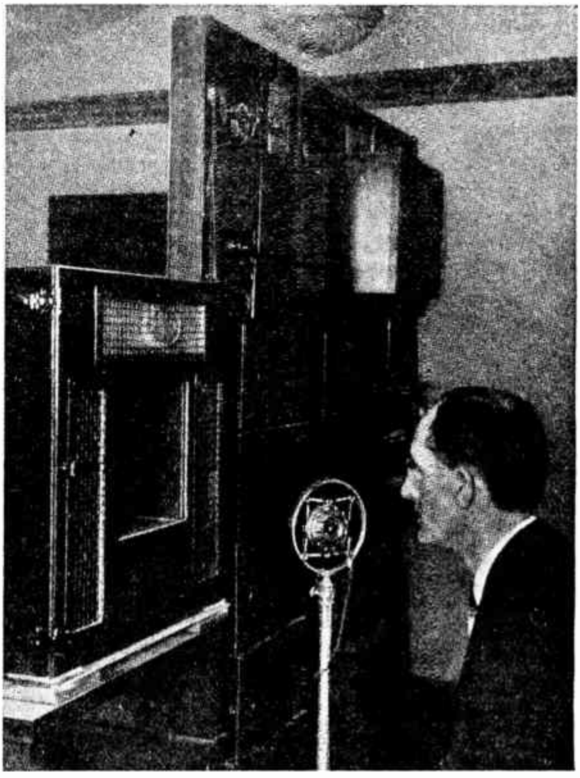


Fig. 3—A close-up of the transmitting apparatus for television at Washington, D. C. When a person talks to the microphone he is viewed by three photo-electric eyes located behind the three screens of the box immediately in front of him.

sitive photo-electric cells. By means of amplifiers like those used in radio stations, the photo-electric cells' tiny current, the electrical counterpart of the light, is magnified thousands of times. And when the spot of light reaches a dark part of the face—the pupil of the eye perhaps—and no light is reflected, no current flows from the cells to the amplifiers.

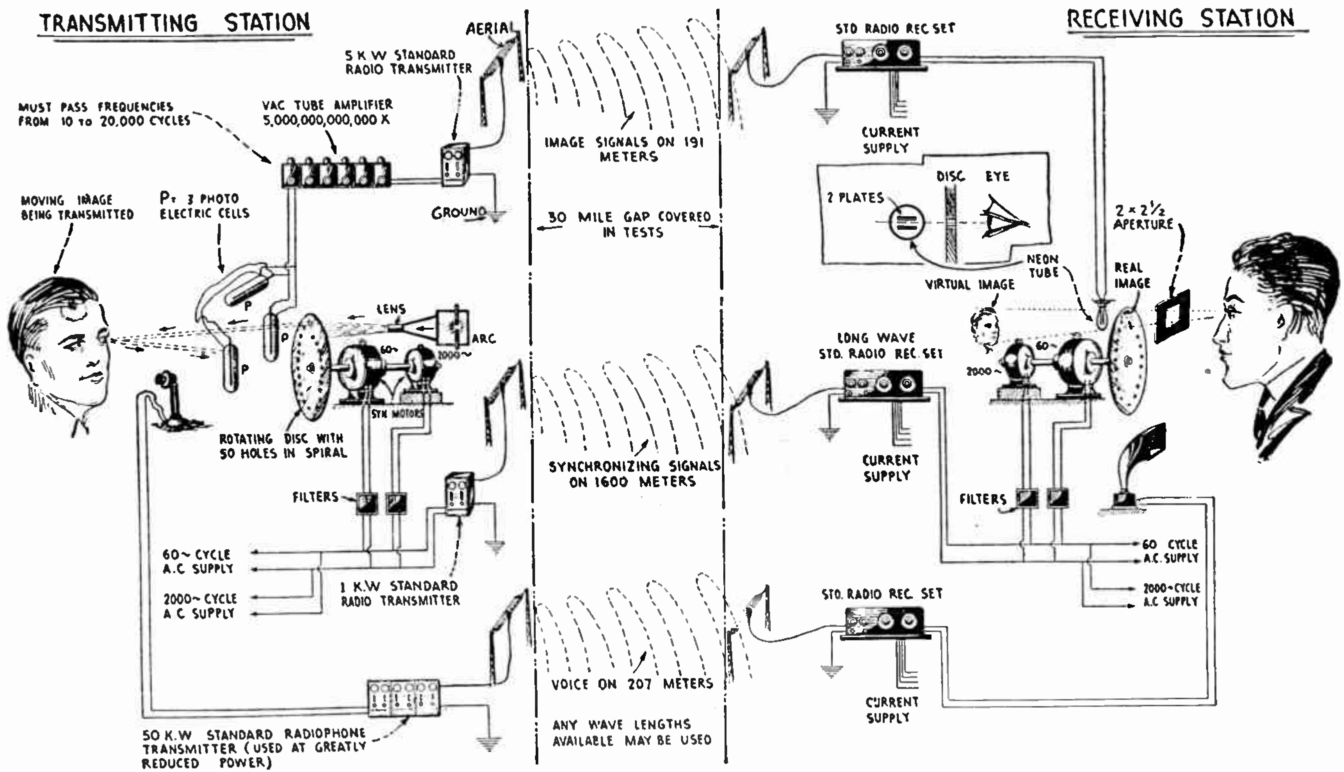


Fig. 4—A comprehensive diagram of the entire Radio television apparatus; the subject, an image of whose face is being transmitted by Radio, appears at the left, while the person observing the transmitted and reproduced image appears at the right. The perforated disc causes rapidly moving targets of light to sweep across the face; the reflections fall on photo-electric cells, P. The light fluctuations are thus transformed into minute electric currents, and these are amplified 5,000,000,000,000 times. The Radio image signals are picked up by a standard receiving set, and after amplification, the image signals pass into a neon glow-tube placed behind a second revolving disc, driven in exact synchronism with that at the transmitter. The observer looking through the small aperture sees the image built up on a plane behind the whirling disc. The voice is transmitted and received in usual manner; while a third radio wave transmits synchronizing signals for the motors.

ESSENTIAL PARTS OF THE APPARATUS FOR SEEING BY TELEPHONE OR RADIO

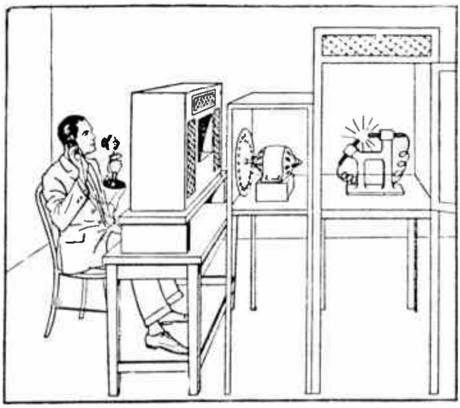


Fig. 5—The Television Transmitter. Light from the arc shines through the holes in the spinning disc, successively lighting different parts of the speaker's face. The reflected light is picked up by three photo-electric cells in the large box in front of the speaker, where it is converted into a pulsating electric current. Greatly amplified by vacuum tubes, this can be transmitted long distances by radio or telephone lines.

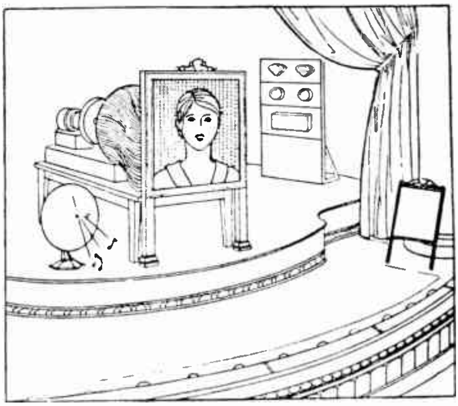


Fig. 6—For exhibition to a large audience the receiver uses a large neon tube of four square feet. This is made up of 2,500 separate elements, each with a separate wire connected with a commutator which runs in step with the revolving disc of the transmitter, so that as the spot of light shines on a particular part of the subject's face, a corresponding part of the neon tube is connected. A loudspeaker reproduces the voice.

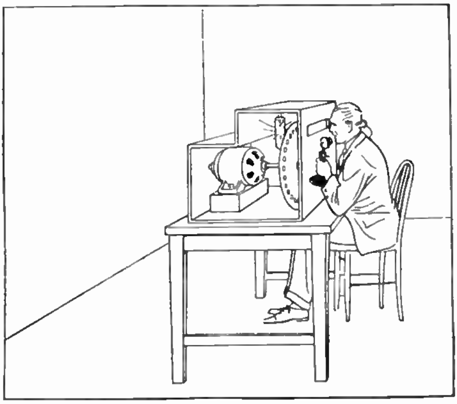


Fig. 7—When one person wishes to talk to and see a friend by telephone, a smaller neon tube is used, which presents a surface of two by two and a half inches. A revolving disc like the one in the transmitter, also in step with it, exposes a part of the glowing surface which corresponds to the part on which the transmitting light is shining at the moment. To keep the two motors at the receiving and sending end running precisely together, was in itself a great achievement.

Thus the lights and shades of the face are transformed into a varying electric current, just as the ordinary telephone transmitter transforms the sounds of the voice into a pulsating current. It travels over the telephone lines for hundreds or thousands of miles, or else on the radio carrier wave for even greater distances. The receiving end picks up the current, amplifies it some more to make up for any losses in transmission, and connects it to the receiver with its neon tube. The variations in current are translated by a neon tube back into variations of light—an inch or more square—with no semblance of a picture of a face or anything else.

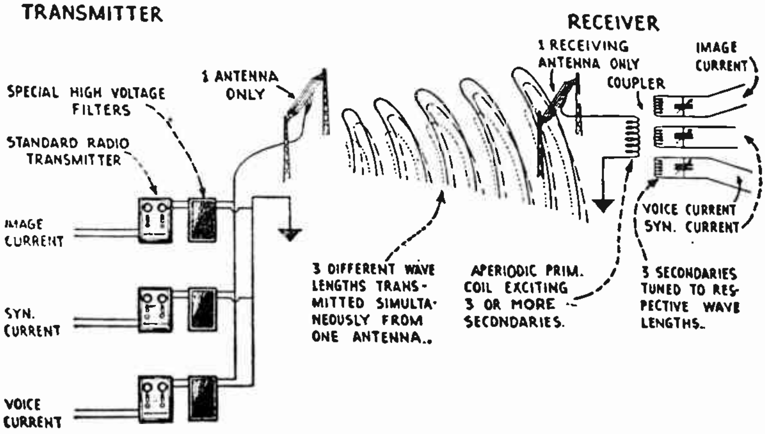


Fig. 8—Simplified system whereby three transmitters, tuned to different wave lengths, are joined to a common antenna through suitable filters.

Here the revolving disc again plays a part. A disc, the exact duplicate of the one at the sending end, revolves in front of the neon tube. Another ingenious invention, made by H. M. Stoller and E. R. Morton, permits the motor running the receiving disc to keep exactly in step with the one at the sending end. If the spot of light in the sending apparatus is shining on the bright flesh, the receiving screen shows a corresponding bright area through the hole. And then as the sending light spot moves to the dark pupil of the eye of the subject, the neon ceases glowing and the screen shows a dark spot. As the spot moves to another white portion, such as the bridge of the nose, the neon again shines through the hole, which has also moved. The receiving disc, like the transmitting one, moves so rapidly that the light appears to the person observing as a continuous surface, blended into a motion picture of the sending scene. The individual changes from light to darkness and back to light again may be over in a twenty-five thousandth of a second.

The 2 by 2½-inch picture produced by the small neon lamp is intended for individual reception. It is the first form of the apparatus that may in future years be attached to the individual desk telephone. But sometimes a large audience may also wish

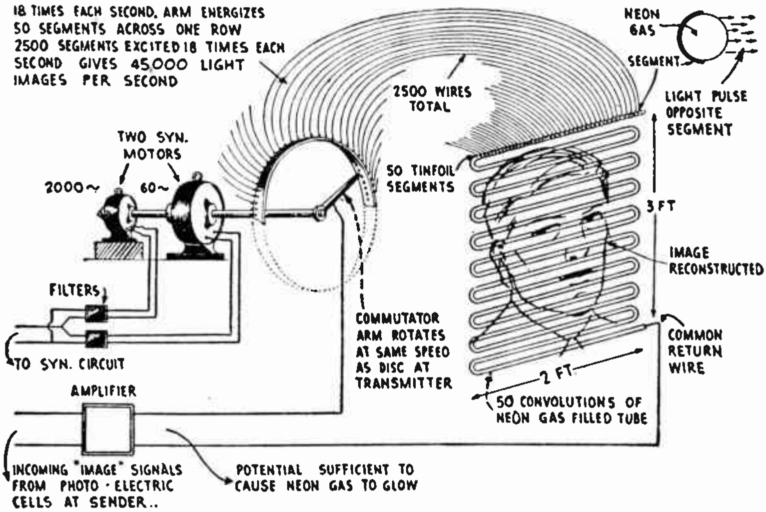


Fig. 9—The large exhibition screen built up of a continuous length of glass tubing along the rear walls on which are cemented 2,500 tin-foil segments. The tube is filled with neon gas; light spots appear opposite each segment when electrically energized.

to receive television, as when Mr. Hoover, in Washington, spoke to the audience in New York and was seen by them more than life-size. This is accomplished with glowing neon also. But a much larger tube is used; in fact, the whole screen, four square feet in area, is made up of a lengthy continuous tube, covering its surface much as lines of type on this page cover the area of this paper. This system is used instead of the revolving disc of the smaller receiver, because a revolving disc so large would not be practicable. The tube is a multiple one, really 2,500 separate lamps in one. A commutator, a disc which makes contact successively with each of the 2,500 separate glowers, is the substitute for the disc with the holes. It also revolves in step with the disc at the transmitter. A spot of light travels in rows across the surface of the large tube, reproducing as it goes, the variations of light "seen" by the photo-electric cells at the sending station. But the big tube is expensive and complicated, as a separate wire must go to each of the 2,500 separate electrodes.

THE BAIRD SYSTEM

At the transmitting end, a battery of powerful lights shine upon the scene to be transmitted. Light reflected from this scene is collected by means of a lens, in much the same fashion as a camera lens collects the light reflected from a scene to be photographed. In the television transmitter, however, instead of a sensitive photographic plate, as in a camera, the reflected light is focused upon a light-sensitive cell.

Between the focusing lens and the cell, however, there are interposed two rapidly revolving discs. One of these discs has a number of lenses mounted upon its face in spiral fashion, as shown in Figure 10. The function of these lenses is to cause the image of the transmitted scene to sweep across the light-sensitive cell in such a manner that the image is divided into fine parallel lines. The rotation of the disc gives the horizontal motion (i. e., draws the lines), while the movement into focus of the next lens (set a trifle nearer the center of the discs) gives the necessary vertical motion to insure that the lines do not overlap. Reference to Figure 10 will assist the reader to understand the action. In this manner, the entire image is flashed across the light-sensitive cell in the space of one-tenth of a second. The light reflected from the high lights of the scene to be transmitted is, of course, very bright, while that reflected from the dim shadows of the scene is very dim. The light-sensitive cell transforms these light variations into electric-current variations, which are then amplified and transmitted over the circuit to the distant receiver.

SPEEDING UP THE TRANSMITTER

The second disc referred to above is a serrated one, and its purpose is simply to interrupt the light at high frequency. By this means Mr. Baird found it possible to eliminate the inertia of selenium, and cause it to respond at a speed great enough to enable him to transmit a sufficiently large number of complete pictures per second, to give to the observer at the receiving station the effect of a smoothly animated scene.

Another advantage of interrupting the source of light is that the output of the light-sensitive cell takes the form of a unidirectional current, interrupted at high frequency, instead of a fluctuating D. C. as would otherwise be the case. A steady D. C. cannot be amplified by ordinary vacuum-tube amplifiers, whereas interrupted D. C. can. As the output current of a light-sensitive cell is extremely feeble, such amplification is necessary before transmission over a wire or wireless circuit can be accomplished successfully.

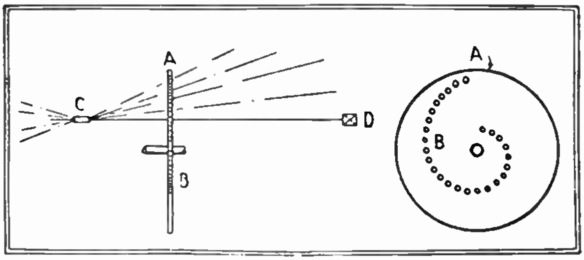


Fig. 10—The action of the Baird television transmitter: A is a rotating disc carrying spirally-arranged lenses, B, through which shines light reflected from scene, and collection by lens C. Movement of disc causes light beam to traverse light-sensitive cell D in two directions, horizontal and vertical.

At the receiving end of the circuit Mr. Baird uses apparatus which, though similar in essentials to that used at the transmitting end, has been reduced to the simplest possible form. There is a source of light and a ground glass screen, and between the two rotate discs similar to those used at the sending station. The incoming current impulses are caused to vary the intensity, or brilliancy, of the light source, in accordance with the strong and weak currents delivered by the light-sensitive cell at the transmitter.

The rotating-lens disc then breaks up the beam of light and throws it on the screen as a complete moving picture. The discs at the transmitting and receiving stations are in each case driven by electric motors, and in order to achieve success, it is necessary that the motors at all receiving stations shall be in exact synchronism with the transmitting motor. This is accomplished in the Baird system by transmitting, in addition to the picture impulses, a low-frequency alternating current, by means of which all motors are kept in step.

In Baird's first public demonstration tremendously powerful lights were necessary to illuminate the sitter whose image was to be transmitted to distant points. So powerful were these lights, in fact, that the "victim" was well-nigh blinded and burned by their intensity.

Obviously, the first necessity was to increase the sensitivity of the light-sensitive cell, in order that the intensity of the light required might be decreased. Within a few months, this was successfully accomplished so that the lighting required was no more brilliant than that used in a photographic studio.

CONCERNING THE SPECTRUM

Not entirely satisfied with these results, however, Baird began experimenting to see if he could not make use of invisible rays, and these experiments led to most important results. In order to understand clearly exactly what has been done, let us consider briefly the spectrum.

Beneath the range of the shortest radio waves are other wave lengths extending in length down to infinitesimally small fractions of an inch. The frequency of these waves is enormously high, and the entire range of known frequencies, from the lowest to the highest, is known as the spectrum.

An illustration of these appears at the left of Fig. 11, showing the wavelengths to which we assign colors, and the range of normal sight.

The composition of the spectrum may be outlined as follows: Starting at the highest known frequencies, the spectrum is divided up into sections in which fall first the gamma rays given off by radium, X-rays, ultra-violet rays, the visible spectrum (light), infra-red rays, and finally, radio waves.

The most familiar of these sections is the visible spectrum, which contains the colors extending from violet to red. It is more familiar to us because it is the only band of frequencies within the entire spectrum to which the unaided human senses are capable of responding. To detect the other frequencies, special instruments are necessary; such as, for example, a radio receiver, when it is desired to detect radio waves.

Light-sensitive cells, such as are used in a television transmitter, are capable of responding to not only visible light, but also to a narrow range of frequencies beyond the upper and lower limits of the visible spectrum; and it is this fact which has made possible one of the latest developments in television.

In his first attempt to make use of invisible rays, Baird used ultra-violet rays; but these proved to be far too dangerous, for they had a bad effect upon the eyes of the sitters.

Turning to the other end of the visible spectrum, Baird next tried infra-red rays, and immediately discovered that his light sensitive cell was capable of responding equally well to these rays, which are invisible to the human eye.

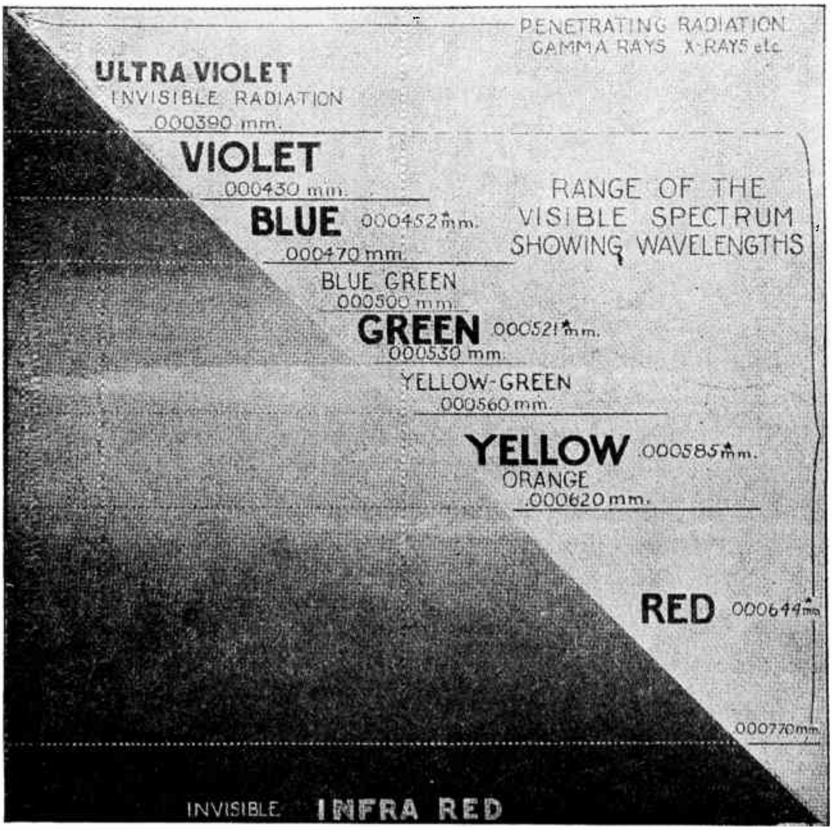


Fig. 11—The electromagnetic rays of the "visible spectrum," one billionth as long as those used in broadcasting, produce on the eye the effect of color (the stars indicate the wavelengths of the primary colors). Beyond its limits, at either end, no sensation of sight is caused. However, photo-electric cells register the impact of both ultra-violet and infra-red rays. The latter are used for "lighting" at the receiver of the Baird Televisor; and at the transmitter are reproduced as visible light, giving a normal effect.

SEEING IN TOTAL DARKNESS!

Within a short space of time the inventor was able to dispense entirely with visible light, with the very startling result that it was possible to "see in total darkness!"

This is, perhaps, the most spectacular development of all in connection with television, and it has an uncanny and impressive effect upon visitors to a demonstration; a vivid description is given in the following words of a visitor who witnessed a demonstration of "seeing by dark light."

"First of all, I was shown into the transmitting studio, the windows and doors of which were heavily draped to exclude all daylight. The place was in complete darkness. Even after having become accustomed to the stygian gloom it was literally impossible to see my hand in front of my face; and yet those watching the receiving screen were able to see me put my hand up in an effort to see it!

Leaving a friend of mine there, I wended my way down stairs to the receiving theatre, where I conversed with my friend over the telephone and simultaneously watched his face on the televisor screen. He assured me that he was "still in total darkness," and yet there was his image on the screen before me, an image which, incidentally, showed considerable improvement over that which I first saw over a year ago!"

Thus have the Powers of Darkness been dispelled—those mythical powers which, right down through the ages of Man's history, have struck terror into the hearts of the ignorant and the superstitious.

It is difficult to estimate the full extent of the importance of this achievement in warfare, for it renders it possible to follow the movement of the enemy when he believes himself to be under cover of darkness.

Attacking aircraft, approaching under cover of the night, will be disclosed to the defending headquarters by the electric eye of television apparatus. They will be followed by searchlights emitting not visible light but infra-red rays, and as these rays will be invisible to them, they will continue to approach until, without warning, they are brought down by the guns of the defense.

Darkness, the great cloak for military operations, will no longer give security. The attacking party, creeping forward for a surprise attack on a pitch-black night, will be swept by an invisible searchlight and watched on the television receiving screen of the defenders. They will be permitted to come well within range and then find themselves, in spite of the apparent protection of darkness and the absence of visible searchlights, overwhelmed and decimated by well-directed gun-fire. It is to be hoped, however, that other uses may be found in peace time for this latest development of television. The fact that infra-red rays possess great fog-penetrating powers opens up possibilities in connection with the navigation of ships during foggy weather.

SEEING THROUGH FOG

To understand the possibilities in this direction, it is only necessary to consider the behavior of ordinary visible light during foggy weather. The most intense white lights, it will be noticed, show through fog as a dull red color. The thicker the fog the duller the red which shines through.

This phenomenon is not due to any change in the characteristics of the original source of light. The fact is that any given light-source emits not one single color of light, but several, which combine to give the effect of a single color. By means of filters which will allow only certain component colors to pass, all other colors can be eliminated. Fog acts as a filter which will pass only red light.

The penetrating power of light varies as the fourth power of the wavelength; so that red light penetrates some 16 times more effectively than blue light, and infra-red light 200 to 300 times.

Red light has already come widely into use in aerodromes and for other purposes where fog-penetration properties are of importance. This new application of television renders possible the use of infra-red rays with their still greater penetrative powers.

They will not, of course, be visible to the naked eye, even through fog. It will be necessary at the receiving end (e. g., a ship at sea) to make use of a television apparatus in order actually to "see" through fog.

In order to generate infra-red rays, any form of lamp may be used which will provide the necessary intensity of illumination, although certain types of lamps are richer in infra-red rays than others. Having selected a suitable light-source all that is required to obtain infra-red rays from it is a filter which will cut off all the frequencies but those belonging to the invisible rays. Several substances may be used as filters, such as, for example, hard rubber.

Thus, in order to transform an ordinary searchlight (which is already very rich in infra-red rays) into an infra-red ray search-light, it is necessary only to cover the front of it with a suitable filter substance.

The infra-red rays are used by Baird in exactly the same way as ordinary visible light. That is to say, the rays are directed upon the sitter, and the "dark light" reflected from his face is passed on to the television transmitter.

IMPROVEMENTS IN IMAGE-EXPLORING MECHANISM

Quite recently, Mr. Baird has made some improvements in his image-exploring mechanism. He has discarded his rotating disc of lenses, retaining only the two rotating slotted discs. To understand his reasons for doing this, let us consider briefly the rotating lens disc and its function in the apparatus.

The lens-disc, it may be remembered, consisted of a large disc upon which were mounted 16 lenses, in two groups of 8, each lens in each group being set a little nearer the center of the disc, or staggered. As the disc revolved each lens took a small portion, or narrow strip of the image and swept it across the light-sensitive cell, so that the entire image was so swept across once for every revolution. The image was thus divided into 16 vertical strips. They were further sub-divided into minute horizontal portions, or flashes, by the two other rotating discs, and each flash was, in turn, thrown upon the light-sensitive cell and signalled to the distant receiver.

From the foregoing, it will be obvious that the fineness of the "grain" of the image as seen on the televisor screen was limited to sixteen vertical strips, or lines. This is all right for a small reproduced image; but when it is desired to enlarge the size of the televisor screen it becomes necessary to retain the fineness of grain during the magnification process. Sixteen image strips are scarcely discernible as such, on a screen only about six inches square; but on a screen six feet square, the effect can well be imagined.

The obvious solution to the problem seems to lie in an increase in the number of lenses mounted upon the rotating lens-disc, but when an attempt was made to do this, mechanical difficulties were immediately encountered. In the first place, in order to accommodate the desired number of lenses, the diameter of the disc had to be increased to such an extent that it became unwieldy. Secondly, the weight of the lenses increased the centrifugal force of the rotating disc to such a great extent that it burst.

Baird, therefore, cast about for some other means of projecting an image in small sections across his light-sensitive cell. Besides lenses, prisms and vibrating mirrors can be, and have been used for this purpose; but they have their own peculiar disadvantages. Finally, the idea of the pin-hole camera occurred to Baird one day, and he devised an apparatus based on this principle.

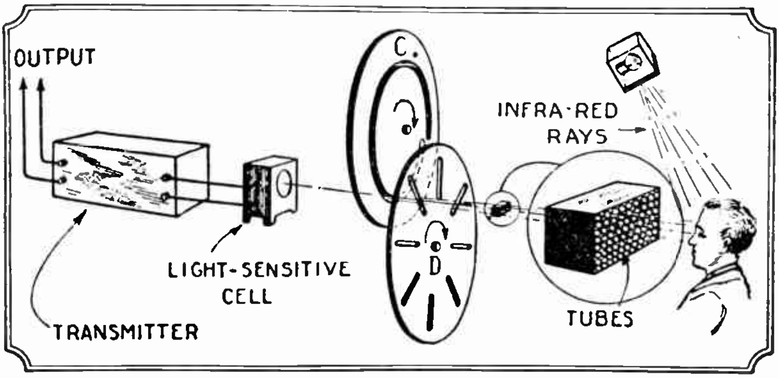


Fig. 12—The infra-red rays are reflected from the object through the tubes, and the revolving slotted discs C and D, where they are broken up, as explained in the text. They are then transformed into electrical energy by the cell, and are fed to the transmitter. At the receiving station they may be recorded on a phonograph, and reproduced at any future time.

PROJECTION TUBES A SOLUTION

This apparatus is illustrated in Figure 12. It consists of a block, or cellular structure, of tubes of tiny diameter which is arranged between the sitter and the two rotating slotted discs. The cellular structure can be seen in the illustration of this block.

Each tube in the block casts an image of a small part of the scene before it, so that the total effect of the block is to split up the entire image into scores of tiny round sections, or dots, and it only remains to impress the light values represented by each individual dot upon the light-sensitive cell in proper sequence. Baird does this by retaining two revolving discs of his original system. One of these discs has a long spiral slot in it, while the other has a series of radial slots. These discs revolve immediately behind the cellular structure, as shown in Figure 12, in such a manner that the discs overlap, the overlapping portions moving past each other in opposite directions as the discs revolve.

The spirally-slotted disc, C, revolving comparatively slowly, exposes layer after layer of the tubes to the light-sensitive cell, shifting in a vertical direction. The slots in disc D, which revolves at a high rate of speed, are so arranged, however, that the light ray of only one tube at a time is exposed to the light-sensitive cell.

Thus, while, say, the lower layer of tubes is open to the cell through the spiral slot, the slots in the disc D swing rapidly along the line and flash the light of each tube in turn upon the cell. Then the next row of tubes is dealt with, and so on, until the entire image has been flashed over the cell.

At the receiving end, apparatus exactly similar is installed, except that the light-sensitive cell is replaced by a source of light which is varied by the incoming electrical impulses, which are strong for high-lights, medium for halftones, and zero for dark parts of the picture. Immediately in front of the cellular structure, at the end remote from the spinning discs, there is a ground glass screen, upon which the picture appears, a faithful reproduction of the original, complete with even gradations of light and shade, and showing the movements of the sitter exactly as would a movie film.

THE NEXT STEP

Whereas the older method used by Baird, employing a spinning disc of lenses to project the image upon the light-sensitive cell, tended to produce at the receiver end a picture made up of closely-fitting narrow strips, the new method gives a picture made up of tiny dots, like a newspaper reproduction.

The grain can be made very much finer by this new method, and the picture enlarged considerably; but, even so, the ultimate degree of fineness obtainable, when enlarging the screen, is limited by mechanical imperfections. Obviously, there is a limit to the number and thinness of the tubes which can be employed, as also there is a limit to the speed at which discs can be revolved.

Recognizing this, Baird continued his research until he has now developed what he calls an "Optical Lever" to replace all his present image-exploring mechanism. It is impossible to describe this latest development, owing to the patent situation, but it can be stated that by means of it any degree of fineness of grain can be optically obtained, and there is no mechanical limit to the speed of operation.

PERMANENT RECORDS OF SCENES

An interesting phenomenon in connection with television is that, if the output currents of the light-sensitive cell are listened to in a telephone receiver, they can be heard as sounds and every object or scene has its own peculiar characteristic sound.

For example, the fingers of a hand held in front of the transmitter will give rise to a sound similar to the grating of a very coarse file, while the human face will cause a high-pitched whistle which will vary in pitch as the head is turned or even when the features are moved.

For experimental purposes, Mr. Baird had some phonograph records made of the sounds made by different persons' faces, and by listening carefully to the reproduction of these records, it is possible to distinguish between one face and another by the sounds they make! With practice, faces may even be recognized by the sounds produced.

A further interesting point of far-reaching importance is that these records can be turned back into images. This is done by replacing the ordinary sound box by an electrical reproducer and causing the output currents from it to vary the intensity of the light source of a televisor. Thus, we can now store a living scene in the form of a phonograph record as well as in the form of a moving picture film! Baird calls this invention a "Phonoscope."

There is room here for the imaginative to indulge in speculation on the scope for future development along these lines.

THE BELIN APPARATUS

The schematic wiring diagram, Figure 13, illustrates the mechanism used in the Edouard Belin system of television. The interior of the projecting lantern contains an electric arc, A, a convex lens, and a slide carrier, O, into which an ordinary positive photograph upon glass is inserted, as if for projecting the image or picture upon a screen in the usual manner.

The rays from the arc pass through the positive slide and project its image through a second or objective lens upon a plane mirror, B, which is attached to a drum completely surrounded by such mirrors, those at the ends of each diameter being parallel. The drum is connected by gears to a motor, by which it may be rapidly revolved. When it is in a state of rest, the image from the lantern slide may be projected by reflection from the mirror B to a diaphragm or screen, C, on which it is reproduced with all its graduations of light and shadow.

If we make a hole, 1/25 of an inch in diameter, in this screen, a luminous ray will pass through it, and fall upon the fixed mirror, D. The point of light it forms will have a diameter larger than the perforation in the screen, because of the spreading of the rays; and the mirror itself will accentuate this effect. Accordingly, we place another lens, E, in the path of the reflected ray, which is thus caused to converge. From this it passes to the mirror F, which again reflects it to the drum of mirrors. Here it impinges on the mirror G, which is diametrically opposite to B, and thence finally to a screen H, where it appears as a luminous point, corresponding to that which fell originally on the spot on C through which we made the opening. Now we start our motor and set the mirror-encased drum revolving; with what results? So long as the first mirror B remains stationary, the image which it projects upon the screen H is motionless; but when we set it in motion, in the direction indicated by the arrow, the image reflected by it will be deflected downward upon the diaphragm C. Over the hole in C all the points constituting a vertical line in this image will pass, and be projected in succession upon the mirror B. Through the reflecting system which has been set up, these will be reproduced in succession upon the receiving screen H. Each mirror which succeeds B in position on the revolving drum will receive the image in the same manner and make it pass through the opening in the diaphragm C.

THE IMAGE REPRODUCED

We now are able to transmit a luminous vertical line, traversing the image from top to bottom, and always composed of the same succession of points. They will not be of equal intensity; because the ray will be very luminous when it represents a transparent portion of the slide on O, and more obscure when it passes through a part representing a darker portion of the image.

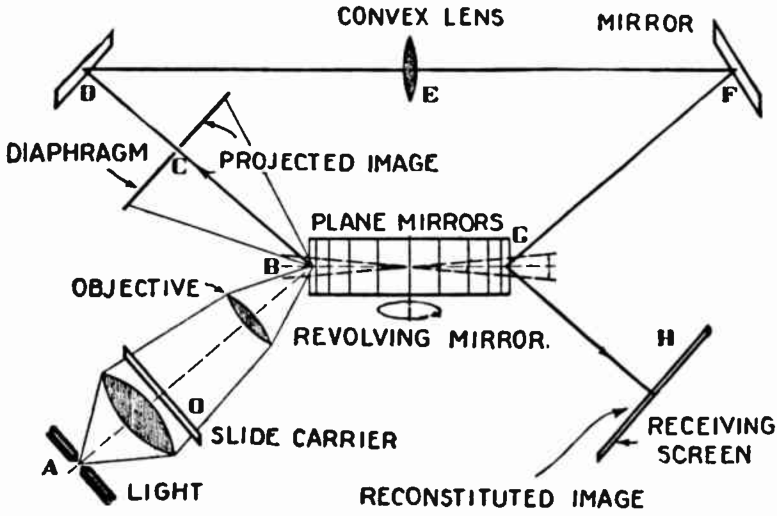


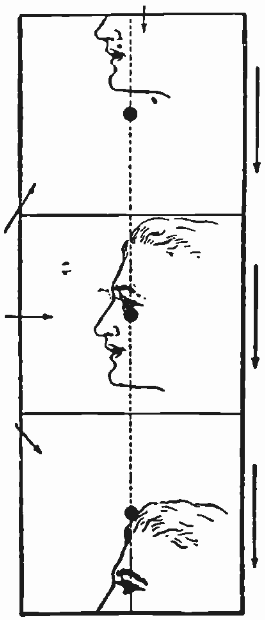
Fig. 13—This diagram is fully explained in the text. The cylinder is covered with plane mirrors, revolving downward on the side toward the lantern. One ray at a time, from 1/25,000 of the area of the image, passes through the opening in C. The fixed mirrors D and F send it back to the mirror G, opposite B on the cylinder, and it is finally reflected against H in a position corresponding exactly to the portion of the image from which it was first taken. The effect of continuous vision is produced.

Now the problem is to cover the whole area of the image on the slide, by causing the luminous line to be displaced at each movement over the screen, taking a course very close and perfectly parallel to the preceding stroke. This is accomplished by giving the mirror-drum a horizontal movement, alternating from right to left; which is accomplished by the use of a double spiral cam attached to its base, which gives it the necessary reciprocal action from right to left and back. Those movements, communicated to the revolving mirrors, deflect the image from side to side upon the diaphragm C. In this manner, the image is made to cover the opening in this screen with every successive point of which it is composed. The revolving mirrors thus transmit to D and its train of reflecting all the points of the projected image, in vertical lines, which by means of the oscillation of the drum, are delineated so close together that each practically touches the preceding one; and no perceptible portion of the image fails to be projected through the opening in C. As the mirror G and those which succeed it reproduce, in reverse direction, the motions of B, the reflected ray at H reconstitutes one by one, in the same order, all the points of the image on C which pass over the opening in that screen. As the entire screen is covered in a tenth of a second, or less, the image will appear clearly upon the receiving screen, as if reflected over its whole surface at once. This ingenious experiment has proved that every luminous emission of sufficient intensity which lasts for 1/250,000 of a second is perfectly registered by the retina, the impression on which persists for 1/10 of a second. This brings out clearly the curious property of the eye, "the persistence of vision," by which the sight of an image is preserved for a period of 25,000 times longer than the duration of the impression.

APPLICATION TO RADIO

To transmit the image by radio waves, we have only to replace the mirror D by a photo-electric tube, such as has already been described. All luminous points in the image will be projected upon the tube, creating impulses which will be transmitted by means of ethereal (Hertzian) waves through space. By means of a properly synchronized corresponding mechanism attached to a receiver, they will be reproduced and projected in the same order upon a screen corresponding to H, producing the phenomenon of television.

It must be pointed out that the luminous ray is not displaced upon the mirror D of our diagram any more than it will be upon the photo-electric tube. If it passed through transparent glass, instead of through the picture on the lantern slide, it would have an unvarying intensity, and the current transmitted would be a continuous one. It is necessary to move the mirrors in order to cause the displacement of the entire image which they reflect over the aperture in the diaphragm. The slide remains fixed in the projecting lantern, and the magnified movements of its image are obtained by the rotation and oscillation of the drum. It would be theoretically possible to move the image in the lantern, or the screen C, to obtain the same result, but not practicable.



The moving image on the fixed diaphragm (C).

Fig. 14—At the left are shown the successive positions of the reflected image upon the diaphragm C. The portion of the image indicated by the (greatly magnified) dot in the center passes through this to the train of succeeding mirrors. In the upper illustrations is shown the effect of the downward rotation of the mirror B. The image passes vertically from top to bottom of the screen, every point in the vertical line shown being successively transmitted to the final screen H. By reason, however, of the upward rotation of the mirror G, these points, instead of remaining in the center of the field, are reproduced in a similar vertical line from the top to the bottom of H. For when B reflects the point at the bottom of the image (as in the top view) down to the center of the screen C, G reverses the motion and throws it up again from the center to the top of the screen H; and vice versa. The position of the ray in the apparatus from B to G is always the same, no matter to what portion of the image it corresponds.

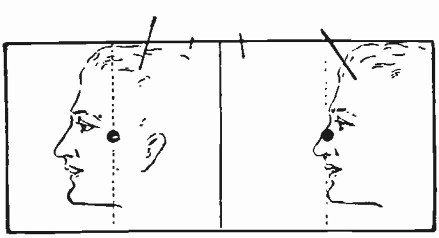


Fig. 15—This shows, in a similar manner, the effect on the image of the oscillation from side to side of the mirrors. It is swung from side to side on the perforated screen or diaghragm, until every part of it has been covered by the vertical lines traced by its movement over the central opening. These motions, also, are reversed by the opposite motions of the parallel mirrors so that the entire image is reproduced in its proper form on H.

Dr. E. F. W. Alexanderson, one of the foremost radio engineers in the world, has been working for the past few months on improvements in telephotography. He has succeeded in transmitting, by radio, photographs in one-tenth of the time that it previously took; and the copies, taken from the air at the receiving end, are excellent reproductions of the originals. Dr. Alexanderson, however, is looking beyond the transmission of photographs; his goal at the present time is "television."

THE TELEVISION SYSTEM OF DR. E. F. W. ALEXANDERSON

Figure 16 shows a mode of a television projector, consisting of a source of light, a lens and a drum carrying a number of mirrors. When the drum is stationary, a spot of light is focused on the screen. This spot of light is the brush that paints the picture. When the drum revolves the spot of light passes across the screen. Then, as a new mirror, which is set at a slightly different angle, comes into line, the light spot passes over the screen again, on a track adjacent to the first; and so on until the whole screen is covered. If we expect to paint a light-picture of fair quality, the least that we can be satisfied with is ten thousand separate strokes of the brush. This may mean that the spot of light should pass over the screen in one hundred separate impressions of light and darkness in each path. If we now repeat this process of painting the picture, over and over again, sixteen times in a second, it means that we require 160,000 independent strokes of the brush of light in one second. To work at such a speed seems at first inconceivable; moreover, a good picture requires really an elemental basis of more than 100 lines. This brings the speed required up to something like 300,000 picture-units (dots) per second.

Besides having the theoretical possibility of employing waves capable of high-speed signaling, we must have a light of such brilliancy that it will illuminate the screen effectively, although it stays in one spot only 1/300,000 of a second. This was one of the serious difficulties; because, even if we take the most brilliant arc-light we know of, and no matter how we design the optical system, we cannot figure out sufficient brilliancy to illuminate a large screen with a single spot of light. The model television projector was built in order to allow us to study the problem and to demonstrate the practicability of a new system, which promises to give a solution of this difficulty.

Briefly, the result of this study is that, if we employ seven spots of light instead of one, we will get 49 times as much useful illumination. Off-hand, it is not so easy to see why we gain in light by the square of the number of light-spots used, but this can be explained with reference to the model. The drum has twenty-four mirrors and, in one revolution of the drum, one

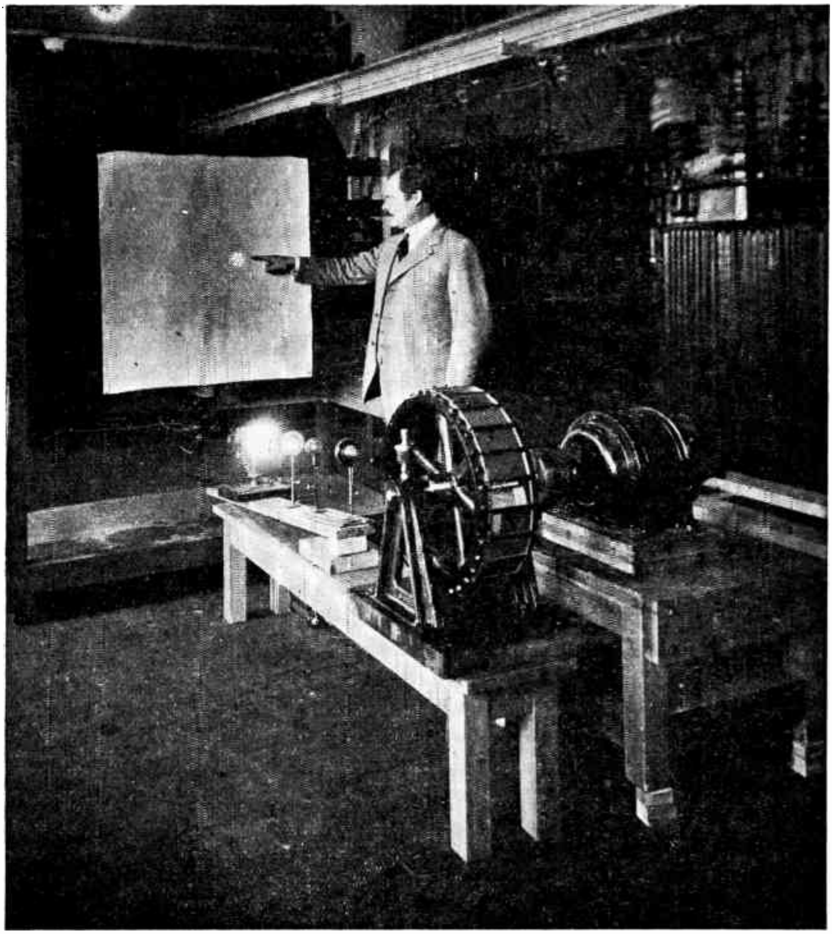


Fig. 16—Dr. Alexanderson in his laboratory indicating the seven light-spots which are used in the method proposed by him for television. In the foreground is the drum on which are mounted the mirrors, with the motor for rotating it. A system of lenses may be seen, together with an arc light.

light-spot passes over the screen twenty-four times; and when we use seven sources of light and seven light-spots, we have a total of 170 light-spot passages over the screen during one revolution of the drum.

ADVANTAGE OF MULTIPLE LIGHT-RAYS

The gain in using seven beams of light in multiple is two-fold. In the first place, we get the direct increase of illumination of 7 to 1; but we have the further advantage that the speed, at which each light beam must travel on the screen, has been reduced at a rate of approximately 7 to 1, because each light-spot has only 24 tracks to cover instead of 168. While the light itself may travel at any conceivable speed, there are limitations of the speed at which we can operate a mirror-drum or any other optical device; and the drum with 24 mirrors has already been designed for the maximum permissible speed. A higher speed of the light-spot can, therefore, be attained only by making the mirrors correspondingly smaller; and mirrors one-seventh as large will reflect only one-seventh as much light. The brilliancy of the light-spot would, therefore, be only one-seventh of what we realize by the multiple beam system, which gives seven light-spots seven times as bright, or 49 times as much total light.

There is another advantage in the use of the multiple light-beam; each light-beam needs to move only one-seventh as fast and therefore needs to give only 43,000 instead of 300,000 independent impressions per second. A modulation speed of 43,000 per second is high with our present radio practice; but yet it is within reason, being only ten times as high as the speed we use in broadcasting.

The significance of the use of multiple light beams may be explained from another point of view.

It is easy enough to design a television system with something like 40,000 picture units per second, but the images so obtained would be so crude that they would have very little practical value. Our work on radio photography has shown us that an operating speed of 300,000 picture units per second will be needed to give pleasing results in television. This speeding up of the process is, unfortunately, one of those cases in which the difficulties increase by the square of the speed. At the root of this difficulty is the fact that we have to depend upon moving mechanical parts.

SEVENFOLD TELEVISION APPARATUS

Our solution to this difficulty is, not to attempt to speed up the mechanical process, but to paint seven crude pictures simultaneously on the screen and interlace them optically so that the combination effect is that of a good picture.

Tests have been made with this model television projector, to demonstrate the method of covering the screen with seven beams of light working simultaneously in parallel. The seven spots of light may be seen on the screen as a cluster. When the drum is revolved, these light-spots trace seven lines on the screen simultaneously, and then pass over another adjacent track of seven lines until the whole screen is covered. A complete television system requires an independent control of the seven light-spots. For this purpose, seven photo-electric cells are located in a cluster at the transmitting machine and control a multiplex radio system with seven channels.

Seven television carrier waves may be spaced 100 kilocycles apart, and a complete television wave band should be 700 kilocycles wide. Such a radio channel might occupy the waves between 20 and 21 meters. If such use of this wave band will enable us to see across the ocean, I think all will agree that this space in the ether is assigned for a good and worthy purpose.

TEST QUESTIONS

Number your answers 46 and add your **student number.**

No. 1. What is television?

No. 2. What is a light-sensitive cell?

No. 3. What furnishes the light in the television receiver of the Bell system?

No. 4. How many times are the minute electric currents from the photo-electric cells amplified in the Bell system?

No. 5. How large is the neon lamp used in the Bell system when it is desired to receive television for a large audience?

No. 6. What is the function of the lenses mounted on the revolving disc used in the Baird system?

No. 7. Name the kind of rays which were used by Baird in his experiments of "seeing in total darkness."

No. 8. What changes should be made in Figure 13 if it is to be used to transmit images by Radio?

No. 9. What is the big difficulty encountered in the Alexanderson system?

No. 10. How many photo-electric cells are used in the Alexanderson system?

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DISTANT CONTROL BY MEANS OF RADIANT ENERGY

The present state of development of distant control by means of Radio, like a great many other branches of the art, is due to the early experiments and farsightedness of some of the inventors and scientists who have followed the growth and development of Radio in all of its various branches. The dreams of the inventor and scientist and some of his experiments are generally performed some years before the invention is so perfected and developed that its practical application can be made use of. Such is the case with distant control. Prior to the time when trans-Atlantic communication was first carried on by means of Radio, Nikola Tesla foresaw the usefulness of distant control by means of Radio and performed numerous experiments along this line. In 1895 he gave demonstrations in New York of his radio-controlled boat. This small boat was only 8 ft. long, but it was entirely controlled by Radio, and operating it in a large pond, the inventor made the boat go through many maneuvers such as turning lights on and off, firing miniature guns, changing its course at will, all to the consternation of the public to whom Radio was then practically unknown.

Following the successful application of Radio communication by commercial companies, other scientists and inventors turned their attention to the development of distant control. John Hays Hammond, Jr., has developed and invented several systems of distant control and his inventions have done a great deal toward making this branch of the art successful. One of his earliest inventions, the so-called "electric dog," could be made to follow the rays from a flash-light or electric-light bulb, and it performed many complex maneuvers in so doing. It was simply necessary to keep the source of light close enough to the "eyes" of the "electric dog" to cause a sufficient amount of light to get through to the sensitive cells within it, which functioned to translate the light into electrical energy, the latter being used to operate the control relays within the device.

A more serious application of this principle was effected in tests which were carried on during the late war, for controlling torpedoes by Radio or light waves. This system was so arranged that, should an enemy ship at night, try to watch out for these radio-controlled torpedoes by means of powerful searchlights, the Radio control operator could release control of the torpedo in such a manner that the moment the beam from the enemy searchlight became focussed on the torpedo, the latter would immediately change its course and travel in the direction of the source of light, subsequently striking the ship upon which the searchlight was mounted, thus destroying or at least disabling the enemy ship that was causing the interference. It was thought that this action of the torpedo would soon discourage the enemy from attempting to interfere with these radio-controlled torpedoes and the Radio control operator was given further leeway, in that it was made possible for him to release, or regain control at will. He could also make this device free from, or subject to, enemy interference, as desired, by the manipulation of the proper controls at the remote controlling station.

Here then was a useful application of the invention. The course of the torpedo could be accurately controlled by Radio, from a remote point, and it could be made entirely free from enemy interference, or could be made to travel toward the source of the interference, if there was any, and destroy this source.

The "electric dog" embodies the basic principle of the action involved in the control of a moving body by radiant energy and though the radiant energy in this particular case is light, and not Radio, it is worth while for the sake of making the fundamentals clear, to give it first consideration. The action is not at all involved as it makes use of well established scientific principles and is merely a new application of these principles.

Figure 1 shows the Hammond "electric dog" being controlled by means of a portable 50-watt lamp held in the hand of an operator, and Figure 2 is the schematic wiring diagram showing the circuits involved in the operation of the control mechanism. The basic unit in this device is the light cell; this cell is sensitive to light, in that its internal impedance to the flow of an electric current varies with the amount of light striking its sensitive surface. It is a two-electrode device that requires a potential in the order of 300 volts (in the case of the potassium cell) between its electrodes for satisfactory action.

Hammond used the type of cell that is called a "selenium cell," in the "electric dog," but there is another cell, of a different type, known as the potassium cell which is more sensitive than the former.

Considering Figure 2, the light from the source O-3 will pass through the condensing lens L-1 and strike the sensitive surface of the selenium cell S-1 within. This cell, S-1, is connected in series with a battery and the coils of the sensitive relay R-1. Before any light strikes the cell, there will not be any flow of current from the battery, due to the fact that the impedance of the cell is infinitely high. When light reaches the

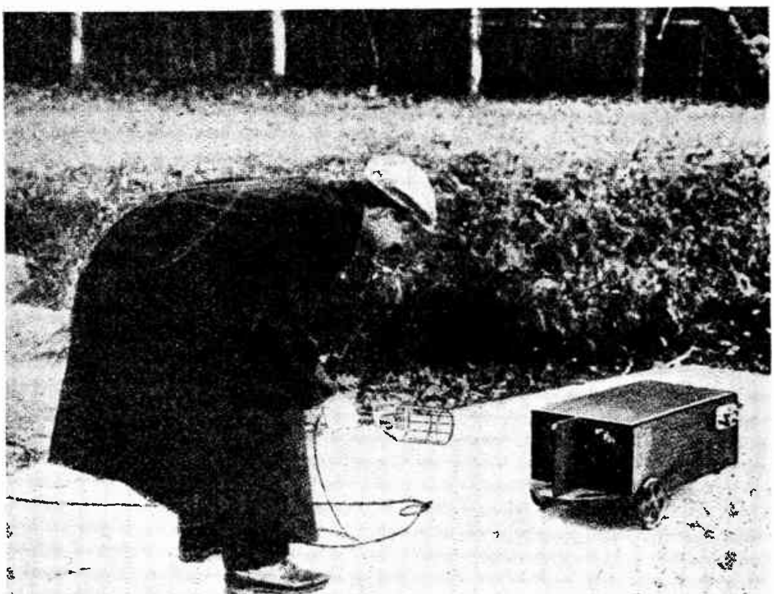

Fig. 1—Photo of the Electric Dog

sensitive surface of the cell, the internal impedance of the cell immediately drops to such a value that sufficient current flows through the light cell circuit to operate the relay R-1.

The tongue of this relay goes over to contact No. 1 thus closing a circuit from the battery B-3 through the field coil of the solenoid R-3. The armature of this solenoid moves upward, closing contact 3-4 and 5-6. This action closes the circuit through one field of the motor M. The battery B-5 is connected directly to the armature at all times and this battery B-5 is also connected to the field in question through the contacts of the solenoid R-3. Hence, when R-3 functions, the motor M rotates, and it rotates in such a direction that it turns the control wheel to which it is geared so that the "dog" tends to move toward the light.

You have probably noticed, in looking at Figure 1, that the "dog" is a three-wheeled affair. It has two front wheels and one rear wheel and it is by the latter that the direction of travel is controlled.

Let us now assume that we have the source of light at 0-2. The rays from this source pass through the condensing lens L-2 and strike the sensitive surface of a second selenium cell S-2. When the light is at 0-2, the rays do not reach the sensitive surface of the cell S-1 due to the light screen between the two light cell compartments just as in the case of the source at O-3, the light does not strike the cell S-2.

The action of the light striking the cell S-2 causes current to flow through the output circuit of this cell and the coils of the relay R-2, are energized. The tongue of this relay closes contact No. 2 and a circuit is closed through the field coil of a solenoid R-4. The armature of this solenoid moves upward closing the contact 7-8 and 9-10. The closing of these last named contacts, completes the circuit through the other field winding of the control motor and due to the fact that in this case, the flow of current through the motor field winding is in the opposite direction to that when the source of light was at O-3 and the relay R-3 closed to operate the control motor, the motor will rotate in the opposite direction and the rear wheel of the "electric dog" will be turned in such a direction that the device will move towards the source of light which is now at O-2.

Now considering the last case. If the source of light is at O-1, there will be sufficient light reaching both selenium cells to produce enough current in their output circuits to operate their output relays R-1 and R-2, and both of the solenoids R-3 and R-4 will function to close the contacts 3-4, 5-6, 7-8, and 9-10. If you trace the circuit through under these conditions you will find that the two motor fields are in parallel and there will be an increased current flow through R-5 due to the shunting of the two motor fields and the increased flow of current will be sufficient to operate the solenoid R-5, the armature of which will move upward cutting additional resistance in the circuit to limit the current flow by means of a rheostat control connected to the armature of R-5. You will now recall that in all previous cases, the current was so limited by the control motor field winding that it was not of sufficient value to operate the solenoid R-5.

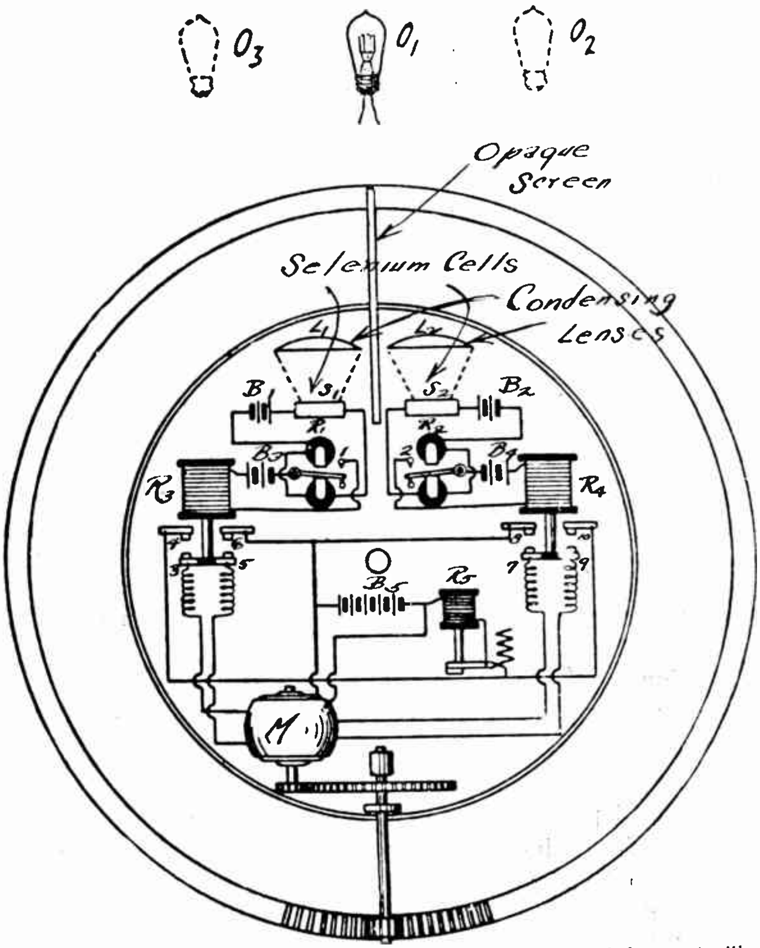

Fig. 2—The schematic wiring diagram showing circuits used for controlling mechanism of the Electric Dog.

We should mention the fact here that the schematic wiring diagram in Figure 2 only takes into account the mechanism which controls the direction of travel of the "electric dog" and it should be mentioned that whenever either relay R-1 or R-2 closes, there is an auxiliary set of contacts which function to close the circuit through a driving motor which puts the device in motion.

In the device shown in Figure 1, the speed of travel was 3 ft. per second and in the smallest circle that it could turn in was 10 ft. in diameter.

RADIO CONTROL OF SHIPS AT SEA

Figure 3 is a schematic wiring diagram which shows the circuit involved in the distant control of a ship at sea. This diagram is the one that appeared in Hammond's original patent and is really the basic circuit for the control of ships, aircraft, vehicles or torpedoes.

We will now first consider the action involved in Radio or distant control and for the sake of variety, we will assume that in this case we are controlling the course of a ship at sea from a point on the land. Referring to Figure 3, you will notice two closed loops 1 and 2 at right angles to each other, instead of the two selenium cells, and the energy that is picked up to actuate the control mechanism is radio energy, instead of light rays. It is assumed that you understand the directive characteristics of the closed loop antenna as well as the fact that the phase of the oscillations received in the loops varies according to the relative positions that the loops bear to the transmitting antenna.

The value of the negative charge on the grids 10 and 11 is a function of the amount of the energy stored in the condensers, which in turn is a function of the relative position of the loop with respect to the source of radio-frequency energy. This specification drawing shows the grids 10 and 11 as both contained in one vacuum tube having as well two plates and one filament. It is true that this tube could be a special tube having two grids, two plates and one filament, but it is more logical to believe that in actual practice, two separate tubes would be used, one functioning from the energy stored in the condenser 3 and the other functioning from the energy stored in the condenser 4.

The potential for the plates 14 and 15 is supplied from the battery 12 through the differential windings 16 and 17 of the differential relay 18. These windings are so arranged that the current from the battery 12 to the plate 14 will create a field in the winding 16 in opposition to that produced in the winding 17 when current is flowing to the plate 15. In other words, the plate current to 14 causes the armature of the differential relay to move in one direction and plate current to 15 causes the relay armature to move in the opposite direction.

A summary of the foregoing shows that the position of the armature 19 of the differential relay 18 depends upon whether the field due to the plate current to 14 or the field due to the plate current 15 through the relay windings 16 and 17, respectively, predominate and this in turn is a function of the charge

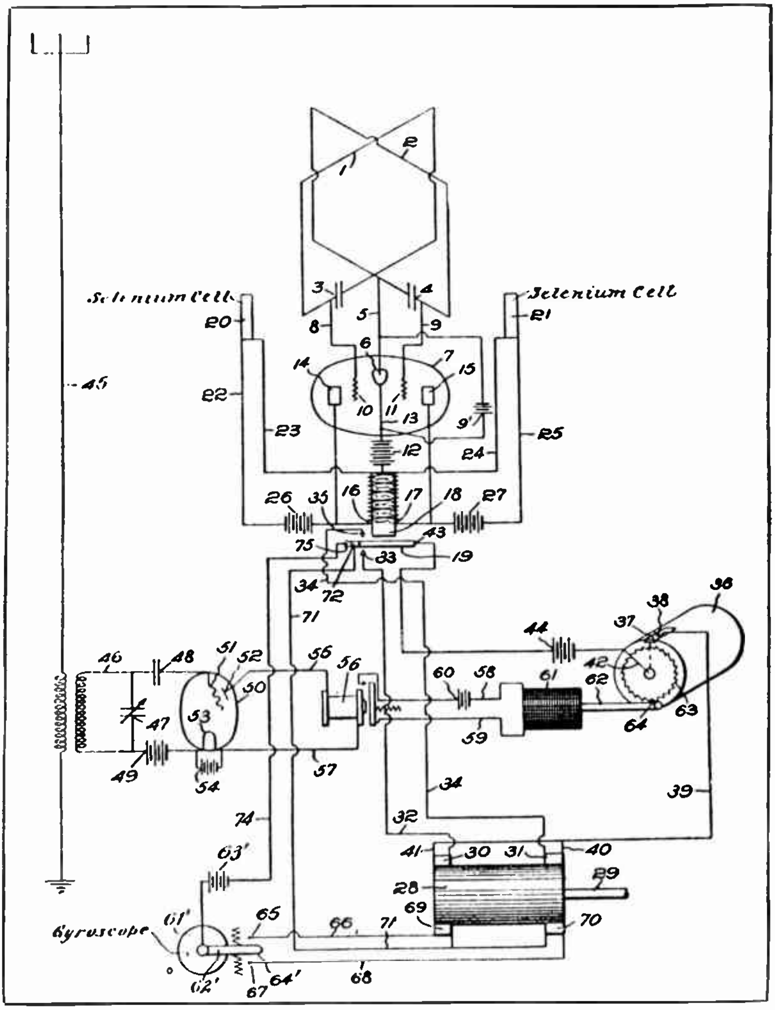

Fig. 3—Schematic wiring diagram showing circuits used for distance control of a ship at sea.

of the respective grids due to the energy in the condensers 3 and 4 which in turn is a direct function of the relative position of the loop with respect to the sending station's antenna.

With this brief explanation as to how the movement of the armature 19 is controlled by means of the radio-frequency energy from the transmitting station, let us assume that the energy comes in such a direction that the armature is pulled towards the relay core causing 19 to make contact with 35. When this takes place, a circuit may be traced from the battery 44 to the armature 19 through the contact 35, through the conductor 34 to the valve mechanism 31 through the conductors 40 and 39 to the brush 38, through the contact 37 and conductor 42 to the negative side of the battery 44. The completion of the circuit just traced operates the valve mechanism 31 which admits compressed air to one end of the cylinder 28 and exhausts it from the other end. Within this cylinder there is a piston 29 which is attached to the rudder of the ship, thus the movement of the ship's rudder is affected, and the amount of movement of the latter depends on the amount of compressed air that is admitted to one end of the cylinder and this in turn depends upon the length of time that the armature 19 remains on contact 35 which in turn is a function of the position of the loop relative to the transmitting antenna.

Let us say, that this movement of the rudder changes the course of the ship to such an extent that the other loop picks up more energy and the armature 19 is pulled downward, closing the contact 33. The closing of this contact completes a circuit from the battery 44 in the same manner as the circuit traced through above, but this time it passes through the valve mechanism 30 which admits compressed air to the opposite end of the cylinder 28 and exhausts it from the end to which it was admitted in the previous case. This means that the piston 29 will now move in a direction opposite to that in which it moved before and the rudder of the ship will also move in the opposite direction and the course of the ship will again be changed. If the ship is moving in a direction such that it receives an equal amount of radio-frequency energy in each of the loops, the armature 19 will remain in a neutral position, touching neither contact 35 nor 33, and the rudder of the ship will remain unchanged, hence, the course of the ship will also remain unchanged.

The selenium cells 20 and 21 function the same (where light is the radiant energy used for control) as the loops function, where radio is an agent or control. The output circuit of cell 20 is completed through the battery 26 and the differential relay winding 16 and the output circuit of cell 21 is completed through the battery 27 and the differential winding 17. Hence, at night.

if the beam from a powerful searchlight were turned on the ship, the armature 19 would move either up or down depending upon which cell received the greatest amount of light, and it follows that the ship's rudder would in turn be controlled by this movement of the armature 19.

If it so happened that the control operator wished to release control of the ship, he could send out a radio-frequency signal on a predetermined wave-length on an auxiliary transmitter. This signal being picked up by the antenna system 45 and subsequently induced in the closed circuit tuned by the condenser 47 and applied to the grid of tube 50 would cause a corresponding change in the current to the plate of the tube sufficient to operate the relay 56. It should not be assumed that there is only one tube used between the antenna system 45 and the relay 56 because this is not necessarily correct. We are simply endeavoring to make the basic principles of this system clear and in so doing have shown only one tube, 50, between the antenna system 45 and the relay 56. However, there might be half a dozen tubes used, depending upon how great a degree of sensitivity was desired. For instance, say there is a modulated wave sent out from the transmitting antenna. Let us assume that this modulation is affected by superimposing a 1000-cycle audio-frequency on the radio-frequency carrier wave. If the vacuum tube (50) were used as a detector tube, there would be a minute alternating current, having a frequency of 1000 cycles in the detector output circuit. This 1000-cycle alternating current would be amplified through several stages of audio-frequency amplification and the last stage of this amplifier could be coupled to a rectifier stage which would function to change the alternating current (1000 cycles) applied to its input circuit, into a direct current, the latter appearing in the output circuit of the rectifier tube and being applied to the windings of the relay 56. There could be a couple of stages of radio-frequency amplification, a detector and three stages of audio-frequency amplification if necessary.

Now let us summarize. If the key of the auxiliary transmitter were pressed down, three times, there would be three trains of radio-frequency waves sent into the ether, modulated at 1000 cycles. This radio-frequency energy would be picked up by the antenna system 45, induced into the closed circuit tuned by the condenser 47, detected, amplified and rectified and the pressing of the transmitter key three times would be manifested in the receiver rectifier output circuit by three pulses of direct current which would energize the relay 56 three times, thus drawing its armature over a like number of times. This last action would cause the closing of the circuit through the windings of the relay 61, having a core, adapted to impart step by step rotations to the commutator 36 by means of the ratchet 63 and the pawl 64 arrangement.

This movement of the commutator 36 would open the circuit closed by the brush 38 and contact 37 which would immediately prevent any action on the rudder to the movement of the armature 19, the latter being controlled by either radio or light by means of the two loops and the two selenium cells. This would mean that the direction of the ship could no longer be controlled by either radio or light and would continue on a course controlled by the gyroscope 61′, this course having been previously determined. This gyroscope would continue to control the course of the ship until such time as the proper number of dashes were sent out by the auxiliary transmitter. This would cause the commutator 36 to be rotated into such a position that the brush 38 and the contact 37 again make contact thus allowing the ship's course to be controlled by either radio waves picked up from the two loops, or light rays intercepted by the two selenium cells.

It should be noted that the control by the gyroscope can only be effected when the armature 19 of the differential relay is in a neutral position. As has been stated before, one time, that this will occur, is when radio and light controls are released by the sending of the proper number of dashes on the auxiliary transmitter. When this happens (the armature 19 in neutral position) there will be a circuit closed by the end of the armature 72 making contact with 75. The armature 72 is a part of the armature 19 but is insulated from the latter. When 72 and 75 make contact there is a circuit that can be traced from the positive terminal of the battery 63′, through the conducting arm of the gyroscope 62′ and out through either terminal 65 or 67. Let us say that the conducting arm is in such a position, due to the operation of the gyroscopic compass, that the conducting arm makes the contact with 65. The circuit is traced from this point through the lead 66 to the valve mechanism 69 which functions the same as the valve mechanism 30. Continuing with the circuit, it is traced from the valve mechanism 69 through the lead 71, the end of the armature 72, the contact 75, and back to the negative side of the battery 63′.

If the conducting armature of the gyroscope 62′ is in the opposite direction, it will make contact with terminal 67 and the battery current will pass through the valve mechanism 70 which functions the same as the valve mechanism 31.

From the foregoing explanation you can see how it is possible to start a torpedo on a predetermined course by means of the gyroscopic control, take control away from the gyroscope by means of the auxiliary transmitter, control the movement of the torpedo by radio, allow the torpedo to be controlled by light so that it would then tend to move in the direction of an enemy ship, should the searchlight from the latter be played on the torpedo.

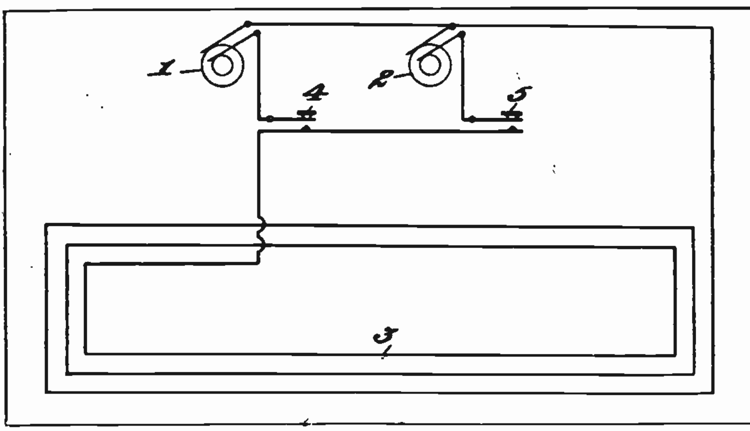

Fig. 4—Fundamental principle upon which the Hanson system of control operates

THE HANSON SYSTEM

The Hanson System of distant control makes use of the generation of different frequencies so as to manipulate the controls of the distant object.

Figure 4 shows the fundamental principle upon which this type of control operates. In this figure you will notice two audio frequency alternating current generators 1 and 2; the output of these generators is impressed on the loop 3 by means of suitable controls such as keys 4 and 5. Generator 1 is a 3000-cycle type and generator 2 is a 6000-cycle type. By closing key 4 a 3000-cycle note is impressed upon the antenna 3, while closing key 5 impresses a 6000-cycle note on the loop. Any number of generators may be used with this system to control the distant object.

The arrangement of the receiving apparatus on the craft to be controlled is shown in detail in Figure 5. A loop antenna 6 is used to intercept the passing waves. The output of this loop is connected to the primary winding 7 of a transformer shown and numbered 8. The secondary winding 9 of this transformer is connected to the input circuit of a vacuum tube 10. The output of this vacuum tube is connected to the primary winding 11 of another transformer 12. These transformers 8 and 12 should be of the iron-core type and should respond to the band of frequencies used. The secondary winding 14 of the second transformer is connected to the input circuit of another vacuum tube 15, the plate circuit of which is connected to the electromagnets 16 and 17. These magnets are provided with tuned reeds 18 and 19 which are adapted to be operated selectively by the energy sent out by the transmitter shown in Figure 4.

The battery 21 is connected to the reeds 18, 19 at the point 18-A and 19-A. It will be noticed that this battery furnishes current through the winding of the electromagnets 22 and 23.

If the operator at the transmitting station closes the key 4, for example, the 3000-cycle generator 1 will transmit radio energy which can be intercepted by the loop antenna 6 of the receiving set, and the receiving energy will be amplified by the vacuum tube amplifier and will cause the reed 19 adjusted to respond to 3000 cycles, to vibrate, which will cause the contact 25 to be broken, thereby releasing the armature 29 of the electromagnet 23. This operation permits the contact 30 and the armature 29 to be closed, thus energizing a power relay 27, which permits current from a battery 33 to energize the motor 32 in such a manner as to cause the shaft 34 to rotate. The shaft 34 as shown is provided with a bevel pinion 35 which meshes with the secondary rack 36, which is connected by a bar pivoted at 37 and supports the rudder 38. Rotation of the shaft 34 which follows the energizing of the magnet 23 in the manner above described will be in such a direction as to cause the rudder 38 to move in a given direction, thereby controlling the course of the craft. The extent of the turning movement of the craft will depend upon the amount of rotation that the shaft 34 makes before its rotative movement is arrested by the release of the control key 4 at the transmitter.

If the operator at the transmitter desires to reverse the direction in which the craft is turning, he releases the key 4 and presses the control key 5. The loop antenna of the transmitter will then be energized by the 6000-cycle generator 2. This fre-

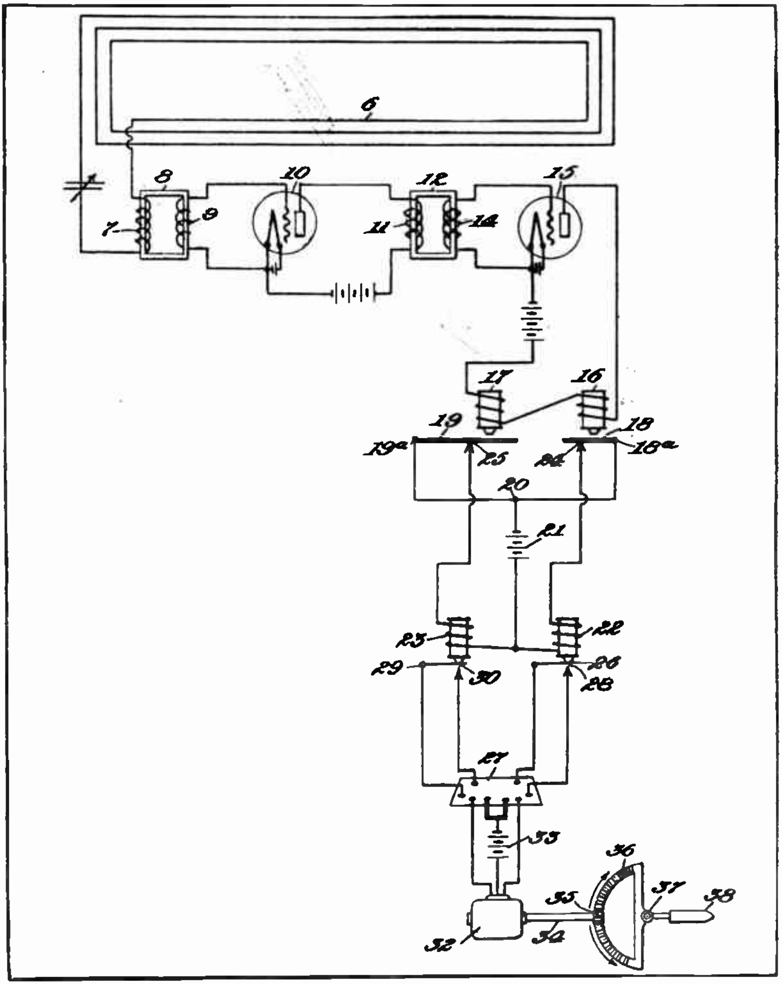

Fig. 5—Wiring diagram of receiving apparatus used on the craft to be controlled

quency will in turn be impressed upon the receiving loop and the signal will be passed through the vacuum tube amplifier. This 6000-cycle frequency in passing through the electromagnet 16 will cause the reed 18 to be actuated and in turn so control the relay 27 as to cause the shaft 34 of the motor 32 to rotate in a direction opposite to its direction of rotation which followed the closing of key 4. This will reversely operate the secondary rack 36 causing the rudder 38 to move in a direction opposite to that which was caused by closing the control key 4.

Figure 6 represents a torpedo carrying the receiving apparatus. The receiving loop antenna is shown at 6 with the lead passing through an insulator 40 and connecting to the winding of the input transformer 8 just as shown in Figure 5. The torpedo 39 may be constructed so as to enable the loop antenna to be arranged in a groove in order to preserve the stream-line effect of the torpedo.

Figure 7 shows a schematic view of how the transmitter is mounted on an airplane. The alternating current generators 1 and 2 are mounted on the airplane so as to be driven by small propellers. The loop 3 is mounted underneath the lower surface in such a manner as to cause the least wind resistance possible. The control keys 4 and 5 are mounted close to the operator so

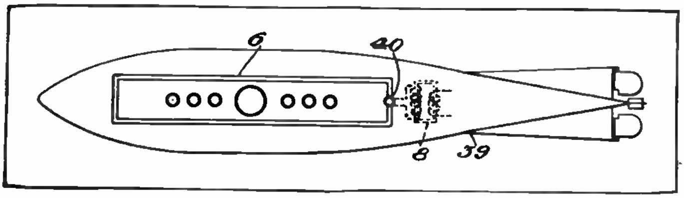

Fig. 6—A torpedo in which is installed the receiving apparatus

that they are easily within his reach and can be operated quickly.

It is not absolutely necessary that the transmitting apparatus be mounted on an airplane, but in this way it is possible for an observer to follow the controlled craft and observe closely its movement. This system is primarily designed to be used in controlling the movement of ships and torpedoes from airplanes, however, it can be adapted to other uses.

Neither is it necessary to use the frequencies mentioned in this description as the alternating current generators may be replaced by vacuum tube generators and frequencies much higher may be used. By using higher frequencies the range will be increased considerably and the size of several pieces of apparatus will be reduced accordingly. However, it must be taken into consideration that the frequencies cannot be increased too high on account of the fact that it will be impossible to use mechanical reeds for selecting the various frequencies such as is done in the scheme shown in Figure 5. There is a limit to the frequency at which mechanical reeds can vibrate and if the frequency is increased beyond this point it will be necessary to use other means of selecting the received frequencies.

U. S. NAVY TESTS OF DISTANT CONTROL

The U. S. Navy Department in conjunction with Hammond engineers conducted some very interesting tests in regard to distant control of battleships. The transmitting and control apparatus was placed on the U. S. S. Ohio and the U. S. S. Iowa was fitted out and equipped so as to be controlled entirely by radio signals sent out by the U. S. S. Ohio.

Some very unique features were developed during these tests which have important bearings upon distant control. The tests covered a period of several months and it was found that it was

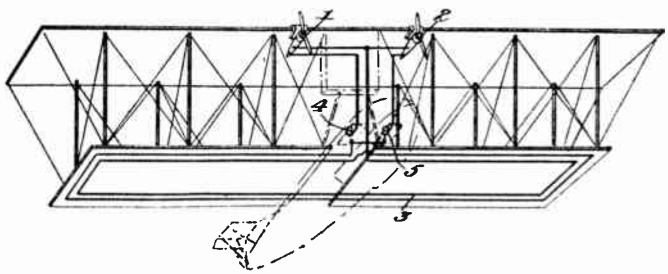

Fig. 7—Schematic view of how the transmitter is mounted on an airplane

possible to completely control a battleship entirely by signals sent out from another ship. The ship was started and stopped at will and caused to take a given course and continue in this course or change its course whenever desired. Guns were fired and various other duties performed just as if it were manually controlled.

The main object of these tests was to determine whether radio control was possible and just how much interference would be experienced and how serious this interference would be in the control of the ship. The greatest amount of interference was encountered due to static. The system of control depended upon the length of the dashes sent and the combination of dots and dashes to perform the various actions of controlling the ship. Therefore, with this in view, any outside or extraneous noises impressed on the output of the receiving apparatus would have a very serious effect upon the control of the ship. This was overcome to a certain extent by using a submerged trailing antenna. This trailing antenna was a lead-covered high-tension cable and completely insulated from the water and suspended some 2 or 3 feet below the surface of the water. By the use of this antenna a certain amount of the strays and static interference was overcome and control could be accomplished in a much more satisfactory manner.

By using these antennas, the danger of having them shot away by gun fire or bombs was obviated to a certain extent. However, it was thought advisable to use more than one antenna so as to lessen this chance of having the antenna destroyed. The apparatus used was very similar to some of the other systems used by Hammond and covered by his patents. All of the data regarding these tests is not obtainable for publication, however, the general lay-out and the general principle is herewith described.

The receiving apparatus consisted of six stages of tuned radio-frequency together with the usual detector and two stages of audio-frequency amplification. The wave-length used in transmitting these signals was in the neighborhood of 1500 to 2000 meters. Figure 8 shows a view of the receiving equipment. The output of the audio-frequency amplifier is connected to a polarized relay. This relay can be seen in the right-hand portion of Figure 8. The output of this relay is then connected to several time relays which are actuated by the length of the signal and the combination of the dots and dashes received. These relays select the signal which is then sent to a commutator as shown in Figure 9. The function of this commutator is to make such connections and control a greater amount of power. As shown in this figure, there are six different controls and circuits and when a signal is received it passes through the receiving equipment, through the relays which select the signal and pass it to this commutator. This commutator is then placed in a position so that the springs on the right-hand side and left-hand side make contact through the cams. As this current is very much greater than the received current, it is used to control the various motors for steering, starting and stopping, and other controls necessary.

Figure 10 shows a view of the complete cabinet in which the receiving equipment was located. You will note that springs were used so as to damp the vibrations present. This was found necessary in order to prevent the jarring of the receiving equipment by gun-fire and other vibrations present in the receiving set. This cabinet was located in the lower part of the ship so as to protect it as much as possible from gun-fire as well as to give it a more stable construction. The whole cabinet was suspended

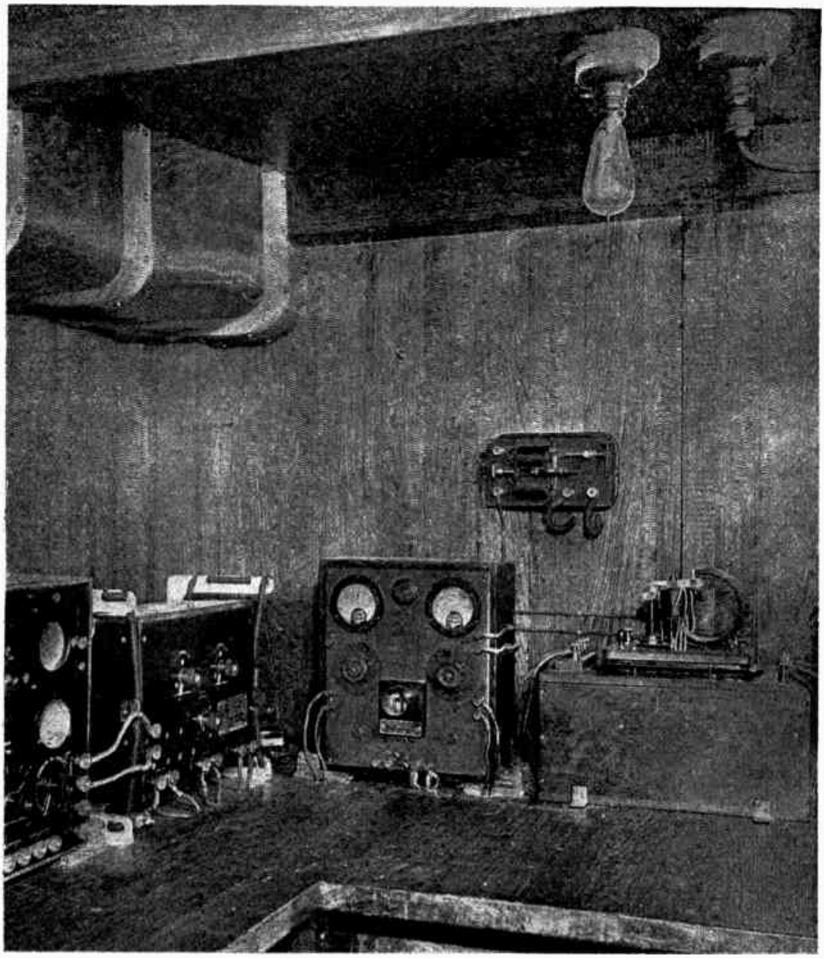

Fig. 8—View of the receiving apparatus installed on the U. S. S. Iowa

from the steel girders by means of the springs and you will note the springs are also attached to the bottom of the cabinet and on all sides so as to make this as near shock-proof as possible.

It was found that it was possible to completely control the U. S. S. Iowa from a ship located as far as 200 or 300 miles distant. However, in most cases, the controlling ship, U. S. S.

Ohio, was located much closer than this. The speed of the propelling motors could be reduced in less than one minute, but in most cases it was possible to make all other adjustments and controls within less time or within a corresponding time according to the operations performed. The speed used in most of these tests was in the neighborhood of 10 or 12 knots per hour

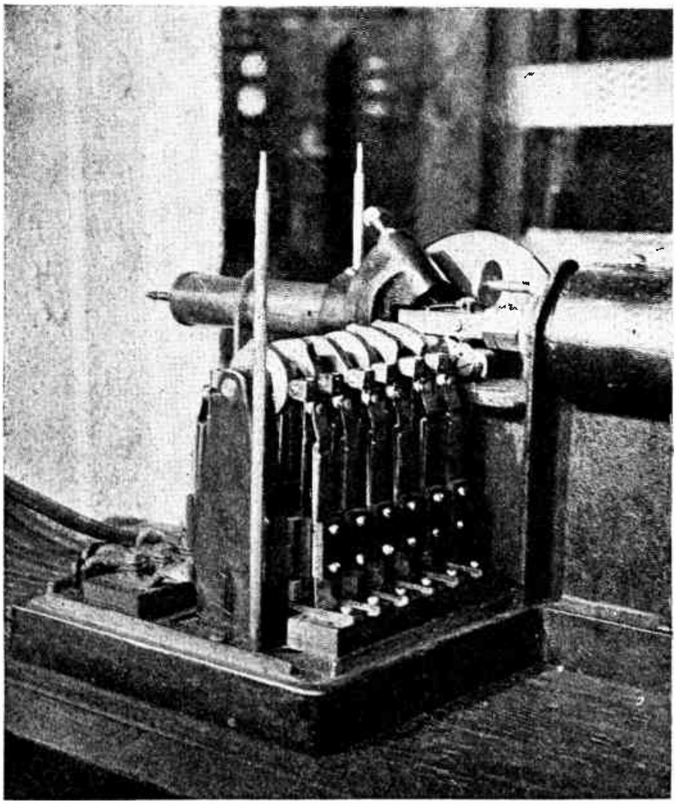

Fig. 9—Photo of the commutator described in the text

and it was found that with this speed it was possible for the U. S. S. Ohio to completely circle the U. S. S. Iowa and at the same time maintain complete control over it.

As a result of these tests it was found possible to completely control the movement as well as the other actions required of a battleship. However, static and strays would undoubtedly cause serious interference and hamper the control. For controlling moving targets, radio control was feasible and practical and the interference caused by static and strays was not so serious as to render the system unreliable and impracticable. With the perfection of apparatus more suitable for this purpose, distant control will be much more satisfactory and applicable for use in the Navy.

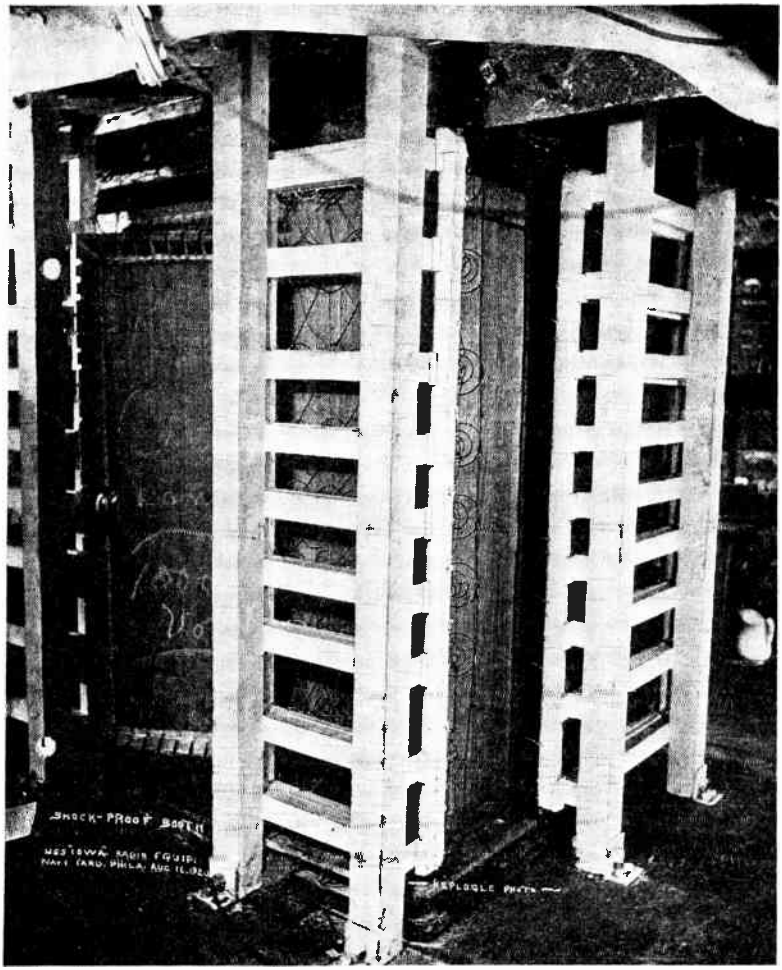

Fig. 10—View of the complete cabinet, installed on the U. S. S. Iowa, in which the receiving apparatus was placed.

A RADIO-CONTROLLED AUTOMOBILE

Figure 11 shows a view of a radio-controlled car together with the controlling mechanism installed on same. The principle used in controlling this car was dependent upon the length of the dots and dashes used or the combination of these dots and dashes sent out by the transmitter. For instance, the letter R, dot-dash-dot, was assigned to the operation of starting the car in reverse, while A, dot-dash, would start it ahead. To stop the car and release all controls, a single dot was transmitted, which would release all the controls and shut off the driving motor current.

The car was thus in complete control at all times. The selection of any operation was accomplished within one second or less, and any operation could be stopped almost instantaneously.

The actual controlling mechanism consisted of 15 relays of the type used in telephone plants, mounted on a small framework such as shown in Figure 12. The wiring was tied together in cable fashion back of the frame and external connections were made by a center binding post at the top of the frame. Any type of radio receiver may be used with this unit provided it has sufficient variation in the plate current of the last tube to operate and release the sensitive relay. The "output" of the selector consists of 11 control wires, leading to the various pieces of apparatus to be controlled such as steering magnets, lights, etc. Each wire corresponds to a code letter. When a letter is received by the radio receiver it "sets up" the relays in such a combination as to connect the corresponding control wire to ground. The operating battery for the control magnets or lights being grounded on one side, this section supplies current over the control wire to the piece of apparatus selected, and it begins to operate.

Then when it is desired to stop the apparatus a single dot is transmitted. This releases all the relays and returns everything to normal, awaiting the next call. The selector relays remain operative, or rather, "locked," as long as any piece of apparatus is in use. This means that only one circuit may be used at once. Consequently the car could not be steered (for example) while it was in motion. To overcome this difficulty, a driving motor relay was built, which could operate in either of two directions, one of them sending the car forward and the other sending it backward. In either position a little latch would drop and hold the contacts in that position. There was a third operating magnet which was arranged to lift the latch and allow the relay to return to a normal position, stopping the motor. In that way it was possible to have the selector free for steering, blowing the horn, etc., while the car was running either way. A code letter for stopping would, when transmitted, ground the lead to the latch-lifting magnet and open the circuit.

Power to operate the relays was supplied from a 22½-volt radio "B" battery. Surprising as it may seem, one battery will furnish enough energy to operate the selector over 2000 calls. This is due to the fact that the relays are highly efficient, most

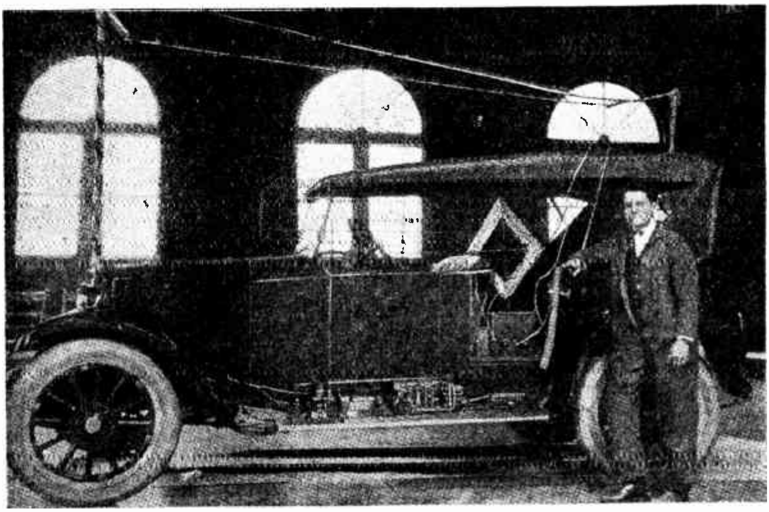

Fig. 11—The radio-controlled automobile equipped with the apparatus described

of them requiring only a few hundredths of an ampere to operate, and to the fact that the selector is not tied up while the driving motor is running.

Figure 13 shows details of the schematic wiring diagram. A relay is shown as a magnet with pivoted armatures at either end, each armature having one or two contacts associated with it. When current flows through the winding the magnet is energized and these armatures are drawn toward it, making those contacts which are shown open and breaking those shown closed. The relays designated CI and S are marked "SR" on the core. This means that they are built to operate quickly, but will not release until about one-third of a second after the current in the winding has been cut off. Most of the relays are supplied with "locking circuits." That is, when they are operated, by any means, they close another operating, or locking, circuit through one of their own make contacts; they remain operated, or locked, after the original operating force is removed. The battery supply is shown as follows: To every point shown grounded is connected the positive side of the battery, which is grounded, and to every point where a battery and ground are shown is connected the negative side of the battery. This convention merely simplifies the diagram.

The relays A, B and C really do the selecting. It will be noticed that, starting at the right-hand armature of A, it is possible to follow eight different paths to control leads, depending upon the combination of relays operated or released. In

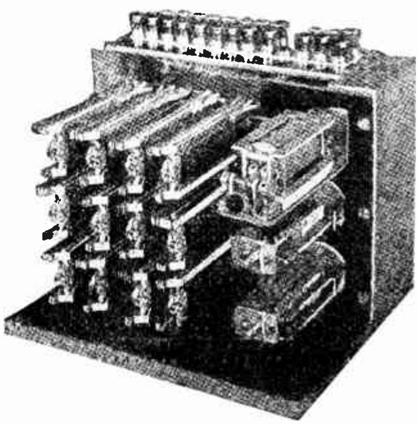

Fig. 12—The bank of relays used to control the different parts of the automobile

order to operate any desired combination of relays we arrange the code signal with the three impulses (dots and dashes) corresponding to the three relays, A, B, and C, in order. If we want A operated, B released and C operated, we send dash-dot-dash.

The relays 1, 2, 3, 1′, 2′ and 3′ operate as follows: The beginning of the first pulse operates 1′, the end of the first pulse 1, the beginning of the second pulse, 2′, and so on. Each relay remains locked after it operates. Note that this action connects a lead from the right "make" contact of the relay S-1 to the windings of A during the first pulse, B during the second pulse, and C during the third. If a given pulse is a dash, the S-1 relay, with the S will have time to operate so as to place a ground on the lead mentioned above, so as to operate the corresponding A, B or C relay. This and a little study should make clear the process of selection. The CI relay, of the slow-release type, is energized with each pulse, but does not have time to release between pulses. Its release after the signal is complete closes ground from its right armature and contact to the circuit, which has been selected. The **R-N** or "return to normal" relay operates when a pulse is received and the relays have been set up for a call long enough for the CI or "cut-in" relay to release. When **R-N** operates, it opens the circuit to ground which has been holding the selecting relays locked. The relays A, B, C and 1′, 2′, 3′ in a

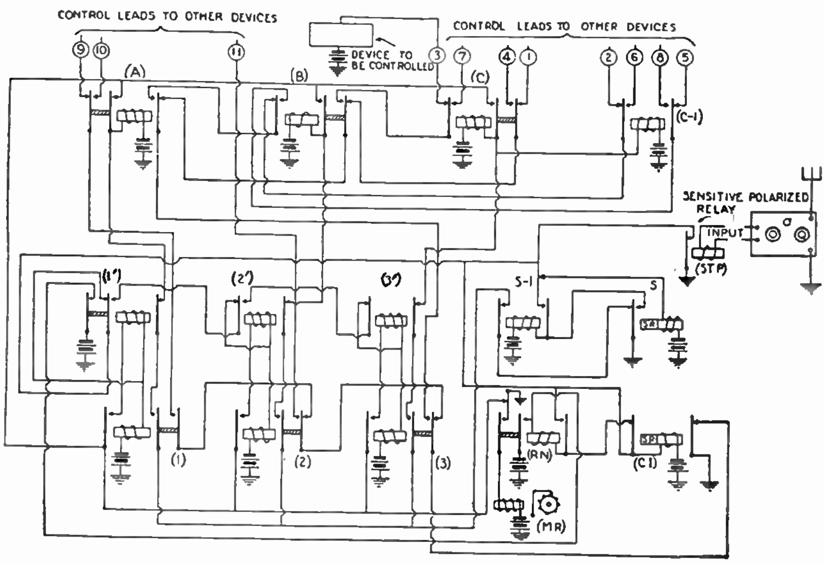

Fig. 13—The circuit diagram of the equipment used to operate the automobile

moment break contact on **R-N**. The STP relay is a sensitive polarized stepping relay, which operates from the radio receiver output. It furnishes ground pulses from its make contact to operate the numbered relays, the CI relay and so on.

Although the process of selecting an operation seems to be very complicated, the relays operate quickly and surely, if the dots and dashes are of the right length, however, if these dots and dashes are not of the right length and evenly spaced, the relays may fail to select the correct circuit. By adjusting the S and CI relays, the circuit may be adapted to high or lower speed accordingly. By connecting an electrical counting device, indicated by MR on the diagram, in this circuit, the number of calls handled by the selector is known at all times.

THE RADIO-CONTROLLED AIRPLANE

The question of making an airplane entirely automatic and radio-controlled, and to replace the skill of the pilot by mechanical devices, is one of the most difficult to solve. The piloting of an airplane may be learned in a few days. The necessary skill, however, is only acquired after many flights and it is a profession which calls mostly for the sporting qualities of an individual. The innumerable factors which must be contended with by the reflex actions of the pilot necessitates the use of such mechanism presenting extreme flexibilities in order to compare with the human control of an airplane which meet with so many varying conditions while in flight.

If it were possible to connect the airplane with a controlling station by means of a cable, the problem would be comparatively simple. Such a solution was employed during the year 1921, where an electrically controlled airplane flew, followed by another one in which were the pilot and the controlling operator, the two planes being connected with a cable. This, however, only displaced the question, since it was necessary to have a pilot in the second plane. Furthermore, this method is not very practical, nor flexible and presents some danger for the controlling airplane. The only practical means of connection to be employed between the automatic airplane and the ground is, therefore, radio. However, on account of the small amount of energy which it is possible to transmit to the craft, it is necessary to use sensitive devices with receiving apparatus, as well as selective circuits to eliminate the possibility of the airplane being accidentally controlled by signals from another source, or atmospheric disturbances.

The first big problem to be solved in controlling an airplane by radio was that of the automatic stabilization of the craft. Since the beginning of aviation, many devices have been proposed to diminish the risk of human control. Among these may be mentioned the Aero-Dynamic Rudder, the Sperry Gyroscopic Stabilizer, the Aveline Mercury Stabilizer, and many others, but none of them gave all the desired results, and for this reason were abandoned.

The problem of automatic stabilization, in fact, is very complex for an airplane in flight tends to take three different rotary motions around three rectangular axes, and three motions of translation along these axes. It is necessary, when the airplane has to fly along a given line, to follow within five or six degrees of possible variation. For this reason it would be necessary to install five different stabilizers on account of the difficulty which is found in designing mechanism having more than one degree of variation. However, it was found possible to limit to three the number of necessary stabilizers. An airplane properly balanced tends, as a boat, to come back to its position of equilibrium if it does not list too far on either side, and thanks to this property, it was found possible to absolutely control and compensate for the variations encountered in flight. To obtain

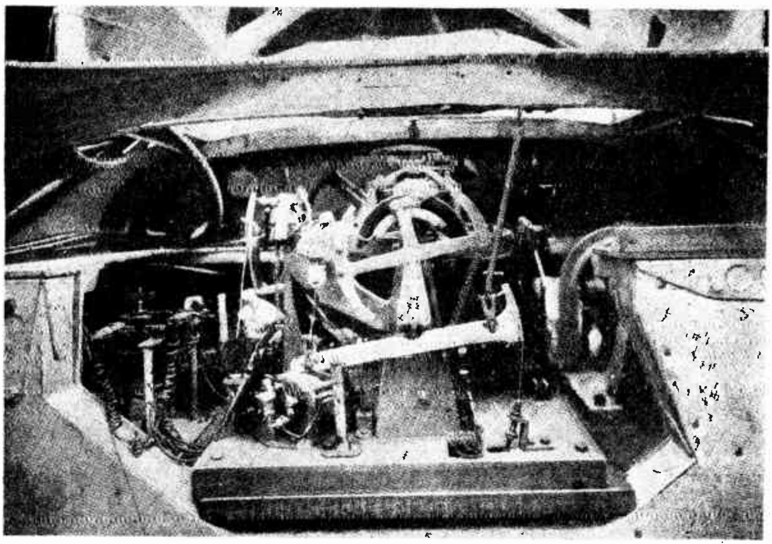

Fig. 14—The gyroscopic stabilizing apparatus shown here takes the place of a pilot and automatically keeps the plane in the proper position while in flight.

the absolute control of the craft the stabilizers must be able to operate some compensating forces capable of bringing it back into the correct position and stop these forces before it has reached it in order to prevent the undesirable oscillating motion. Six organs must, in principle, constitute a stabilizer for automatic airplanes:

First, a fixed point connected to the airplane itself.

Second, another point fixed to a given unvariable plane, which may be at a given angle, so as to stabilize the plane in relation to the air currents.

Third, several controlled motors acting upon the various organs of the control.

Fourth, an inertia compensator preventing the reactions of the fixed point which must be unvariable. It is well known that a pendulum, moved in space, for instance, may be subject to acceleration when changing its period and not indicate the vertical line. This is why its use, as well as that of similar devices, is prohibited on board an airplane.

Fifth, a controlling organ connecting the fixed point to the movable one so that the action of stabilization may stop before the normal position is again reached.

Sixth, a controlling device to prevent the reaction of the air upon the controlling organ to impress the controlling apparatus.

Of course, these six controls must function perfectly and independently, no matter how great the disturbances impressed upon the airplane. This gives an idea of how complicated the first condition of automatic control is, for in practice every one of the organs must be carefully adjusted, and this requires a great amount of work.

The type of automatic stabilizer most commonly used in airplane radio control is shown in Figure 14. It is a form of the Sperry Gyroscope modified so as to make it fit for this particular purpose. It consists of a disc of small weight but turning at a very rapid speed (15,000 to 18,000 revolutions); it has considerable inertia and among other properties tends to remain always in its rotating plane. One of the most detrimental properties of the gyroscope when used in aviation control is the tendency which it has to move perpendicularly to its plane of rotation when it is displaced from this plane. Thus, the gyroscopic effect must be compensated for by another gyroscope rotating in the opposite direction and playing the role of the fourth organ mentioned previously, the inertia compensator. For properly balancing and distantly controlling an airplane, it must be equipped with two gyroscopes coupled together and rotating in opposite directions so as to control the upward and downward flights, another one for the lateral equilibrium and a third to control the direction. These systems of gyroscopes are equipped with a fixed sector upon which a brush contact is made and moves when the airplane is unbalanced in one plane or the other. These establish electric contacts which by means of electric motors, such as shown in Figure 15, control the action of the rudder and wings.

The flexibility of this type of control is such that the airplane thus controlled may fly in strong winds and always come back to the normal position when it is deviated from one plane or the other. In order to start the airplane from the ground and control its flight it is necessary to suppress the action of the automatic stabilizers. It is at this point that radio control is employed to change the ratio of the gears controlling the various stabilizers. This is accomplished by a mechanism somewhat similar to the transmission of an automobile. For quick action the movement of the brushes sliding upon the sectors may be stopped and the former kept in a fixed position so as to make the airplane go up or down or turn quickly, the speed being regulated by the transmission arrangement method above. All

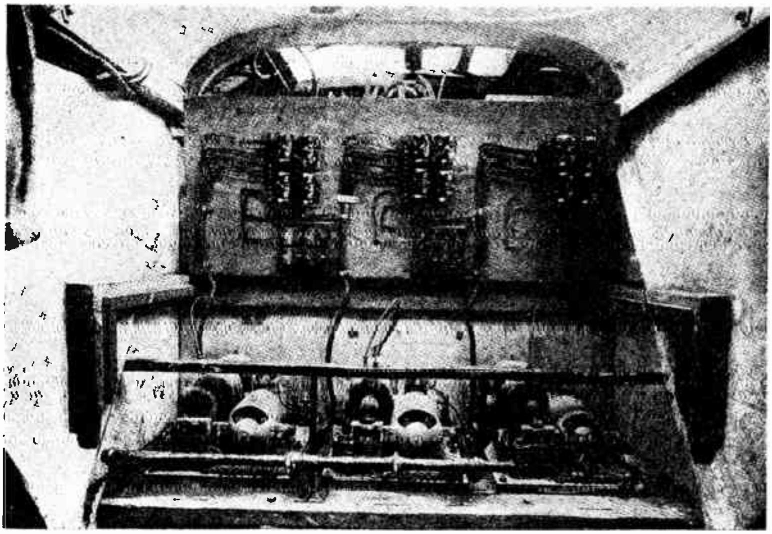

Fig. 15—The electric motors operating the various organs of the plane

these controls are assembled on a panel and are operated by a series of relays connected to the radio receiver. Once a control has been set in a certain position, it remains so until it is opened by radio signals, thus if the airplane is put in such a position, so as to fly around, it will do so until the proper control is operated to change its course.

In this system of radio control, a special modulated wave was employed with a very low-frequency amplifier which was designed especially to amplify the sub-audible modulation permitting the controls to be operated only at the will of the operator. By means of the special chopping system this sub-audible modulation may be interrupted to form signals which operate the distributor and selector systems connected after the amplifying device. The distributor consists of a cylinder upon which are cut slots corresponding to the various controls; a series of blades may fall in each one of these slots as the cylinder is rotated at a fraction of a turn at a time. This establishes contact with a local control circuit through a relay which delays the action; hence from one-tenth of a second to one second elapses before the control is operated.

The controls on board the airplane not only operate the various controls of the engine but also move the brushes on the gyroscopic system so as to cause the airplane to respond to the commands of the operator, who is able to direct it and vary the speed according to the necessity of flying conditions. The efficiency and flexibility of this radio-control system was proven by a number of tests. Five tests had to be passed, consisting of flights of 15 minutes at various altitudes, several turns to the right and left, landings and flights at 1500 ft. and 3000 ft. In the last test the aircraft had to effect a spiral landing of 1000 ft. in diameter from an altitude of 3000 ft. which it accomplished perfectly. These tests present considerable interest, for they show that the automatic radio-controlled airplane is practical and may be developed to such a degree of perfection that it will be possible in the near future to use it for commercial purposes. It could be sent up, directed toward a certain city and taken down by means of another radio station, installed on the landing field, which would take over the control of the plane upon its arrival within the radius of the controlling station, the plane flying by itself between the two aerodromes.

All the apparatus previously described are applicable in controlling the largest sizes of aircraft, thus the pilot, not having to worry about the control of the airplane, will be able to keep in touch with the ground and other aircraft by means of radio and to closely follow his route by checking its position on the map. This system will also permit the use of pilotless airplanes for the transportation of cargo and meteorological observations at high altitudes. In this case recording apparatus equipped with electric contacts would control various mechanisms which it is necessary to operate when reaching high altitudes. This control might also be operated by means of clocks since the speed of the airplane is known and also the angle at which it goes up. These methods of control are only practical within a short radius.

or for a limited number of operations; as soon as the airplane has to fly over great distances and through a great many varying conditions, the controls must be more flexible and radio is then employed to operate, on board, the controlling devices.

TEST QUESTIONS

Number your answers 47 and add your **Student Number.**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Who invented the "electric dog?"
2. How large a potential is necessary for the satisfactory action of the potassium cell?
3. Draw a diagram illustrating the fundamental principle upon which the Hanson system of control operates.
4. How may the frequencies be obtained in the Hanson control system?
5. What kind of an antenna was used in the U. S. Navy tests to overcome static?
6. What kind of a receiver was used in the Navy tests of radio control?
7. Where was the receiver placed in the radio-controlled battleship?
8. What was the speed of the ships used in testing the radio-controlled battleship?
9. How many relays were used in the radio-controlled auto described in this text-book?
10. Why is it necessary for the receiver used on a radio-controlled airplane to be very selective?

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PUBLIC ADDRESS SYSTEMS

Every new improvement which science provides for overcoming the age-old obstacle of distance gives another great impetus to man's knowledge and to the advance of civilization. Just as the printing press has extended learning throughout the world, as the railroad and the automobile have broadened our vision and the extent of our acquaintanceships, so Radio has brought us all into direct and personal contact with one another. The recent development of public address amplification adds still another link to the chain of modern communication—by making available to a multitude the same personalized message which heretofore could be grasped only by an individual or small collective group.

Ever since man first came into being, his steady striving has been to increase his own effectiveness. His progress has been tightly tied up with his ability to address, impress, and convert or educate, his fellowman to each new idea. Governments, whole civilizations, schools of culture and philosophy, the very civilization in which we live today, are all tightly and indissolubly bound up with the rapid and effective dissemination of ideas.

Three thousand years ago one man could address just as many other men at one time as he could at the beginning of the twentieth century—not a single forward stride had been made during three thousand or more years towards increasing the effectiveness of personal address—unless, possibly, the megaphone may be classed as a modern invention.

In the last few years man has been enabled to reach out and talk to, not paltry hundreds, but literally thousands upon thousands of other men at one and the same time. Radio has made this possible, but, like most machine inventions, has at the same time shorn the speaker of his visible personality.

Today, through public address amplification, a man may talk to, and at the same time bring the full force of his visible, physical personality to bear upon countless thousands of his fellowmen. It is today possible to be brought into the vital, living presence, and hear the unstrained natural voice of a speaker whom a few years ago would have seemed but a straining pygmy, impossible of understanding, far away across the heads of a swaying crowd.

For instance, the minister in some architectural masterpiece of a cathedral or modern church may be preaching his Sunday sermon to an attentive congregation swelled to overflow by those anxious to hear his words. He may be old, possibly have a cold, and his voice, perhaps, is weak, though his message vital and strong. The members of the congregation in the rear pews strain forward to catch his words, while the very nooks and crannies that contribute to the beauty of the church seem to conspire to absorb and deflect his voice. We all know this sensation of straining to catch a word here and there—but how many have ever had this experience after a public address microphone, amplifier and horns have been installed, and the minister's voice comes out full and clear to even the farthermost recesses.

To go to an opposite extreme—a prize fight in a large and crowded hall or stadium. With the big bout of the evening about to start, the announcer draws himself up, expands his chest and shouts an unintelligible series of names successively in four directions to a seething, whistling mass of humanity, only to stagger out of the ring, his lungs exhausted in an effort that conveyed, perhaps, only to his nearest listeners the names of the fighters. Suddenly the public address system is turned on, and in a great voice, clear and natural, the entire audience is told of the next event by a man at the ringside speaking in a low voice, into a small, round microphone. If the crowd yells and howls, up goes the volume of the unstrained voice until every last man has heard the announcement, clearly and distinctly.

Again, at a country fair a prominent citizen makes an important address. It may be heard only by a comparative few of the strolling crowd, many of whom are intent upon the exhibits. In a second, the public address amplifier is turned on, and from loud-speakers all over the fair ground issue the words of the speaker, unstrained, poised, unhurried, and, above all, clear and distinct.

A political stump speaker, traveling from ward to ward of a large city, talks to each group of constituents far into the night. If his car is provided with a public address amplifier, at each stopping point he merely has an extension cord plugged into a nearby lamp socket for power and easily, without fatigue, addresses large crowds through two loud-speakers mounted on

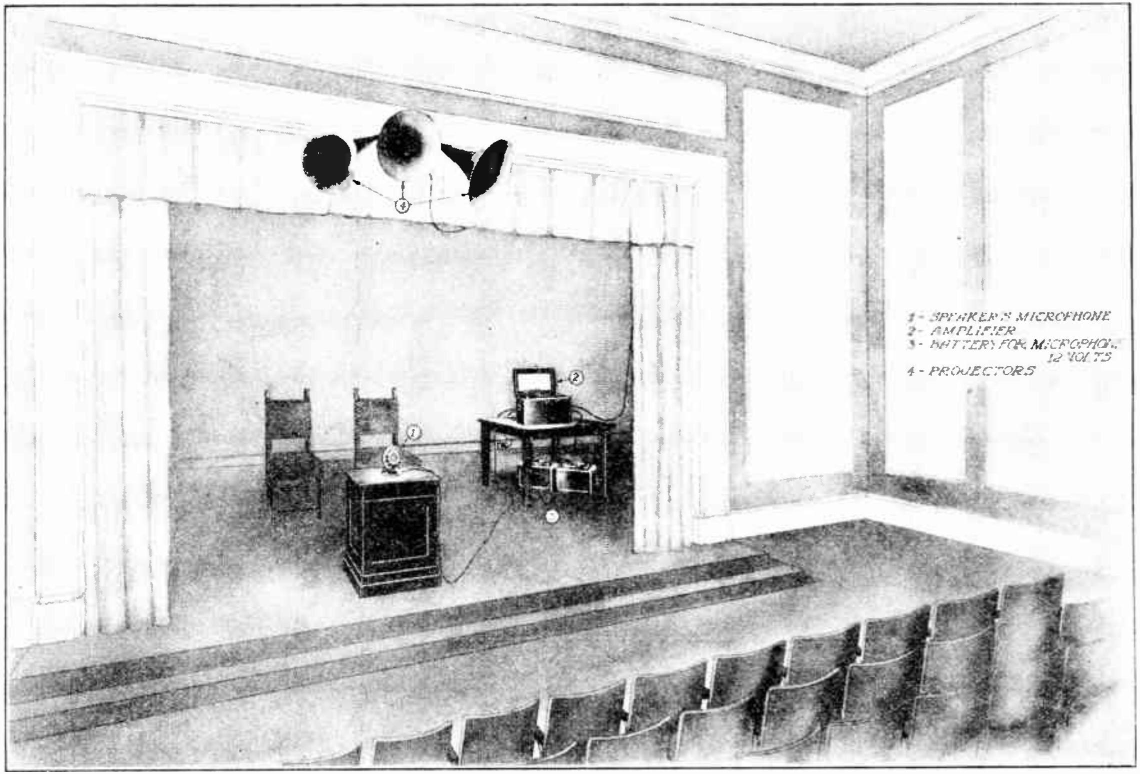

Fig. 1—Typical Public Address System installed in a small hall.

the top of his car—without even having to stand on top of it—and is heard a block away!

The schools of every progressive city and township are arranging to benefit from the Walter Damrosch concerts. Here, public address amplifiers are indispensable, for no single standard radio set is powerful enough to do justice to Walter Damrosch's music in the larger classrooms. The school that installs any good Radio set, augmenting it with an address amplifier, can recreate the Symphony Orchestra's programs at full, natural, undistorted volume, either in the school auditorium, or in from ten to twelve separate classrooms, all at one time.

These illustrations serve to suggest merely a very few examples of forward strides marked by public address amplification. It is hardly necessary to add such applications as factory or office building call systems, hotel and apartment house installations; and picnic, newspaper, athletic field, and a host of similar needs which a public address amplifier can satisfy.

To our children, public address amplification will be as commonplace as the telephone is to us, and the benefits that it will confer need not be withheld a single day. Today no progressive municipality would think of building a school, community center, auditorium, fair ground, or even a hotel, without arranging for suitable amplification, for the benefits it brings are truly marvelous.

Public address systems have within the past few years enabled literally thousands to hear the voice of a speaker. This great feature, like many others, can be classified under some of the various applications of the vacuum tube.

One of the first commercial uses of the vacuum tube as an amplifier was in wire telephony. The losses encountered in the electrical transmission of the voice over a telephone line had limited the usefulness of this invention and the distance that could be covered in such cases. With the advent of the vacuum tube and understanding of its ability to amplify and exactly reproduce electrical impulses, its value in wire telephony was soon recognized. Without going into detail of this application the result was that amplifying stations were distributed along transcontinental telephone lines so that the line losses could be made up by amplifier resulting in the listener being able to hear a speaker's voice at a distant point with the usual clearness and natural volume. This all occurred before broadcasting came into being, or rather was made use of as a public entertainment feature.

Far-sighted research engineers soon conceived the idea that it was entirely plausible to place a microphone before a public speaker or entertainer and to pass the electrical impulses created in the microphone into an amplifier and then reproduce the speaker's words in such a way that it could be heard by a vast audience. Development work was soon started along this line with the result that a speaker was able to be heard by a larger

Fig. 2—Double-button carbon microphone.

audience and in a manner which exactly reproduced his own voice.

As in a previous paragraph, the public address system consists essentially of four separate component parts: first, a microphone upon which sound waves are impressed and converted into electrical impulses varying in frequency according to the frequency of the sound waves impressed on the diaphragm of the microphone. Second, a vacuum tube amplifier consisting of several stages of audio-frequency amplification; the exact number of stages required being determined by the strength of the electrical impulses created in the microphone and the required volume of reproduced sounds. Third, reproducing units which convert the amplified electrical impulses into sound waves. Fourth, the power supply unit which supplies electrical power necessary to operate the microphone, amplifier and reproducing units.

As a further expansion on this subject, let us now go into a detailed study of the various units previously characterized.

THE MICROPHONE

The function of the microphone is to convert the sound waves impressed upon the diaphragm into electrical impulses which vary in frequency exactly as the frequency of the sound waves. Considering the fact that high quality reproduction is desired, a very high class microphone is essential. The usual broadcast or studio type microphone commonly used for radio transmission purposes is usually essential in public address systems.

The broadcast microphone is constructed along lines of research that have been developed during the period of some twenty-five years. Figure 2 shows a view of such a microphone. It is ruggedly built into a steel frame which is machined to shape. The diaphragm is of a special composition steel which is heavily gold plated. Quite a number of screws are used between the steel frames and draw the two sides of the frame together, so as to stretch the diaphragm and pull it into its correct tension. By stretching the diaphragm its tendency to vibrate at its natural period or frequency is decreased, thus avoiding the introduction of unnatural sound and the efficiency is also highly increased. Two electrodes are provided, one on either side of the diaphragm of carbon steel. The cups are of the correct size to contain the carbon and the steel edges of the cups are protected from the diaphragm by felt washers. The maximum movement of the diaphragm is permitted by the proper spacing of the cups from the diaphragm.

Most broadcast microphones will not operate in other than an upright position. The proper protection, in the form of a collar, is provided to eliminate the possibilities of damage to the diaphragm, which is ordinarily occasioned when the microphone is improperly handled. A third, or center leg of the microphone is provided on the edge of the frame, and battery connection is made thereto. There are three connections to this microphone and these connections should go to the input of a proper transformer and battery. This transformer is usually known as a modulating transformer and the schematic connections are shown in Figure 4.

High-grade microphones are constructed so that extraneous noises cause very little fluctuation of the diaphragm. Therefore the speaker or entertainer must be properly placed before the microphone. By stretching the diaphragm and by other means these undesirable noises outside the speaker's voice are eliminated. In so doing the diaphragm does not vibrate as much as in the ordinary telephone microphone, thus the electrical impulses are much weaker and require amplification before they can be reproduced with natural volume. High-grade or broadcast microphones are usually classified as being so many "miles down." This phrase means that the electrical impulses are comparable to electrical impulses which have been sent through a standard

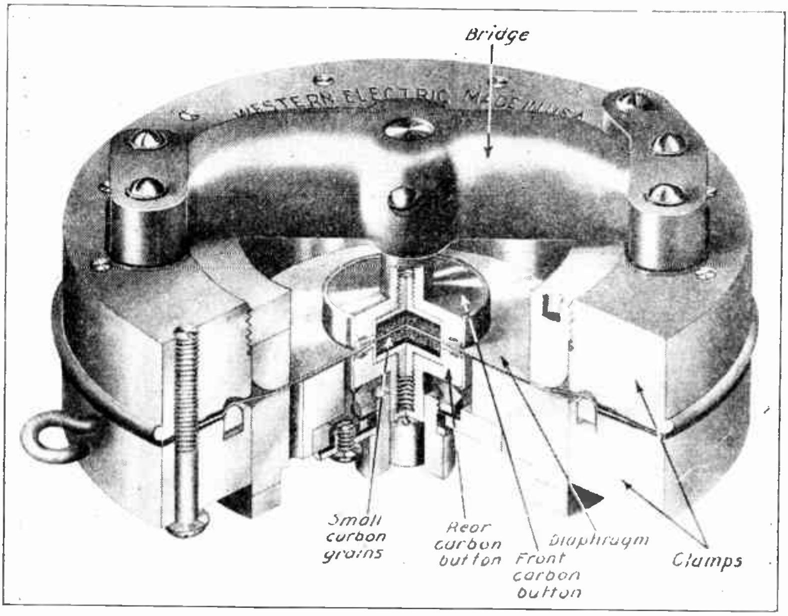

Fig. 3—Detailed construction view of Broadcast microphone.

cable of so many miles length. When transmitting electrical impulses through a very long cable such as a telephone cable, line losses occur which must be compensated for by amplification and so it is with a microphone. The ordinary broadcast microphone has a characteristic of something like "forty miles down." Roughly speaking, this means that three stages of a power amplifier will bring this up to a volume of about a person's ordinary speech. The current through most carbon microphones is in the neighborhood of ten to twenty milliamperes, the battery milliammeter and rheostat being placed in the third or center connection of the microphone. This is the total current through both buttons, there being one-half this current through each button. The direct current resistance of each button or electrode is approximately 16 ohms. Of course, these figures vary for different types of microphones but are given so as to familiarize the student with the approximate amount.

Every broadcasting microphone should be equipped with a proper protective housing to eliminate the possibilities of damage to the microphone. The usual stand has a number of eyelets permitting the sound waves to be properly impressed upon the diaphragm. Usually springs or rubber bands are used to support the microphone inside of the stand thus doing away with undesirable vibrations of the microphone proper.

Best results are obtained from a microphone when it is used in conjunction with a modulating or microphone transformer of

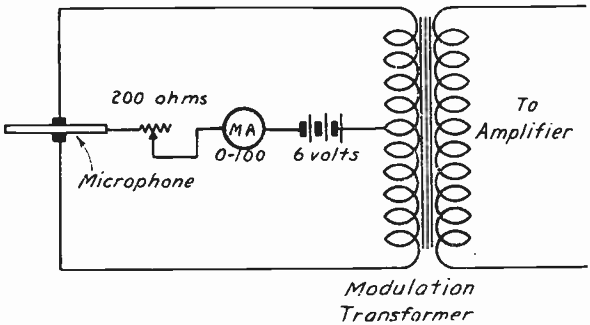

Fig. 4—Connections from microphone to modulation transformer and battery.

correct impedance. Although the impedance of the various types of microphones differ considerably, one such modulating transformer has a very large core and the complete transformer weighs about two pounds. It has an amplification curve practically even from 90 cycles upward to 5000 cycles falling off very little below 90 cycles. The primary impedance is 28,400 ohms and the secondary impedance is 390,000 ohms at 60 cycles, the primary inductance being approximately 90 henries.

It goes without saying that the secondary of this transformer is connected to the input circuit of a vacuum tube and thence so on through the amplifier proper.

MAGNETIC PICK-UPS

Under certain conditions it is desirable to supplant a microphone with an instrument whereby Victrola records can be used as the source of entertainment instead of the human voice or musical instruments. In this case a microphone is not used, the proper instrument being what is commonly termed a Magnetic Pick-up. Practically speaking, this instrument receives the mechanical vibrations from a phonograph record and converts these mechanical vibrations into varying electrical impulses. Once these varying electrical impulses have been obtained, the problem then becomes the same as in the public address system—that is, they are amplified and then reproduced.

There are a great number of magnetic pick-ups on the market but in general they follow the same principles of construction. In Figure 5 is shown the details of the construction of a simple type of magnetic pick-up.

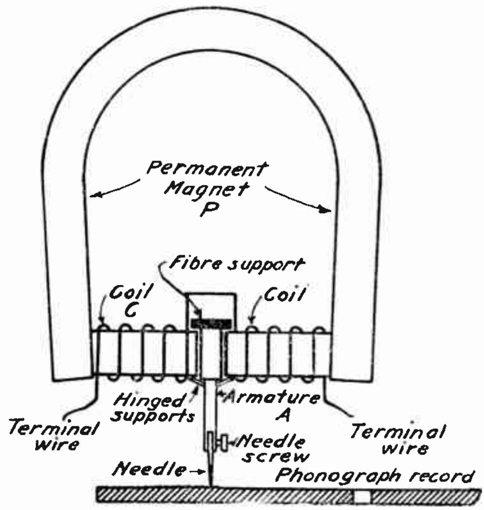

Fig. 5—Details of construction of a magnetic pick-up.

It is a fundamental principle of electricity that when a coil of wire is cut by a changing magnetic field, a voltage will be set up in the coil which changes in direct proportion to the manner in which the magnetic field is changing. This induced voltage causes a current to flow through the coil when the circuit is completed. Applying this principle, then, to the present problem, we can easily understand the operation of this unit. First, we must have a needle bearing upon a phonograph record so as to receive the changes of impressions on the record. By referring to Figure 5 it will be noted that the needle is attached to an armature which is hinged. When the needle follows the impressions of the record, the armature is caused to move. The armature is mounted between the electromagnets or coils "C." A permanent magnet "P" is mounted with the electromagnets at its terminals. The permanent magnetic field formed by the permanent magnet "P" is distributed whenever the armature "A" is in motion. The permanent magnetic field passing through the coils "C" does not cause any current to flow but the moment the magnetic field is disturbed the lines of force change and cut the coils "C" causing a current to pass through these coils which is in direct proportion to the manner in which the armature "A" disturbs the permanent magnetic field. The current in the coil "C" is then passed into a proper amplifying transformer, the secondary of which is connected to the input circuit of a vacuum tube amplifier. This instrument performs a somewhat similar action to the microphone.

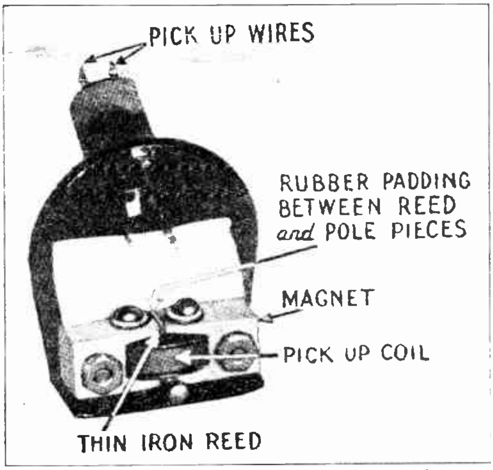

Fig. 6—A typical magnetic pick-up unit.

Due to the friction caused by the needle bearing upon the phonograph record a scratchy sound will prevail unless precautions are taken to eliminate it. In most cases a scratch filter is used to eliminate this undesirable sound. While the connection of a small fixed condenser such as .006 mfd. connected across the output of the pick-up or input to the amplifier will remove this noise, such an arrangement would also remove many of the higher audio-frequencies and lower the quality of reproduction. For this reason an electrical filter circuit, tuned to stop the passage of only those currents in the neighborhood of the scratch frequency, is used.

The difficulty in completely eliminating the scratch lies in the fact that the scratch frequency is not any one frequency, but quite a wide frequency band. If, however, the filter circuit is tuned to approximately 4500 cycles, the greater part of the scratch noise is removed without the sacrifice of tone quality. The residual hiss, when the scratch filter is employed, is practically unnoticeable and cannot be detected except for the first few seconds or so before the music starts.

Figure 7 illustrates the connection for one form of scratch filter. In this case the inductance "L" is a 1500-turn honeycomb coil, the capacity "C" is a .008 mfd. fixed condenser. This filter is tuned to approximately 4500 cycles and will eliminate a greater majority of the scratch frequencies.

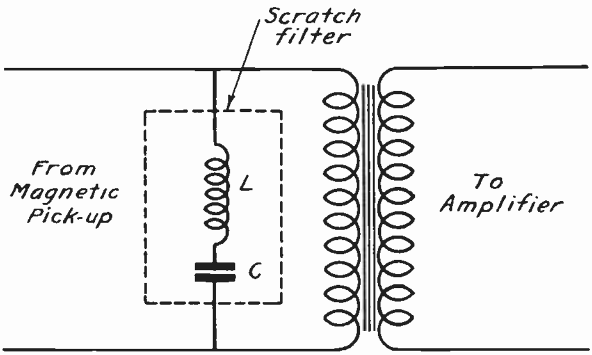

Fig. 7—Scratch filter connections.

AMPLIFIER

The amplifier used in a public address system is purely an audio-frequency amplifier. Since the frequency of the electrical impulses lies within the limits of the so-called voice frequency, all that has been learned of audio amplification in the past can be applied in this instance.

Instead of having the output voltage from the detector, we merely have the voltage developed in the modulation transformer.

Since the microphone is rated as several miles down, it is necessary to use two or three stages so as to amplify the electrical impulses and have the reproduction of normal speech volume. Then, if several loud-speakers are to be operated, power amplification must be used so as to increase the volume above the normal amount. Therefore, it becomes apparent that the number of stages in the amplifier depends upon the type of microphone used and the volume of the desired reproduction.

For a small hall where one or two loud-speakers will suffice, only two or three stages without power amplification may be used. Where great volume is required in a large assembly hall or for reproduction in the open for a multitude, the number of stages must be increased accordingly. Each loud-speaker requires a certain amount of power to operate, and taking this into consideration, the amplifier must be designed accordingly. In large public address systems power tubes having an output rating as high as 50 or 200 watts are often used. Every installation is an individual problem which must be dealt with accordingly.

REPRODUCING UNIT

Ordinary loud-speakers will generally accommodate requirements for a small public address system. One power speaker may be used to deliver a greater amount of volume, but for a large assembly hall or for open-air reproduction several such speakers may be required. The acoustic condition of the hall or surrounding country must be taken into consideration and the speaker placed accordingly. The echo effects and reverberation usually cause considerable trouble and in such conditions the best policy is to use several ordinary speakers instead of a power speaker and place them in such a manner that the echo effect is minimized.

In some cases a number of ordinary speakers are grouped and in such cases as the National Conventions in an exceedingly large assembly hall, groups of these speakers are placed at various points throughout the hall. Usually considerable experimentation is required in order to determine the correct locality of each group of speakers. Also, the echo and reverberation effects will vary considerably when the hall is filled with people as compared to being empty; more echo usually being present when the hall is empty. However, more volume is required when the hall is filled with people.

As in the case of the amplifier, the exact number of speakers may be compared to the exact number of stages of amplification by saying each installation presents an individual problem and must be solved usually by experimentation in order to determine the best conditions.

A KIT FORM ADDRESS AMPLIFIER

The Silver-Marshall 685 Unipac, public address type amplifier, is available in two styles. Type 685 WIRED is furnished completely wired and tested by the factory; the same instrument can be obtained in kit form, ready to assemble and wire.

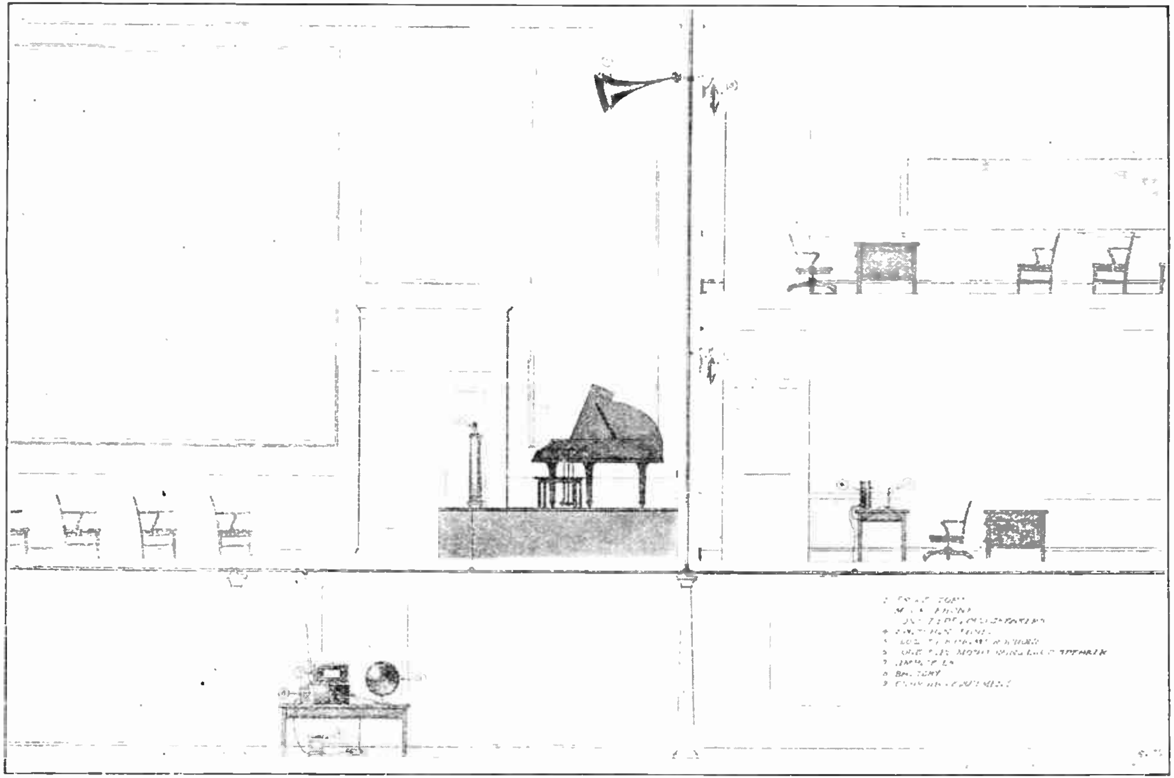

Fig. 8.—Typical school installation.

The 685 Unipac is a light-socket operated power amplifier drawing all power from any 105 to 120 volt, 60 cycle, alternating current source. It will amplify the output of a microphone, magnetic phonograph record pick-up, or the output of a Radio set detector tube up to an undistorted power level of 5 watts. This power will give intelligible high quality speech and music through one to six large loud-speakers for auditorium, theater, church or

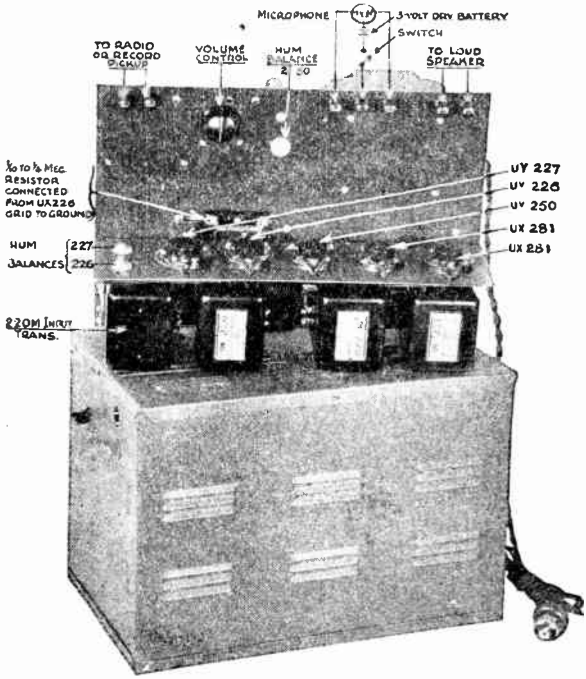

Fig. 9—SM 685 Unipac. All tubes are mounted on the shelf as shown, with amplifying transformers below. The bulkhead assembly is shown on top of its steel housing cabinet.

outdoor grandstand coverage for 2,000 to 10,000 people. This output will also handle up to twelve standard Radio loud-speakers at ordinary home volume, with the speakers located in different rooms of a building, as in a hotel, school or apartment house. Loud-speakers may be located up to 500 feet away from the Unipac; connections from microphone, Radio set or pick-up should be as short as possible and not over 50 feet long. A control knob is provided to regulate volume smoothly from a whisper to full maximum.

The Unipac apparatus is mounted upon a heavy steel bulkhead, to which a tube socket shelf is attached. This assembly

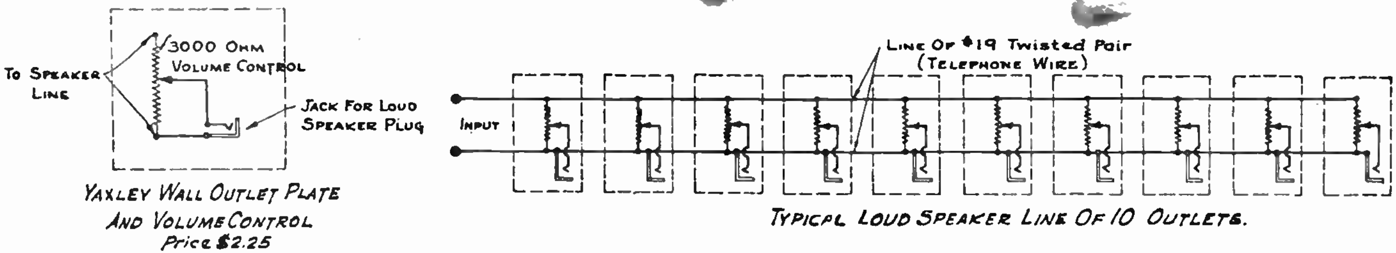

Fig. 10—Method of connecting one to twelve loud speakers in different rooms, with independent volume controls.

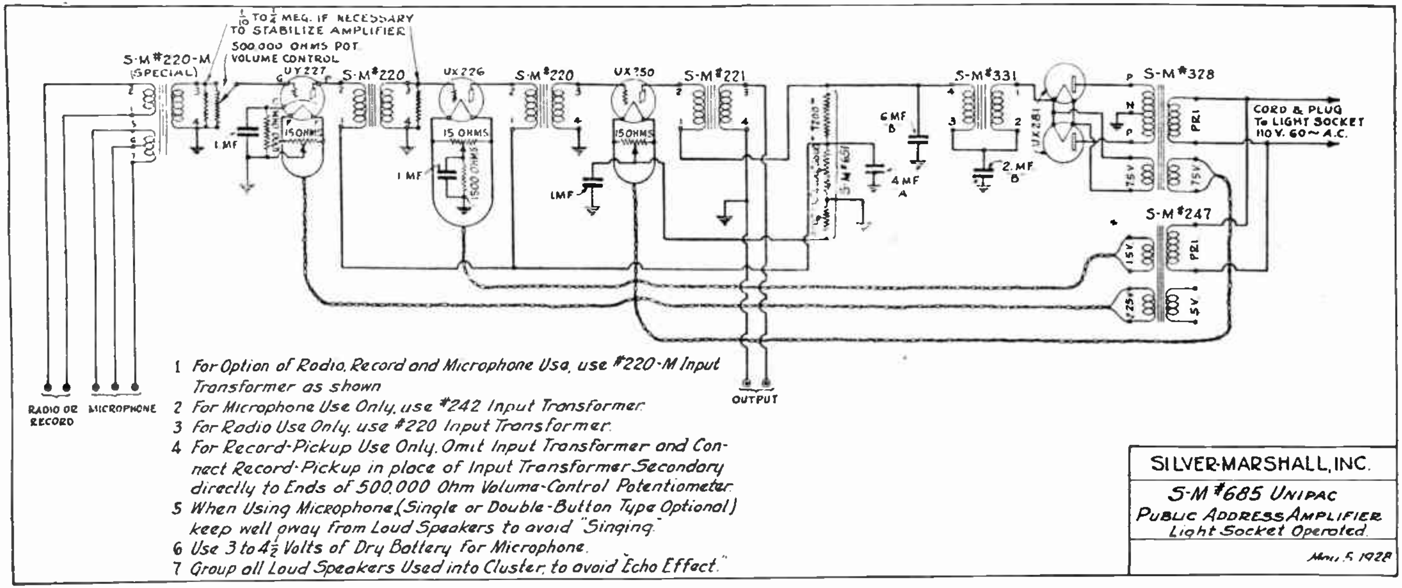

Fig. 11—Schematic diagram of SM 685 light socket operated Unipac.

is fastened in the center of a brown crystalline finished steel case provided with a hinged cover over tube compartment, ventilating louvres and two carrying handles. Binding posts are provided for loud-speaker, Radio or record pick-up, microphone and microphone battery connections. The Unipac weighs approximately 70 lbs., and is 17½" long over carrying handles, 9¾" wide, and 10½" high, with cover closed. It may be used as a portable amplifier or permanently installed either indoors or outdoors. If instantaneous changeover from Radio, record or microphone amplification is required, external switching is necessary, as described under "Input Switching."

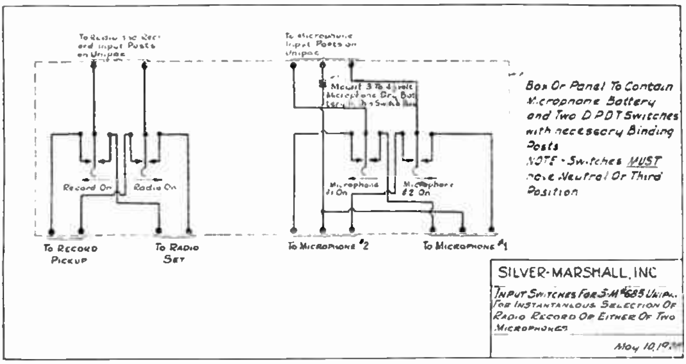

Fig. 12—Switching arrangement for microphone and pick-up.

Two UX281 rectifiers, one UX250 power amplifier, one UX226 A. C. amplifier and one UY227 A. C. amplifier tubes are required for operation, in addition to input apparatus and loud-speakers.

DIRECT CURRENT OPERATION

When an alternating current lighting circuit is not available to operate the Unipac, but a 110 to 120 volt DC lighting circuit is at hand, a small rotary converter may be used, such as an Esco, Janette or Bodine machine of at least 200 watts rating.

OPERATION

First completely unpack and inspect the 685 Unipac. Place the R. C. A. tubes listed below in the sockets, from left to right, in the order given. Equivalent Cunningham tubes may be used.

One	One	One	One	One
UY227	UX226	UX250	UX281	UX281

Turn the volume control knob all the way to the left. Insert the attachment plug in any 105 to 120 volt, 60 cycle, A. C. lighting socket, and turn on power at the socket. Within fifteen seconds the "V" or "W" shaped filaments of all tubes should heat to a cherry-red color, excepting only the UY227 tube. Within one minute the round central rod inside this tube should attain a dull cherry-red color.

No blue glow, or at most very faint traces of blue around the metal structure of UX250 and UX281 tubes should be observed. With power turned off, connect the loud-speaker to the two "SPEAKER" binding posts. Switch the power on again and allow a minute for tubes to heat to operating temperature. A low-pitched A. C. hum should then be heard at the loud-

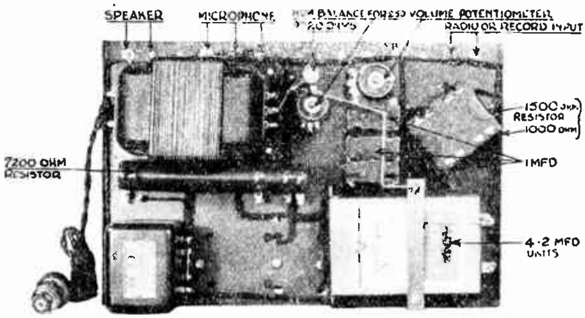

Fig. 13—View of power transformer filter, etc.

speaker. **This hum must be balanced down to a minimum value for each location in which the amplifier may be used.**

Balancing is done with a long screw-driver wrapped with friction tape so that the metal shank cannot touch the metal carrying case. The screw-driver is used to adjust the three slotted screw-heads, labeled "HUM BALANCE" in the photos, to the point of minimum hum. Two are on the left end of the tube shelf, the third on the bulkhead behind the UX250 tube. This operation should be carefully repeated with the volume knob set at the half-way position. A certain amount of hum will always remain, but so little as not to interfere with auditorium or outdoor use. Make sure the grid resistor is in its clip; either a 1/10 or ¼ megohm resistor, whichever is necessary to reduce the hum to the desired point without losing amplification.

A magnetic record pick-up should be connected to the two left-hand "INPUT" binding posts and a record played. Volume should be adjusted by the volume knob on the bulkhead to a point where music is audible several hundred yards from the speaker. Similar results should be obtained if the same pair of Unipac "INPUT" posts are connected to the output of a radio receiving set detector tube, assuming a good strong signal to be used for this test.

If a double-button microphone (Kellogg No. 501 or equal) is connected to the three right "INPUT" posts, with a 3-volt dry battery and a battery type cut-off switch connected between the center binding post and the center wire from the microphone, good speech should be obtained. If the microphone is too near the loud-speaker, or volume is turned up too far, "singing" will occur.

A lower priced hand microphone (Kellogg No. 21-C, equipped with cut-out button switch) can be used for announcements, if preferred, connecting it in series with a 3-volt dry battery to the center and one of the outer "INPUT" posts of the group of three at the right.

The following paragraphs deal with the use of the 685 public address Unipac for different classes of coverage, with suitable accessories. It is well to emphasize the fact that satisfactory public address operation may not be had by merely installing equipment without thought and trial, and expecting it to work perfectly. Each installation requires individual experimentation over a period of several days or even several weeks, for upon the carefully worked out and tested placement of loud-speakers and microphone depends the degree of satisfaction that will be had.

SCHOOL, APARTMENT, BUILDING, ETC.

Where a 685 Unipac is to be used to operate up to twelve loud-speakers in different rooms of a building, the loud-speakers should be connected as shown in Figure 10. For each loud-speaker one Yaxley or equivalent single wall outlet plate, carrying a 3,000 ohm wire-wound potentiometer and open-circuit jack should be provided. For one to six speakers, the standard S-M 221 output transformer is correct. For six to twelve speakers, the special S-M type 221-D low impedance output transformer should be used in the Unipac instead of the standard 221 type. This arrangement will provide ample volume for home or classroom purposes, with independent volume control at each speaker outlet, and a substantially constant volume level, whether one or twelve outlets are in use.

AUDITORIUM, THEATRE, ETC.

For auditorium or theatre use, one or two large speakers, such as the 36" cone speakers, may be used, placed close together, or not over ten to fifteen feet apart at most. Through careful trial, the speakers should be so tilted and directed as to give intelligible speech and music throughout the auditorium. This arrangement will suffice for a hall not over half again as long

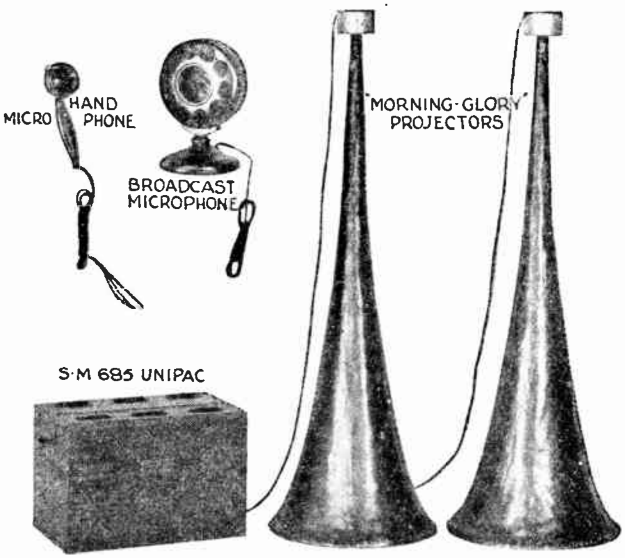

Fig. 14—A typical portable Public Address Amplifier System which will give voice coverage of from one to five thousand people. It consists of a microphone, either hand or broadcast type, three dry cells (not shown), the 685 Unipac amplifier, and two "morning glory" projectors. Up to twelve speakers could be used, and the amplifier would reproduce phonograph records upon the addition of a small portable phonograph equipped with a record pick-up. It can also be operated from a radio set at will.

as it is wide, though for a very large hall (say 100x150 feet) three or more speakers might prove necessary.

If dynamic speakers are preferred they may be used if of the low voltage, trickle-charger-operated-field type. If two speakers are used, series and parallel connections should be tried. Three speakers should be connected in parallel; four, in series-parallel. **Speakers should be so placed that the microphone, if one is used, is always well behind a line crossing the speaker faces or radiating openings.** For auditorium installation, as in a church to intensify a preacher's voice, only a double-button type of microphone should be used, and the loud-speakers should be swung above the speaker's head, and far enough away to allow the desired volume to be obtained without "singing."

LARGE HALLS OR OUT-OF-DOORS

For a very long hall, or outdoor use, the long horn-type speaker is often preferable (of the "morning-glory" type) since the sound waves can be radiated away from the microphone and in any desired direction. A typical installation for a hall 100x200 feet, with the speaker's rostrum at one end, would consist of a cluster of four "morning-glory" horns ten feet or more above the speaker's head, two horns pointed at the far end of the hall, and two pointed at the middle of the hall and diverging slightly. With the microphone located five to ten feet behind the loud-speaker mouths, "singing" should not be troublesome. The effect gained will be a realistic intensification of the speaker's voice—not the development of so much volume that the whole impression gained is of an inhumanly loud and artificial voice.

OUT-OF-DOORS

The above suggestions are applicable for voice coverage of a baseball park or similar gathering. Generally, cone speakers are preferable for high quality, with "morning glories" used only to avoid "singing" due to the loud-speaker reaction on the microphone; or in order to project sound waves in one direction. When voice coverage is not needed, and radio or record coverage only is desired, cone or dynamic speakers are to be preferred. Speakers should never be left out of doors for long periods, for dampness will deteriorate them. When installed out of doors an adequate canopy must be provided to protect them from rain and dampness. Microphones must be most carefully protected from moisture.

VOICE ANNOUNCEMENTS AND SPEECHES

For occasional voice announcements to be made between musical selections a hand microphone is quite good enough for intelligible speech. For amplification of entire speeches or addresses, where high quality is desired, the double-button microphone should be used, and a switch provided to cut off the microphone battery when not in use.

INPUT SWITCHING

With the standard 685 Unipac, either Radio, record, or microphone inputs may be amplified. When one source is being

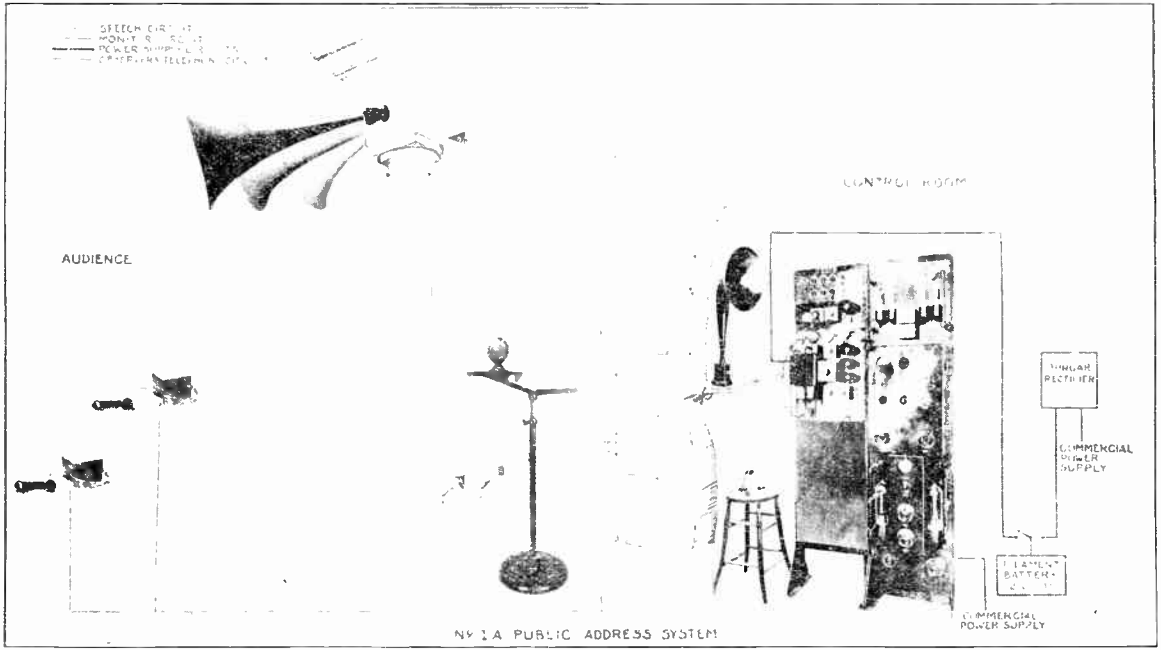

Fig. 15—Typical installation of W. E. No. 1A system.

used the others must be disconnected from the Unipac. It frequently becomes desirable to have either microphone, voice, or record inputs available instantaneously, and at a uniform volume level. A switching circuit is shown in Figure 12 to accomplish this. It consists of two D. P. D. T. (double pole double throw) key switches (Federal, Yaxley or Carter), arranged to cut the three inputs in or out. The microphone switch is shown as a D. P. D. T. type, with connections for two microphones, should they be needed. In this arrangement the volume control in the Unipac is used as a master control for all three classes of input. Radio volume is controlled at the set, record volume by the control accompanying the pick-up, and voice volume by a 5,000 ohm variable resistor across the microphone (a simple and fairly satisfactory method for the volume levels used). A separate panel or boss carrying the switches would have to be constructed.

WESTERN ELECTRIC PUBLIC ADDRESS SYSTEMS

The Western Electric Company, on account of its experience in the telephone field, naturally became one of the pioneers in the development of a public address system. Having already applied speech amplification to the transcontinental and other long distance telephone communication, this company was in a good position to pioneer this work. In fact, they were one of the earliest to introduce the public address amplifier.

Several such units have been developed to take care of varying conditions and small, intermediate and large audiences. The Western Electric public address systems No. 1A and 2A are for use when and where the audiences are large. The No. 3A system was developed for use where smaller audiences were to be dealt with. No. 4A public address system is a small portable outfit for use in small or moderate size halls or auditoriums, schools, churches and similar places.

THE W. E. NO. 1A PUBLIC ADDRESS SYSTEM

The Western Electric No. 1A public address system is the largest piece of equipment made for this purpose and is designed for use with the largest audiences, outdoors or indoors. It is adapted for either permanent or temporary installation. The efficiency of this system was first brought to the attention of the public during the inauguration ceremonies of the late President Harding in 1921 when, by its use, an audience of more than

125,000 people, gathered before the National Capitol at Washington, was enabled to hear distinctly the President's Inaugural Address. The same system was used in 1925 when President Coolidge was inaugurated and also during the National Conventions of 1924 and 1928. In Figure 15 is shown a typical installation of the 1A public address system.

Considering the amplifier panel, the upper left-hand portion is the volume control panel supplied for use in connection with

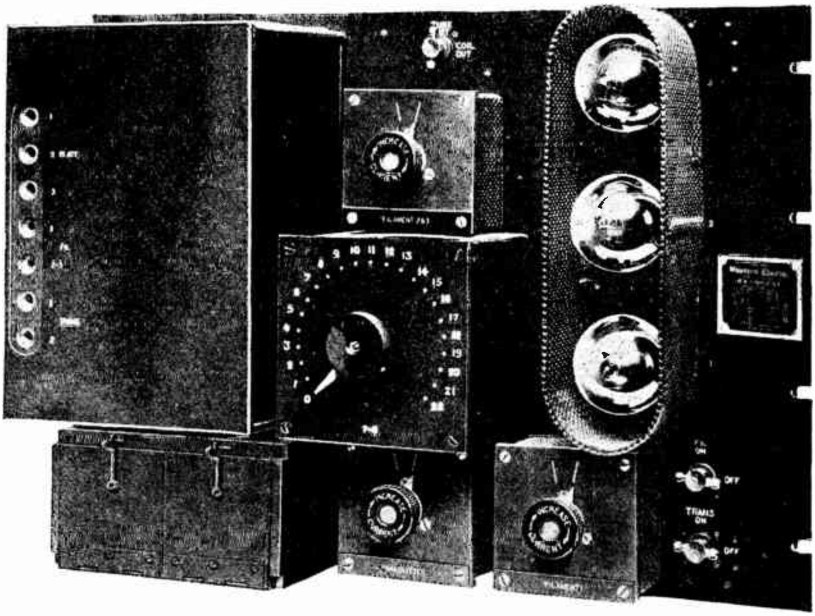

Fig. 16—View of three-stage 8B amplifier panel.

the amplifying equipment. It provides a means for adjusting the volume of sound from the different groups of speakers to fit the acoustics of the parts of the auditorium which they cover. By means of adjusting the rheostat knobs, it is possible to regulate the power supplied to the various speakers or projectors. Just below the volume control panel is the volume indicator panel. The meter on the extreme left of this panel gives a visual indication to the operator of the output volume of the system.

Next comes the 8B amplifier panel. This is more clearly illustrated in Figure 16. The amplifying equipment receives the speech frequency currents and amplifies this energy to a level high enough to permit its distribution through the loud-speaker projectors to the audience. It provides three stages of amplification and makes use of three vacuum tubes, one type 102-D having a very high amplification constant, and two 205-D type having a low amplification constant but a much greater power output. The amplifier is provided with suitable controls for regulating the amount of amplification.

In the upper right-hand portion of the main panel illustrated in Figure 15 is the 10A amplifier panel. It receives the amplified voice currents direct from the 8B amplifier. It supplies a single stage of amplification but makes use of four of the 211 type power tubes. These tubes operate on the push-pull principle, two tubes in parallel on each side of the circuit. The output of the 10A amplifier is controlled by the amount of energy received from the 8B amplifier.

The two lower panels in the right-hand portion of the main panel shown in Figure 15 are the power control and the rectifier panels respectively.

THE W. E. NO. 2A PUBLIC ADDRESS SYSTEM

Though somewhat smaller than the No. 1A system, the 2A system is capable of taking care of large crowds either outdoors or indoors. The No. 2A system is at present being widely used in auditoriums and hotel banquet halls throughout the country. A typical installation of the 2A system is shown in Figure 17.

The main amplifier panel is shown at bottom of picture. It will be noticed that this main panel is very similar to the main panel of the 1A system. However, it does not include the 10A amplifier using four 211 power tubes in push-pull fashion. It uses a 9A amplifier instead. This is a single stage power amplifier consisting of two 205-type vacuum tubes operating on the push-pull principle, handling a comparatively large amount of power at voice frequencies without distorting the complex wave form of the voice currents.

THE W. E. NO. 3A PUBLIC ADDRESS SYSTEM

A typical installation of the 3A public address system is shown in Figure 19. This system is suitable for use in auditoriums, the cubical contents of which do not exceed 150,000 cubic feet: For example, an auditorium of approximately 100′ by 75′ by 20′ high.

It will be noticed that a portable amplifier is used with this type of apparatus. The whole apparatus is mounted in an oak box with the tubes and control units on a panel. On the panel are mounted four 205-type vacuum tubes and the necessary transformers, resistances, condensers, switches, etc., for three stages

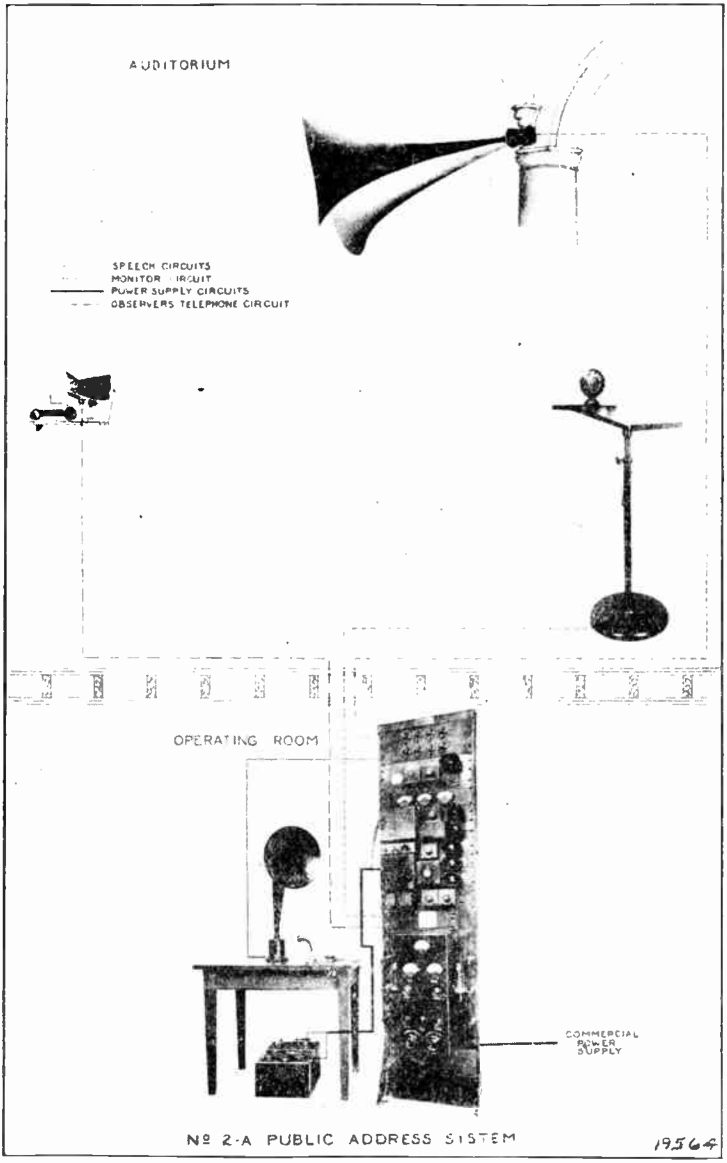

Fig. 17—Typical installation of W. E. 2A system.

of amplification. The amplifier has been especially designed to minimize frequency distortion and to obtain the requisite amplification throughout the central range of voice frequencies without sacrifice of the quality of reproduction. Two separate tubes are used in what is commonly called a push-pull circuit in order to handle amplified currents introduced into the last stage.

The volume is controlled by means of switches and keys mounted on the amplifier panel. A switch turns the filament current on and off. One key enables the operator rapidly to connect

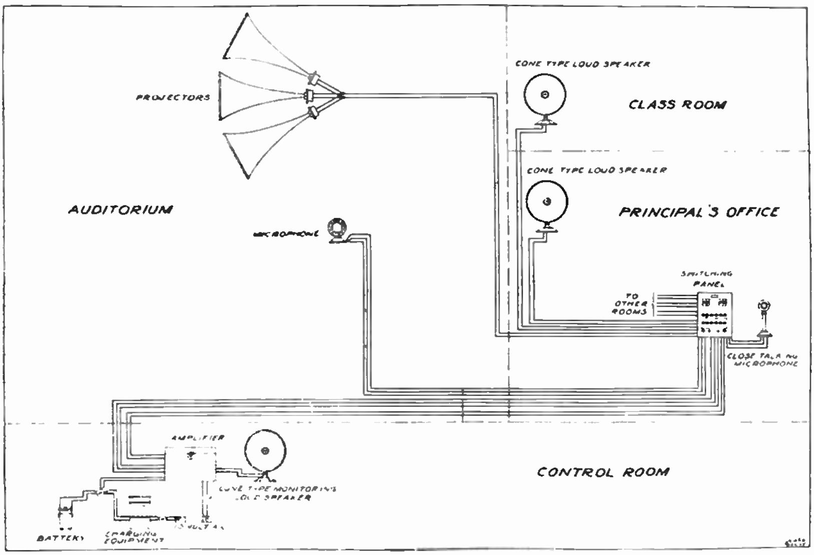

Fig. 18—Installation and wiring diagram of W. E. 4A system.

or disconnect the microphones in either of the two microphone circuits available. Another key enables him to connect or disconnect the loud-speakers without disconnecting the monitoring telephone. The volume of sound emitted is regulated by an adjustment of the amplification. This is controlled by means of a nine-point switch and a key.

THE W. E. No. 4A PUBLIC ADDRESS SYSTEM

A typical installation of the 4A is shown in Figure 18. The 4A system is the smallest of the Western Electric public address systems and is of the portable type. Figure 20 illustrates the portable amplifier and the apparatus mounted below the panel. This is a four-stage amplifier and is operated by the commercial

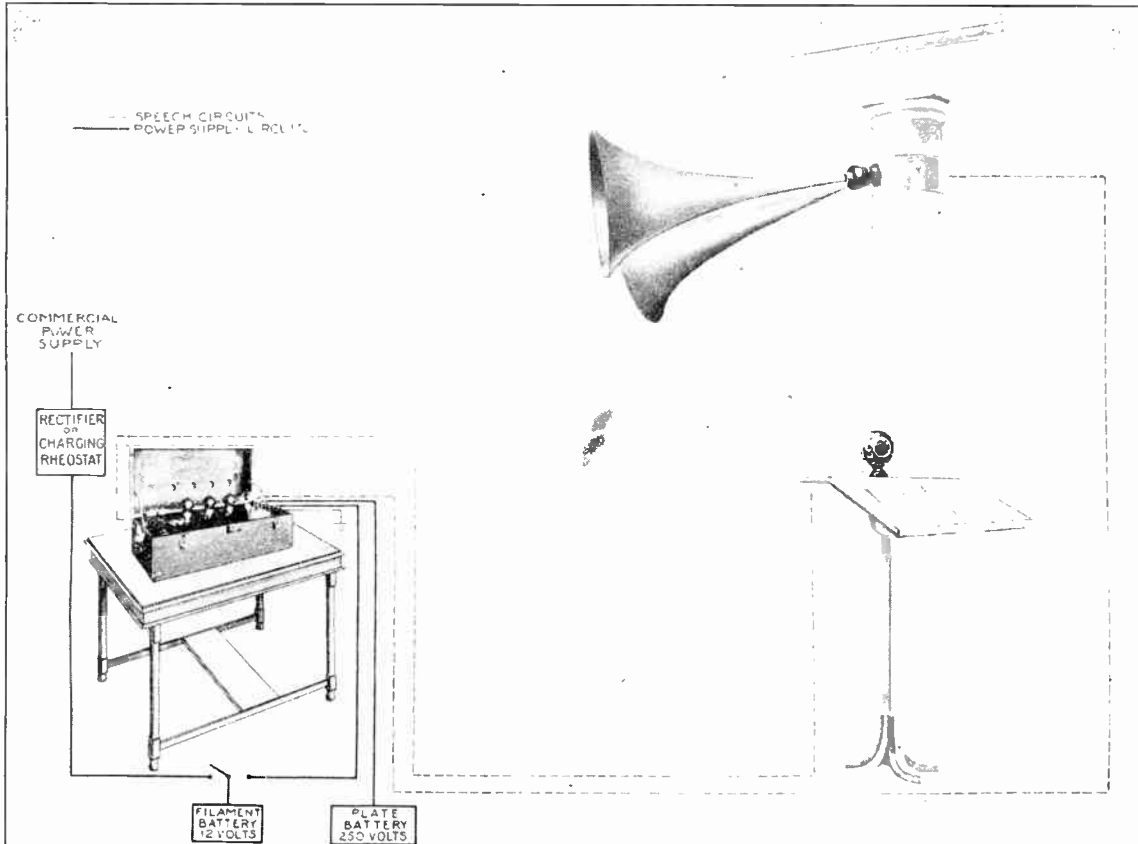

Fig. 19—Typical installation of W. E. 3A system.

lighting circuit which supplies plate current for all the vacuum tubes, and filament current for the tube in the last stage and for the rectifier tube in the current supply set contained in the amplifier. Filament current for the first three tubes is supplied by the battery provided for the microphone. The tubes require only 60 milliamperes at 3.3 volts on the filament. The amplifier is provided with two input circuits for the microphone. Plug

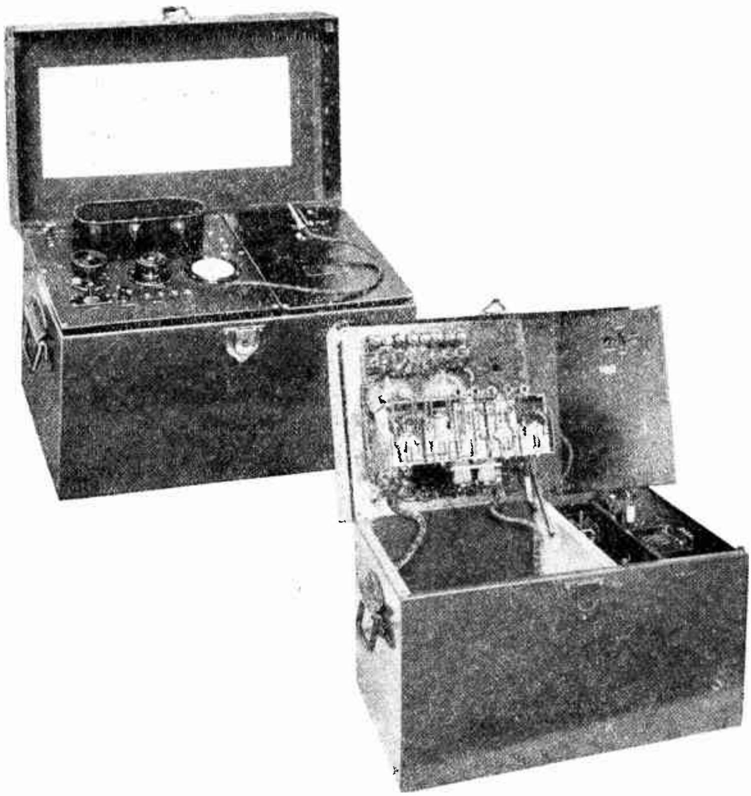

Fig. 20—Portable amplifier showing cover open and interior view.

connections are provided for connecting the amplifier to the microphone and a key is provided for switching between the microphones. Monitoring connections are also provided as well as a shut-off key for the loud-speakers.

When the operator is not located where he can judge the operation of the loud-speakers, he can monitor the program by the addition of a loud-speaker connected directly to the amplifier.

TEST QUESTIONS

Number your answers 48 and add your Student Number.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. For what long felt need does Public Address Amplification fill?
2. Name the four component parts of a Public Address system.
3. What is the function of the microphone?
4. What precaution is used to prevent the microphone from jars and vibration?
5. Upon what fundamental principle does the Magnetic Pick-up work?
6. Draw a diagram showing the method of connecting a scratch filter.
7. Is the amplifier in a Public Address system for audio or radio-frequency amplification?
8. How far behind the loud-speaker should the microphone be placed to prevent singing?
9. Draw a schematic wiring diagram of the complete S. M. Address Amplifier.
10. How can an operator monitor a program when not located near the loud-speakers using WE 4A Public Address System?

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An aim in life is the only fortune worth the finding; and it is not to be found in foreign lands, but in the heart itself.

—*Robert Louis Stevenson.*

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MARINE AND AIRCRAFT RADIO BEACON AND DIRECTIONAL FINDERS

The problem of improving the safety of marine and aerial navigation in time of fog and poor visibility has always been an important one.

During the past few years, the application of strictly radio methods to the art of navigation has been increasing, both in

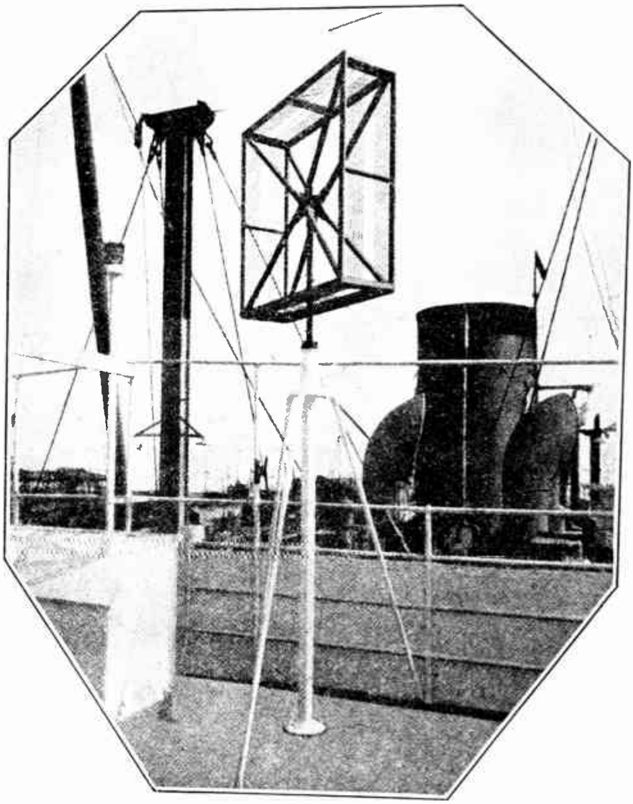

Fig. 1—An Early Type of Radio Compass Loop Installed on Shipboard.

usage and in the actual number of new installations made on shipboard. This is also true to its application in aircraft of all varieties. We shall take up Marine Direction Finders first.

The radio direction finder is becoming an accepted part of modern navigation. Both the active and non-active types are used. Radio-beacons are called "active," while those located on shipboard, taking directions from distant transmitters are "non-active."

The present state of the art of direction finding is due to the tireless work of a number of radio engineers, located in the various countries of Europe, and in America.

The first types of direction finding receivers were combined with special antenna systems consisting of large fixed

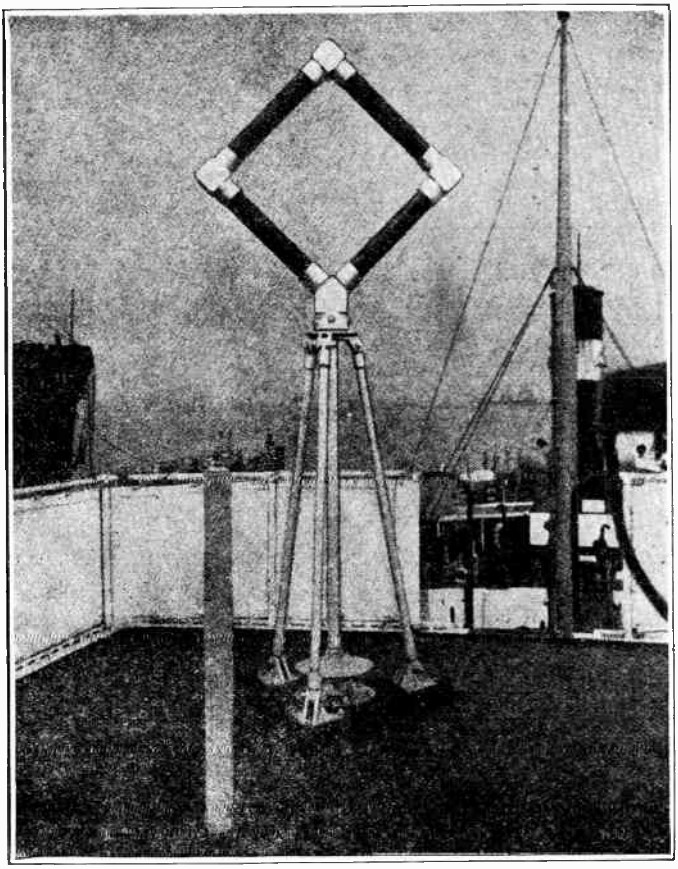

Fig. 2—Typical R. C. A. Radio Compass Loop Installed on Board Ship.

loops and working with an instrument that has been termed a "radio-goniometer." (This device permits determination of the line of travel of waves as received.)

More recent systems have been developed along the line of the shielded rotating loop antenna, with a specially shaped field that readily detects a minimum field strength when rotated against the direction of the incoming radio signals. With this type of apparatus, the operator can, in a few seconds, get accurate bearings on a far distant transmitter. This bearing is usually read in degrees and can be easily compared with some known direction—as determined by the magnetic compass, for instance.

These two systems are both of the ship installation variety, and the use of the latter is increasing aboard American vessels.

Fundamental Principles

It has long been known that an antenna system of a loop or closed coil has directional properties. The fundamental Radio circuit is made up of inductance and capacity. These elements appear in various forms, and in the ideal circuit, as shown in symbol form in Fig. 3, the inductance is entirely

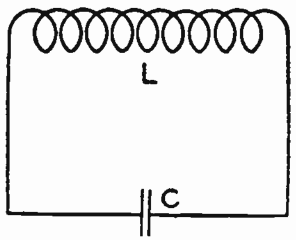

Fig. 3—Simple Closed Coil Circuit Using an Inductance Coil, L, and a Variable Condenser, C.

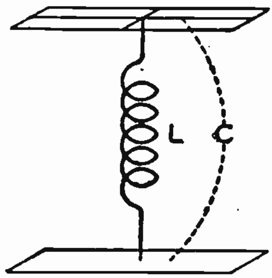

Fig. 4—Antenna (Condenser Type) Consisting of Elevated Conductors, Inductance Coil L, and Ground or Counterpoise.

concentrated or lumped in the coil L, and the capacity is likewise concentrated or lumped in the condenser C.

Power may be supplied to such a circuit either by applying a resonant voltage across the condenser C, or by inducing a resonant voltage in the coil L, or by action of both in proper phase relation. In the ordinary antenna system, as used in present-day radio communication, we find, generally speaking, that the inductance is substantially concentrated in the form of coil L, and the capacity is formed by a conductor or group of conductors elevated above the ground. The elevated conductor is forming one plate of the condenser while the ground or counterpoise forms the other plate, as shown in Fig. 4.

It may be said, therefore, that energy is received in the ordinary radio antenna system by virtue of the fact that its capacity is exposed to the incoming electromagnetic waves. In other words, energy enters the system by way of its capacity, thereafter to be transferred to its inductance. The electrical capacity of an antenna, as well as the potential impressed upon it by the incoming electromagnetic waves, depends largely upon its physical dimensions. Generally, the size and height of its elevated area is the chief factor, but in special types of antennas, the length of the antenna wires is most important.

In Fig. 5, we have what may be considered as the reverse of the antenna system shown in Fig. 4. In this system, the energy is received by virtue of the fact that its inductance, L, is exposed to the incoming electromagnetic waves. In other words, energy enters the system by way of its inductance, thereafter to be transferred to its capacity.

The inductance of the coil, L, depends upon the number of turns, the area enclosed, and the spacing of the turns of wire.

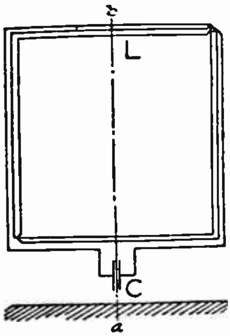

Fig. 5—Antenna (Inductance Type) Consisting of Closed Coil, L, and a Variable Condenser, C.

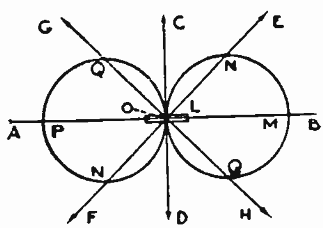

Fig 6.—Theoretical Directional Characteristic of a Closed Coil Antenna (Figure-of-Eight Characteristic).

The current in the receiving circuit depends largely upon these factors, as well as the resistance of the circuit. For given physical dimensions, however, any value of inductance may be obtained by winding the proper number of turns of wire on the coil, L. The electrical dimensions of the coil system are not so dependent upon its physical dimensions as in the ordinary elevated antenna system. As a matter of fact, a coil system of very small dimensions, as compared with an elevated antenna, may be used for the reception of radio signals with a sensitive vacuum tube receiving set.

The chief advantage of using a coil receiving system lies in its directive properties. If the coil, L, in Fig. 5, for example, is rotated about its vertical axis AB, the received signal intensity, from any given source of transmission, will vary approximately in accordance with the diagram shown in Fig. 6.

Maximum signal intensity OP or OM is obtained when the plane of the coil, L, lies in the direction of the source of transmission A or B. If the source of transmission is in the direction of C or D, or exactly normal, or at right angles to the plane

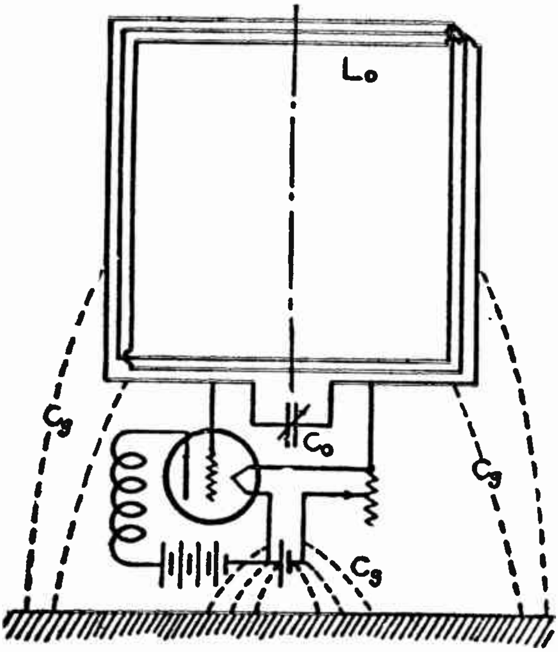

Fig. 7—Coil Antenna Circuit, Showing a Symmetry of Distributed Capacity to Earth.

of the coil L, then the signal intensity is zero. In all other directions, the intensity varies in accordance with the figure-of-eight characteristics in Fig. 6. For example, in directions OE or OF, OG or OH, the distances ON or OQ, respectively,

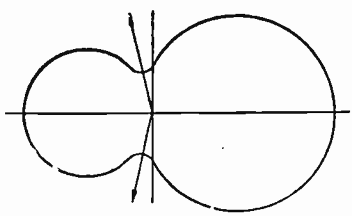

Fig. 8—Characteristic Curve for Coil Type of Antenna Showing the Effects of Both Direct Earth Capacity and the Effect of the Current in the Coil Due to its Capacity Effect to Earth.

represent the relative signal intensities as compared with the maximum OM or OP.

It is immediately apparent, therefore, that if the coil, L, in Fig. 5 is of sufficiently small dimensions to permit rotation about its vertical axis, signals transmitted from any other given source will be received with gradually varying degrees of intensity until the coil becomes normal, or at right angles to the direction in which the transmitting source lies. Then the signal intensity becomes zero. This position of silence is critical and, therefore, may be used to indicate, with great accuracy, the direction of the source of transmission.

It is upon these simple principles that the direction finder, as developed by radio engineers, is based. The theory of its

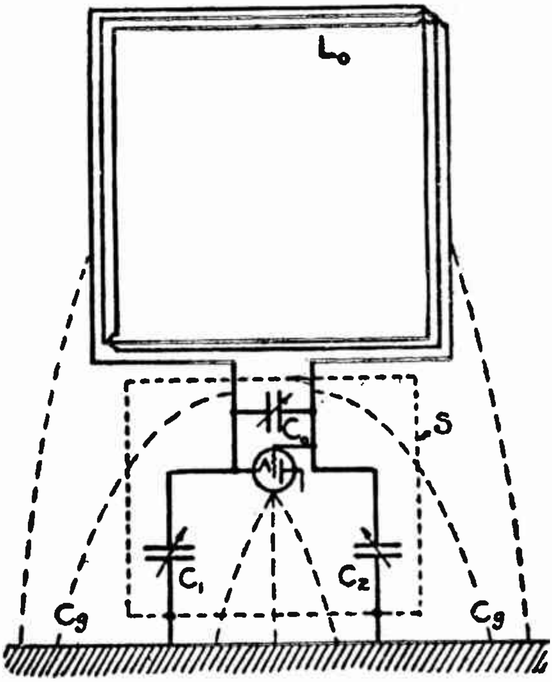

Fig. 9—Diagram Illustrating the Method of Balancing Out the Error Caused by the Capacity Effect to Earth.

design and operation presents a number of interesting problems, however, and it is not until these problems are thoroughly understood that the ideal conditions for accurate direction finding can be realized. In the matter of design, it is important to determine, under given practical conditions, the number of turns of wire and the spacing of the turns which will give maximum received signal intensity for the wavelength or frequency to be received.

Capacity of Loop Circuit to Ground

An important factor which has to be taken into consideration when using a loop antenna in its application as a direction finder is the effect produced in the coil by virtue of the coil structure having an appreciable capacity to earth. Also, the entire coil system, including the detector and amplifier circuit, is electrically unsymmetrical with respect to earth. This results in a distortion of the ideal figure-of-eight "signal intensity" characteristics obtained by rotation of the coil upon its vertical axis. The critical position of "zero signal" intensity no longer exists and the directive qualities of the coil system are distorted.

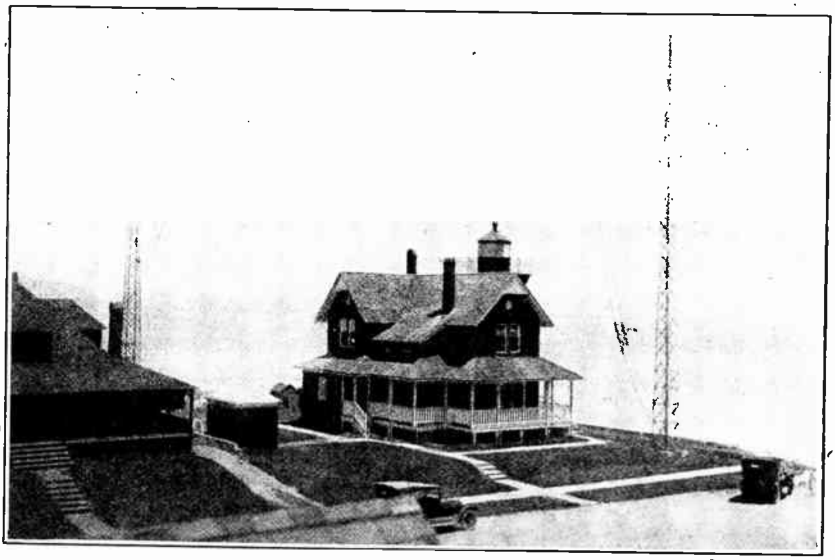

Fig. 10—Radio Fog-Signal Station at Sea Girt, N. J., Lighthouse, Showing Antenna Towers.

The Automatic apparatus for sending radio Signals, three dashes at brief intervals, is located in a small room of the building, and is in charge of the one regular lightkeeper at this station.

An examination of Fig. 7 will show that the vacuum tube circuit connected to the variable condenser, Co, will be affected by the potential across the condenser as produced by the current received in the coil Lo, by the direct action upon the coil of the incoming electromagnetic waves. It will also be affected to a lesser extent by the voltage applied to the electron tube due to direct action upon it of the incoming wave through the earth capacities, Cg.

Furthermore, because of the electrically unbalanced relation of the coil system with respect to earth, an appreciable current will be set up in the coil circuit by the incoming wave acting through the earth capacities, Cg. The potential produced by this current across the condenser, Co, will likewise operate upon the vacuum tube.

The ideal figure-of-eight signal intensity characteristic is, therefore, distorted by these additional effects, the degree of distortion depending upon their relative magnitudes. In practice, it often happens that the signal intensity produced by direct action through the earth's capacity is sufficient to destroy the critical zero signal characteristic of the coil when its plane is at right angles to the incoming wave front.

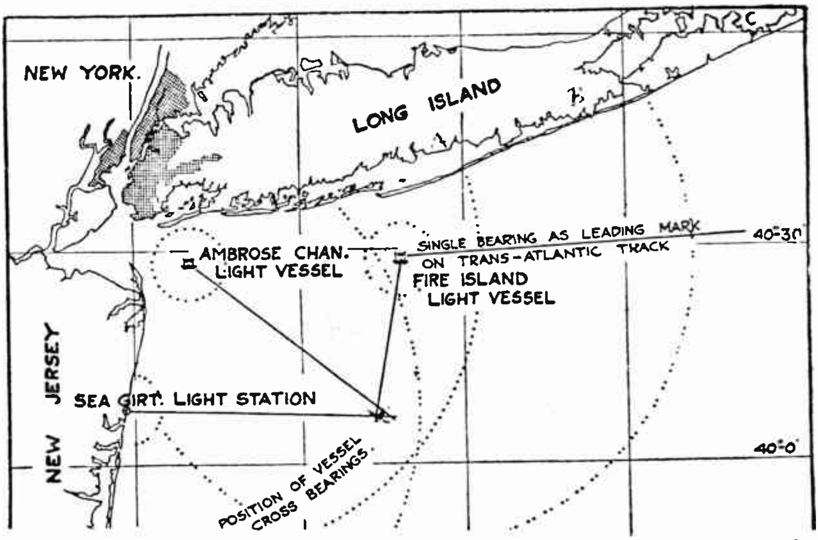

Fig. 11—Sketch Illustrating Radio Beacon Stations Used to Locate Incoming Ships to New York Harbor. Lines Drawn on Chart Indicate Position of Ship.

The complete solution of this problem depends upon obtaining the exact electrical balance of the entire coil system, including the auxiliary vacuum tube apparatus, with respect to earth.

This is accomplished by balancing out this so-called antenna effect by proper adjustment of the variable condensers C1 and C2 connected as shown in Fig. 9. Furthermore, the condensers C0, C1 and C2 together with all auxiliary apparatus should be shielded as shown by the letter S.

In the matter of operation, it is important to obtain, as nearly as possible, the ideal figure-of-eight characteristic with its critical or sharply defined position of "zero signal" intensity.

Also, the operating circuit adjustment and the method of reading bearings must be simple and rapid.

There are two methods of using the direction finding loop. In one case, a number of loops located on shore are used to obtain the position of a ship at sea by simultaneous bearings, see Fig. 11. In the other case, the loop is mounted on the vessel and used to obtain the bearings of the beacon stations on shore. In this case, when the loop is designed for extreme accuracy and provisions are made for determining the unidirectional sense of the signals, it is called a radio compass.

The U. S. Navy Department has established a system of directional finding stations on shore in the vicinity of harbor

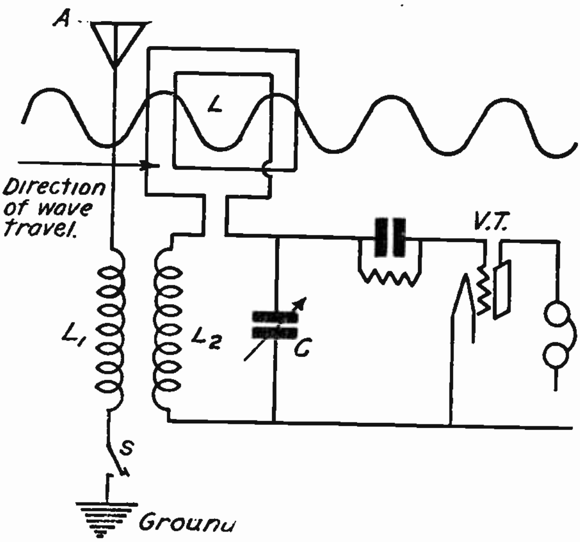

Fig. 12—Circuit Diagram Showing a Loop Antenna in Conjunction with an Elevated Antenna Used for a Direction Finder Having Directional (Unilateral) Characteristics.

entrances or places dangerous to navigation. Each group of receiving stations is connected to a control station which is equipped with a transmitter.

Figure 11 illustrates how three Radio Beacon Transmitting Stations enable ships to determine their bearings or course by the triangulation method.

A vessel desirous of learning its position sends a series of signals to the control beacon station. Each loop station fixes on the vessel and sends the bearing to the control station. If only one loop station is available, only one bearing can be furnished the vessel. Usually, at least three bearings are obtained, thus permitting the latitude and longitude of the vessel to be read direct from a chart. This information is then forwarded by the transmitter to the vessel by radio.

In operation, this system develops several serious faults. If it is used in a very busy harbor, a number of ships may ask for their positions at the same time, and be forced to wait their turn. This is just the reverse of the use of the radio compass aboard ship, for any number of ships can take their positions at the same time, from the same beacon station.

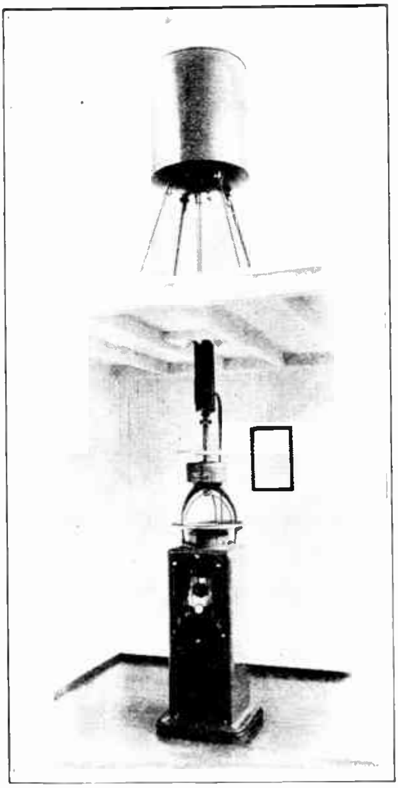

Fig. 13—Kolster Radio Compass Installation on Board Ship. (Courtesy of Federal Telegraph Co.)

Directional Finders on Board Ship

In the second application of the direction finding loop installed on board ship, the automatic radio beacon stations on shore, or installed on light vessels and lighthouses, send out radio signals similar to light flashes.

Using this method, a bearing is taken from the beacon station. The position of the station is determined from a chart, by the characteristic signal it sends. The observation is then made by the captain or master of the vessel and the results are immediately available.

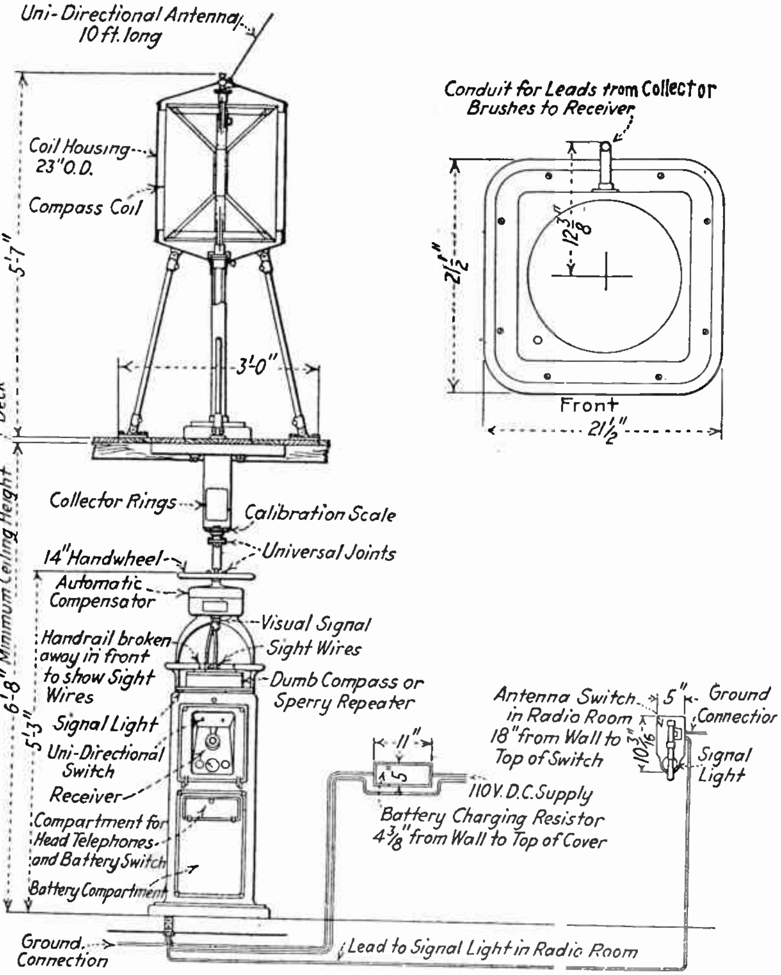

Fig. 14—Drawing Showing Complete Installation of Kolster Radio Compass on Board Ship With the Important Parts of the Equipment Indicated, Also Some of the Dimensions.

In addition to its use with beacon stations, this system can also be used for determining the position of another ship. This makes it possible for vessels so equipped to pass each other safely during a heavy fog.

We see from the foregoing that it is not sufficient to just determine the direction of a signal. It is also necessary to know the position of the source, or the strength of the incoming signal. Therefore, use is made of the uni-directional properties of a loop, and an antenna. When this is done, the loop is no longer merely a directional finder, but is a radio compass.

Bi-Lateral and Uni-Lateral Methods

There are two methods of using the radio compass loop. First, the "bi-lateral" method, consisting of finding the direction of the oncoming electromagnetic waves from the transmitter by turning the loop until the signals in the phone are a minimum, or silent. In this method, the position of maximum signals covers a much wider turning position of the loop than does the position of minimum. The minimum signal is exactly at right angles to the direction of the received electromagnetic waves. However, it has the disadvantage of being "bi-lateral"—that is, it indicates either one of two points, exactly opposite each other. Usually, the radio operator on board ship has a sufficient idea of his whereabouts to know that the signals could be coming from only one of the two directions indicated. But this is not always the case. When this point is uncertain, the "uni-lateral" method is used to determine the approximate direction of the signals, after which a sharper tuning in this direction is obtained by use of the minimum tuning method.

The "uni-lateral" method uses the loop antenna in conjunction with a regular elevated antenna, such as shown in Fig. 12. This method is based on the polarity phase of the loop. In the bi-lateral method, when the loop was turned to a position where signals were loudest in the phone, the loop was standing parallel to the direction from which the signals were being transmitted, and the question was to know from which side of the loop or coil they were coming. When the loop was turned completely around, the signals were as loud as before. In turning the loop around, the direction of the current in the loop was reversed, but the received signals were still at maximum strength. In other words, the polarity of the loop was reversed and in the bi-lateral method, practical use of this fact was not made. But this is the foundation of the "uni-lateral" method.

By inductively coupling the loop antenna, L, to the elevated antenna, A, through the coupling coils, L1 and L2, some of the received energy of the elevated antenna is conveyed to the loop antenna. Therefore, we have a means of taking advantage of the relative polarity of the elevated antenna current and the loop antenna current. When the loop antenna is in such a position that the currents from both sources of transmission are flowing in the same direction, the signals heard in the telephone will be louder than without the induced elevated antenna current. But when the two currents oppose each other, turning the loop antenna parallel with the oncoming electromagnetic waves will only produce very weak signals. This is because the elevated antenna current does not reverse with the reversal of the loop antenna. By this method, it can be seen that the approximate direction of the transmitter can be obtained.

However, as the maximum signals cover a wider range of the compass dial than the minimum, this is never accurate and the loop must then be disconnected from the elevated antenna coupling and used separately to determine the exact direction of the oncoming signals by tuning the signals out.

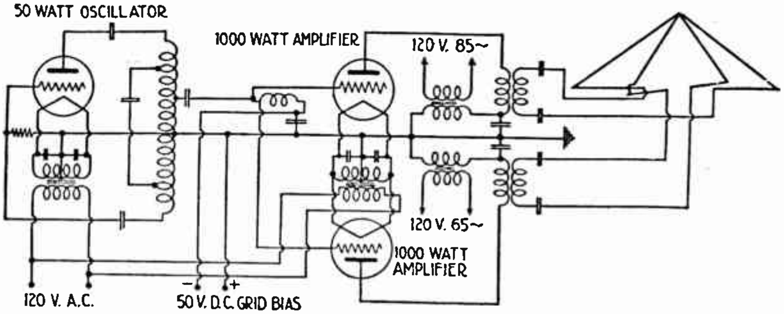

Fig. 15.—Schematic Diagram of Radio Beacon Transmitter Developed by Radio Service, U. S. Bureau of Standards.

It must be understood that the elevated antenna and the loop antenna to be used for uni-directional radio compass work must be calibrated together. A pointer on the shaft which turns the loop antenna must be arranged in such a position that it indicates the direction of a known transmitting station, when the two antennas give the loudest signals. After this, with the two used together and loudest signals heard, the pointer will show the direction from which the signals are coming. By varying the coupling, L1 and L2, between the elevated antenna and the loop antenna, the current can be controlled. Too much antenna current will overcome the energy picked up by the loop, and make it difficult to determine the direction of the loudest signals.

Description and Operation of a Kolster Radio Compass

A typical shipboard radio compass installation is shown in Fig. 13. In the drawing shown in Fig. 14, you will find the details of a complete installation, with the important parts of the equipment indicated. A suitable loop frame is wound with several turns of special radio frequency wire to form a coil. The frame is mounted edgewise upon a vertical hollow shaft which is in turn supported on a ball thrust bearing for ease in turning. The coil is completely enclosed within a circular housing, so that it is entirely free to rotate, even under the most severe conditions of wind and waves. The housing also protects the coil from mechanical damage. The coil and housing may be mounted at any desired height above the deck, and are rigidly supported by four braces clearly shown in Fig. 13.

The shaft on which the coil is supported extends through a suitable housing to the room in which the compass is located. The leads from the coil pass through the tubular shaft to collector rings. From the collector rings, the leads pass through a conduit to the compass receiver which is located in the upper part of the compass binnacle. At the lower end of the shaft is attached a pair of sight wires which travel over a compass card, or degree scale, by means of which the angle between the station upon which the bearing is taken, and magnetic North, true North, or the ship's direction (depending upon the type of installation) can be read directly. The sight wires are not rigidly fastened to the shaft, but are connected to it by a simple mechanical device which automatically corrects any error caused by the influence of the ship's hull and rigging on the apparent direction of the incoming radio waves. This device is called the "automatic compensator."

As the coil is rotated by a hand wheel, the characteristic signal from the beacon station will be heard in the phones with a gradually varying degree of loudness, until the plane of the coil is at right angles to the direction of the incoming electromagnetic waves. At this point, the signal fades out entirely. This position of silence is very critical and sharp, and indicates with great accuracy the line of the direction of the waves. By means of cross bearings on two or more stations, or by several bearings on a single station, with the distance logged between bearings, the position of the ship can be determined by simple triangulation, with an accuracy equal to sight bearings on visible fixed objects.

In obtaining a compass bearing, it is essential to eliminate the so-called "antenna effect" of the compass coil. This is accomplished by a simple adjustment on the receiver panel.

It is often desirable to know the true direction from which the waves are approaching, while the bearings obtained above do not indicate more than their line of travel. Although in the majority of cases this direction is known to the navigator, the occasion may arise wherein the location of the signalling station is not known—for example, the position of another ship at sea. To obtain the true direction, it is necessary to unbalance the

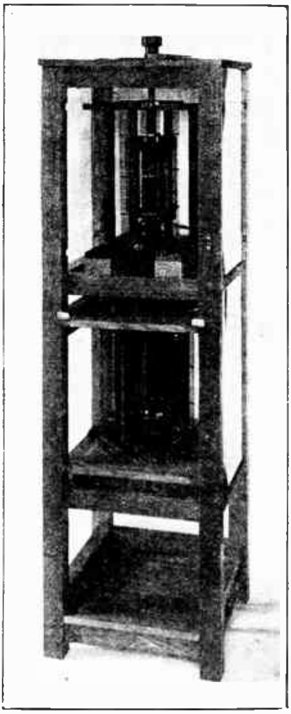

Fig. 16—Goniometer Used to Shift Course in Any Desired Direction.

compass coil by exaggerating the antenna effect. This is done by connecting a small antenna, usually not more than 20 feet long, to the receiver through a suitable switch, also located on the receiver panel. Normally, this uni-directional switch is open when taking a bearing, but when the true direction is desired, the operator closes the switch and turns the compass coil to the position of maximum signal strength. At this point, the plane of the coil lies in the direction of the signalling station and points toward it, as indicated by an index pointer provided for that purpose.

The radio compass receiver is located directly beneath the compass, as shown in the various photographs, and utilizes a circuit especially designed to give maximum sensitivity and selectivity, together with simplicity. The receiver contains eight tubes, so operated that they are equivalent to four stages of radio frequency amplification, a detector, and two stages of audio frequency amplification. The receiver is designed to operate over a wave-length range of approximately 550 to 1050 meters.

The A and B batteries for the filament and plate, respectively, are located beneath the receiver at the bottom of the binnacle. The A battery consists of an Edison storage battery which is designed for reliability and long service. A double pole double throw switch is located within the phone compartment directly beneath the receiver, by means of which the battery may be connected to either the receiver or to the ship's mains for charging.

A charging resistor, to limit the current, is mounted in some suitable location in series with the ship's supply.

The antenna switch and signal light shown in the illustration are for the purpose of assuring that the ship's main antenna is open when bearings are being taken. This antenna switch is normally located in the ship's radio room under the control of the radio operator. Red lights on the base of the switch and on the radio compass binnacle indicate that the antenna switch is open. If the light on the compass is not lit when it is desired to take bearings. the navigator communicates with the radio personnel and sees that the antenna switch is opened before operating the compass.

The principles of operation of the R. C. A. and Federal Radio Directional Finders as used on board ship are practically the same with the exception of the receiving apparatus. The R. C. A. compass uses a Super-Heterodyne receiver, while the Kolster radio compass uses a very sensitive tuned radio frequency receiver.

There are several methods of making the installation on shipboard, depending somewhat on physical conditions and circumstances. The apparatus may be mounted at any convenient place on the upper deck reasonably clear of riggings, stacks and bulkheads. It is desirable that the coil be at least three or four feet from all metallic structures. Logically, the coil should be overhead with the indicator directly beneath. The most favorable installation on a large vessel is to place the coil over the chart room on the flying bridge and on the fore and aft center lines of the ship. In this case, the indicator and receiver are conveniently located in the chart room. On the other hand, the coil can be mounted on the roof of the wheel house

Fig. 16-A—Dr. F. A. Kolster, Inventor, Inspecting an Installation of a Small Radio Compass on a Sea Skiff.

and the indicator inside over the steering compass, or the coil can be placed on the roof of any deck house with the indicator located in any available room below. In such case locations are not available, it is possible to install the entire equipment within a frame work on the open deck.

When a radio compass is first installed on board ship, it is necessary that a careful calibration be made to correct certain constant errors due to a distortion of the approaching wave front caused by the metallic mast of the ship and any conducting material in the vicinity of the compass coil.

The dimensions shown in Fig. 14 give an idea as to the required installation space of such apparatus.

For some years, only one type of Kolster radio compass has been manufactured, which on account of its size and cost has been better suited to the larger vessels.

The Radio Beacon Service is available to all types of vessels, both large and small, therefore, it is particularly desirable that small vessels in coastwise navigation should be equipped with a suitable Radio Compass.

The Federal Telegraph Company has, therefore, developed a small, compact, direct-reading radio compass which can be readily installed on the smallest vessels at a very moderate cost.

With this small radio compass, accurate bearings on any of the established radio beacons can be taken over distances up to 25 miles or more, depending upon the power of the transmitting beacon, thus enabling small crafts in coastwise navigation to take full advantage of the Radio Beacon Service in fog and thick weather, enabling them to avail themselves of an important aid to navigation and to enjoy equal safety at sea with the larger ocean-going steamers.

AIRCRAFT RADIO BEACON DEVELOPMENTS

We shall now discuss the "ways and means" of aircraft radio-beacon systems.

The possible applications of directional radio devices to aerial navigation may be broadly classified in three different groups, namely, "directional radio receivers on aircraft," "directional receiving stations on ground," and "directional transmitters on ground."

Radio communication between aircraft and ground developed during the World War. Such communication is a powerful aid to air navigation, since in conditions of storm or poor visibility, the pilot can be informed of conditions along his route or told where a safe landing can be made. The first attempt to develop a radio device as an actual navigation instrument involved the direction finder, which had been developed and used with great success in marine navigation. It was not possible to duplicate this success in air navigation because of the engine ignition system interference, a limited space, excessive noise. Also, preoccupation of the pilot diminishes the possibiity of taking useful bearings in airplanes with direction finding coils.

The reverse procedure (use of direction finders on ground) is employed with a certain amount of success abroad. However, only aircraft having complete transmitting and receiving sets can receive aid from this system. This eliminates the small airplane. Furthermore, errors in the bearings taken are apt to result with this system, owing to the inclination of the airplane transmitting antenna.

Efforts to develop a radio navigational device was made by the U. S. Bureau of Standards in 1921. Working on the air navigation problem at the request of the Army Air Service, the Bureau devised the cross-coil or double-beam directive type of radio beacon.

This beacon consists essentially of two separate coil antennas, set at an angle with each other. These send signals

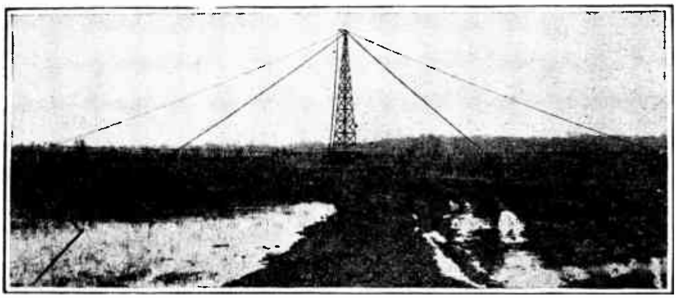

Fig. 17—Radio Beacon Station at College Park, Md.

at alternate intervals. Equality of signal strength from the two antennas is obtained along a line bisecting the angle between the plane of the two antennas. The advantage of this system is that its use requires nothing more than a radio receiving set on the airplane.

Aircraft Radio Beacon Transmitting Apparatus

The directive radio beacon station is usually located at an airport just off the landing field. This transmitter, as stated previously, employs two loop antennas, crossed at an angle of 90 degrees. Each antenna emits a set of waves which is a maximum in its plane, and a minimum at right angles thereto. Both antennas transmit 290-kc. waves, but modulated at two different frequencies.

A master oscillator producing 290-kc. current feeds two

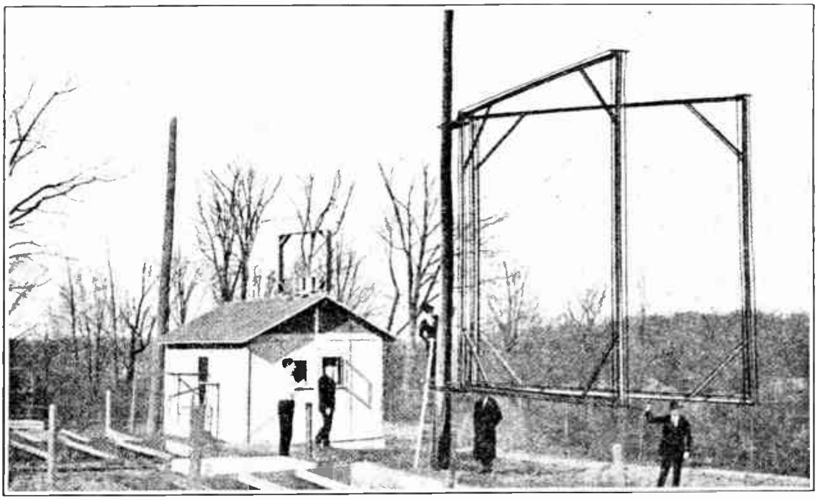

Fig. 17-A—Experimental Type of Double-Coil Antenna, Arranged to be Rotated About the Telegraph Pole as an Axis.

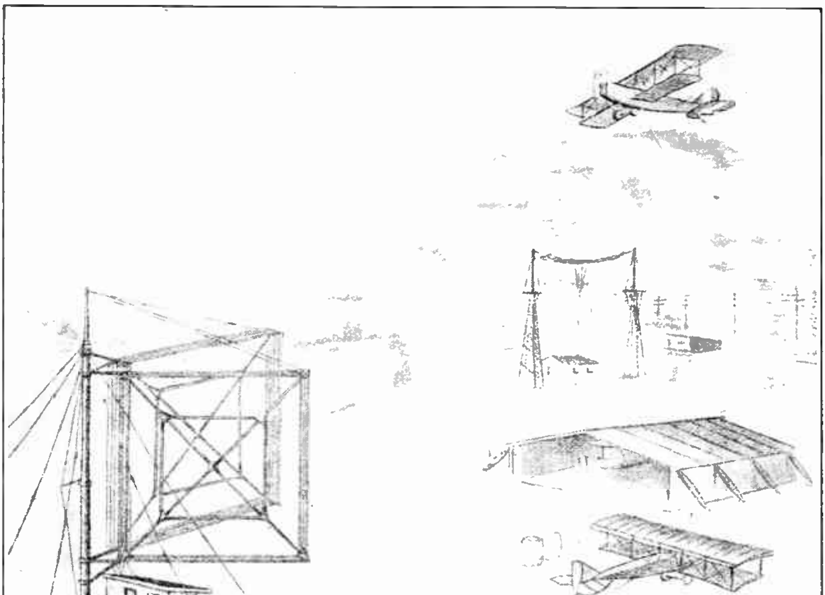

Fig. 17-B—This illustrates the Use of the Directional Transmitter in Connection With an Aeroplane Field.

power amplifiers. These are modulated by two different low frequencies. Their output goes separately to the two loop antennas. Figure 15 is a circuit diagram of the radio transmitter in simplified form. The two loop antennas terminate in tuning condensers and coils, as shown in the diagram. They are both tuned to 290-kc. and so adjusted that there is no coupling between them. The coils are coupled to the plate circuits of the two 1000 watt amplifiers.

A radio frequency voltage is applied to the grids of the two amplifiers from the 50 watt master oscillator operating at 290-kc., and direct voltage is applied to the plate.

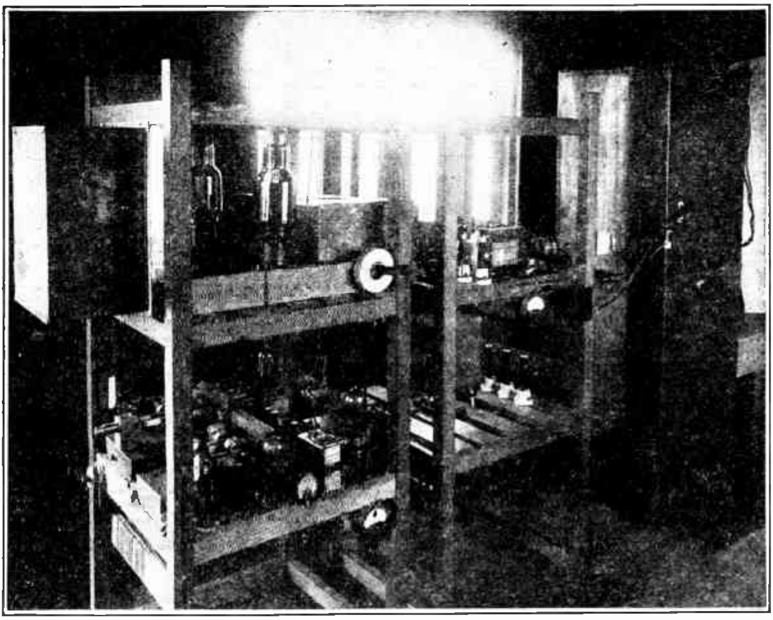

Fig. 18—Interior of a Beacon Transmitting Station.

The plates of the amplifier tubes are supplied with high voltage alternating current through transformers. One is connected to a source of 85 cycle voltage, and the other to a source of 65 cycle voltage. These are the two modulation frequencies to which the reeds of the visual indicator installed on the aircraft are tuned. Such visual indicators will be taken up later on in this text book. Each power amplifier passes radio frequency current every alternate half cycle, the frequency being 85 or 65 cycles. This occurs each time the plate is positive. The completely modulated output from one amplifier supplies power to one of the antennas only, and the other amplifier supplies only the other antenna.

The use of a common master oscillator prevents any shift in the indicated course, due to tuning of the receiving set. This might occur if two master oscillators were used, if they differed slightly in frequency.

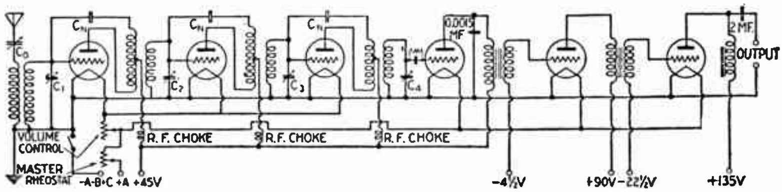

Fig. 19—Schematic Diagram of Aeroplane Radio Receiver Used to Receive Radio Beacon Signals and Weather Reports.

A number of other methods for modulating the carrier frequency at the low frequencies required are possible and have been used. The method just described involves the supplying of plate power directly to the amplifier tube at the low frequencies desired. This method was not found entirely practicable because the constancy of the low frequencies depends upon the steadiness of the frequency of the power source

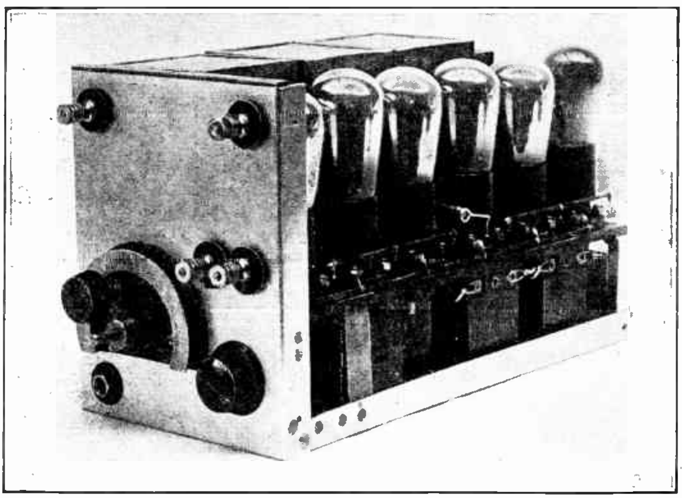

Fig. 20—Unicontrol Receiving Set for Beacon and Telephone Reception.

available, which varies somewhat in most cases. Even with a steady source available, alternators with synchronous motors of special design to drive them would be necessary.

The vacuum tube oscillators controlled by tuning forks which supply sufficient voltage to enable grid or plate modulation of intermediate amplifiers have been developed, and solved the difficulty of keeping the low frequencies steady.

In the "grid modulation" method, the modulating frequency is impressed on the grid of one of the amplifier tubes. With the plate modulation method, the low frequency voltage is applied to the grids of the modulating tubes, the plates of which are connected to the output of one of the amplifiers in a circuit arrangement analogous to that of the ordinary method of plate modulation employed in broadcasting stations. Both methods give satisfactory performance, although the plate modulation scheme has some advantage in that less distortion in the wave form is introduced.

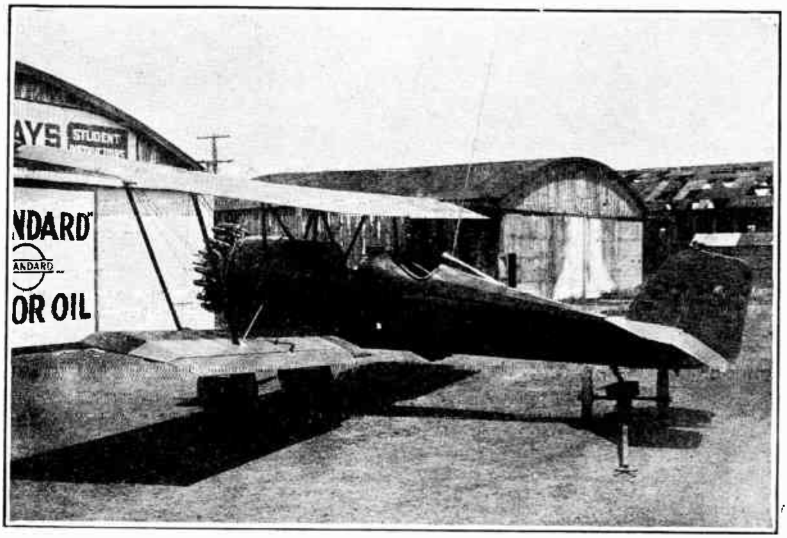

Fig. 21—Pitcairn Mailwing Airplane, Showing Vertical Pole Antenna.

When the beacon is to be used for air routes in several directions, a "goniometer," not shown in Fig. 15, must be introduced. This is a coupling arrangement between the two antennas and the amplifiers, the rotation of which is equivalent to rotating the antenna. The goniometer designed for use with this apparatus is shown in Fig. 16. It has two pairs of coils, each pair consisting of an 8 turn rotor and a 32 turn stator. The stator coils are fixed at right angles to each other and so are the rotors. The rotation of the rotor coils, with respect to the stator coils, orients the path marked out by the beacon in any desired direction. At airports where several courses intersect, the beacon course can be set successfully on the several courses for fixed time intervals. The simultaneous serving of two or more courses with a single beacon appears possible. Extensive work is now going on to incorporate this feature into the beacon system.

Aircraft Receiving Equipment

The beacon system can be used with any receiving set which operates at the frequencies used; it merely replaces the telephone receivers by a simple reed indicator unit. There are however, special conditions involved in receiving on an air-

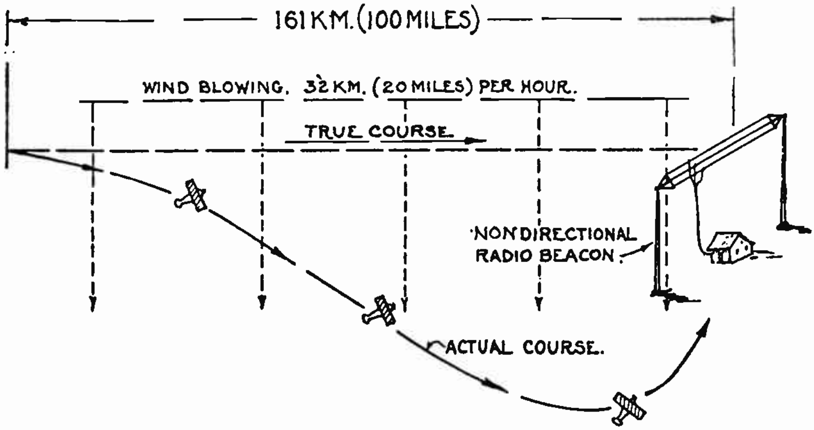

Fig. 22—Effect of Wind Drift on an Aeroplane.

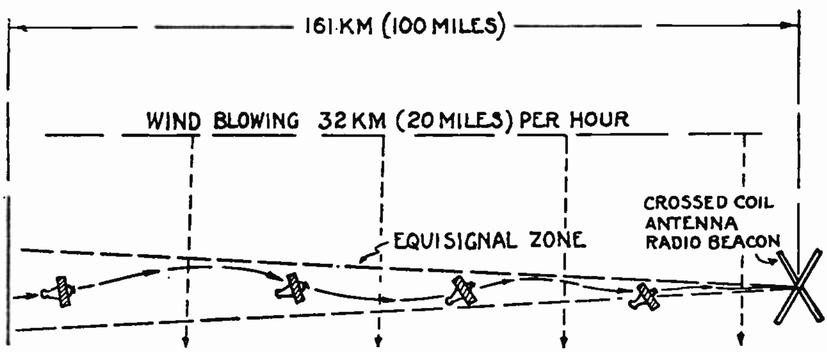

Fig. 23—Method of Eliminating Effect of Wind Drift on an Aeroplane By the Use of a Cross-Coil Antenna Radio Beacon.

plane, and the Bureau of Standards has developed special receiving sets in order to use the beacon system under the most advantageous conditions.

The receiving set designed weighs less than 15 lbs. and the auxiliary batteries weigh an additional 10 lbs. The receiving set operates in the frequency range from 285 to 350-kc. and is used to receive either the beacon signals or radio telephone or telegraph messages. The circuit diagram is shown in Fig. 19.

This receiver is provided with interstage shielding as well as shielding against the extraneous interference. The selectivity of the set designed is supplemented by the great selectivity of the reed vibrators, which help greatly in reducing interference. The set has remote control arrangements for tuning

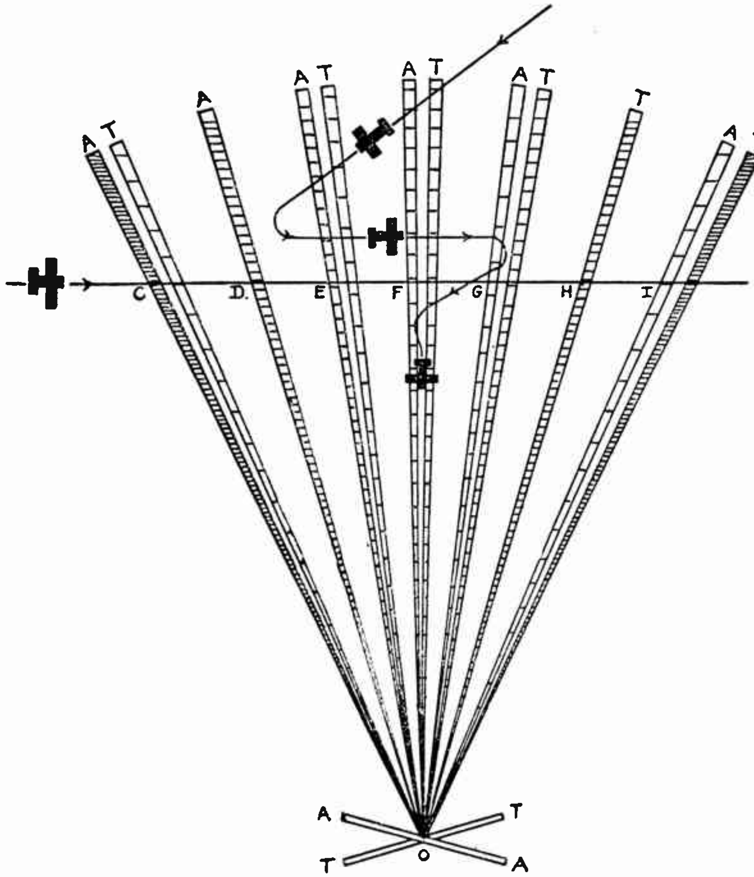

Fig. 24—This Illustrates the Method of Guiding an Aeroplane by the Equisignal Zone Method.

and volume, so that the set itself can be out of the way in the tail of the airplane.

The development of receiving sets having the necessary sensitivity made possible the use of a new antenna system on airplanes. It consists of a metal pole about 10 feet long, extending vertically from the fuselage. The use of a trailing wire antenna with its attendant inconvenience and possible danger is thus eliminated. A great advantage of the vertical pole antenna is that it is entirely non-directive, and as a consequence, night direction variations in the beacon course are considerably reduced. In addition, since this type of antenna is not affected by the horizontal component of the electric field radiated by the beacon, a region of zero signal strength is met with, directly above the beacon power (where no vertical field exists). This serves quite effectively to exactly locate the flying field. With the trailing wire, it was a very difficult feat to guide an airplane right to the beacon, and it became impossible when the side wind produced a slight slant to the antenna.

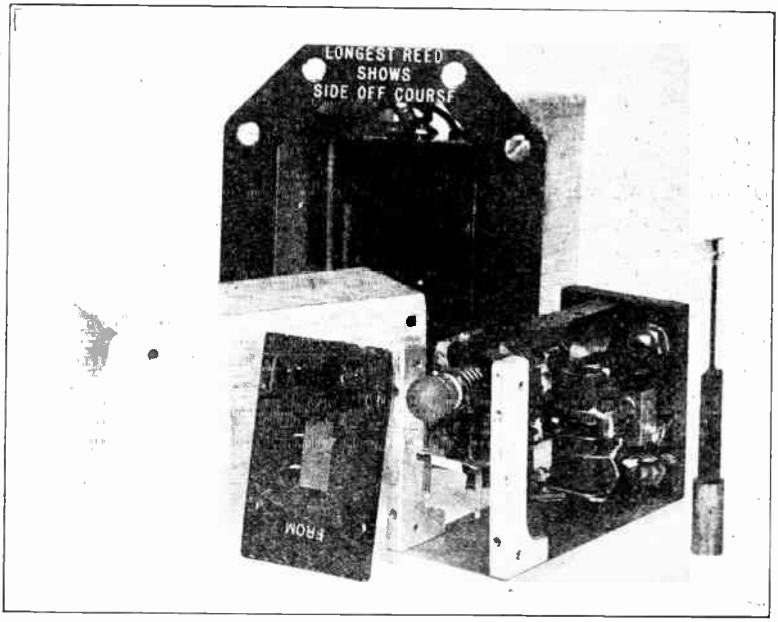

Fig. 25—Visual Reed Indicator Unit (Cover Removed.)

Therefore, the vertical pole antenna makes it very simple to fly directly towards the beacon. Now, the beacon can be located within 100 feet, when the airplane is not over 1000 feet above it. This is a most valuable aid to landing in fog.

Reed Type Visual Indicator

Figure 25 and Fig. 26 show the reed indicator units. They are designed to match the output impedance of the receiving set and give full scale deflection with 10 volts across the terminals. This reed indicator unit consists of two vibrating steel reeds. Their vibration gives the visual indication, while they, themselves, provide the necessary tuning to the two modulation frequencies.

The indicator is very simple and rugged. It is mounted on the instrument board in front of the pilot, and electrically connected to the receiving set output in place of the telephone receivers. It consists of a set of coils through which traverse the audio output currents of the receiving set acting on a pair of short steel strips or reeds. These two reeds are tuned to the beacon modulation frequencies, 65 and 85 cycles per second.

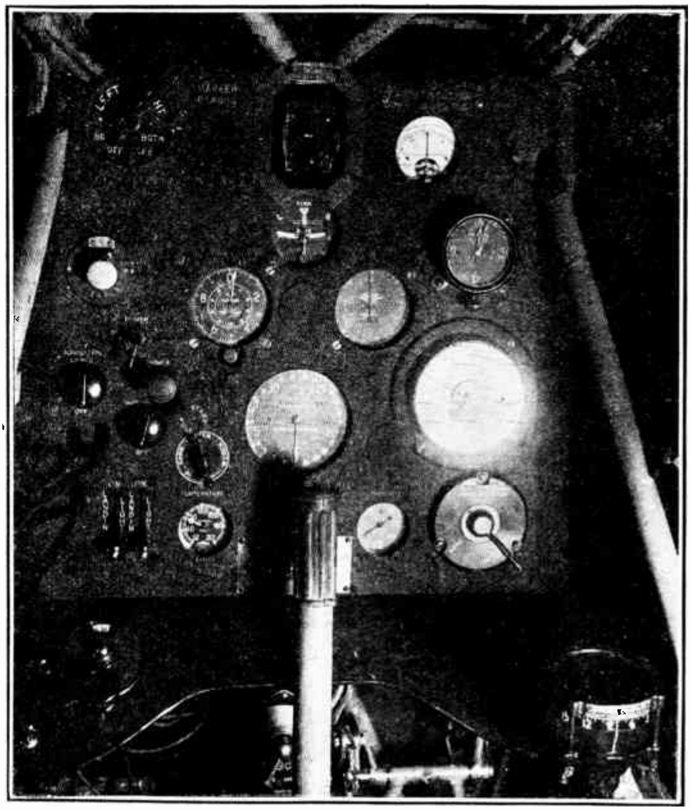

Fig. 26—Photograph Showing a Reed Indicator Mounted on an Airplane Instrument Board (top center).

When the beacon signals are received, the two reeds vibrate. Since they are tuned to the two modulation frequencies used at the beacon, they indicate the equality of received signals from the two loop antennas. The tips of the reeds are white against the dark background so that when vibrating they appear as vertical white lines. For use in night flying, suitable indirect lighting of the reed strips is provided.

When the two white lines are equal in length, the airplane is on its course. A deviation from this course to the left increases the deflection of one reed, and decreases that of the other. The reverse is true if the airplane deviates to the right. To return to the course, the pilot turns in the direction of the shorter reed. By piloting the airplane so that the two lines are always of equal length, he remains on the indicated course. The reed indicator is very sensitive, requiring less than 2.5 volts across the indicator terminal for full reed deflection.

A phenomenon quite common to mechanicallly tuned devices is the change in their vibratory frequency, caused by changes in the surrounding temperature. This phenomenon was observed in the case of the vibrating steel reed. A simple compensating device has been perfected which nullifies this effect, making the reed frequencies entirely independent of temperature.

The Bureau of Standards has experimented with a number of possible visual indicator systems. One was by using a neon lamp device. The output of the receiving set was fed into two selective circuits containing the neon lamp. Both lamps lighted indicated the position of the course location. One lamp lighted meant off course on the side corresponding to the frequency used to light it. This method was abandoned after several trials because of the need for too many amplifiers to operate the lamp. Neither could the distance deviated from the course be told, as the lamps were either on full, or not at all.

It can be seen from the foregoing that with the radio beacon made practical and dependable, air route operations enter a new era of regularity and safety. Most of the trips which are now omitted, or undertaken only at great risk, can be confidently made.

For those not familiar with the navigation of airplanes, the following should be of interest:

The method of aerial navigation called "instrument flying" is in common use. When the pilot cannot see the earth below, he forgets the outside world, and, concentrating all his attention on his instruments installed on the airplane instrument board (see Fig. 26), he then navigates his craft from the information these instruments convey. For example, one instrument tells him his elevation, another his speed, another whether he is turning or flying straight away, and his compass indicates his general direction. But, accurate as all these instruments may be, they do not tell him if he is drifting sidewise due to a cross wind, nor do they tell him exactly at what speed he is travelling, because there may also be a head or tail wind to slow him down, or to speed him up. Thus, while instrument flying may enable a pilot to keep his craft at a safe altitude and in a generally correct direction, the hazard of getting farther away from the course into strange, unfamiliar, and possibly dangerous areas is ever present.

What instrument flying has hitherto lacked is precisely supplied by the radio beacon system, because with its use the pilot can always know his location.

TEST QUESTIONS

Number Your Answer Sheet 49 and Add Your Student Number

1. What important piece of apparatus in Radio makes direction finding possible?

2. What is the position of the plane of the coil antenna for maximum and minimum signal intensity?

3. State the two methods of using a direction finding loop.

4. What is a Radio Beacon Station?

5. State the meaning of bilateral and unilateral characteristics in Radio compass work.

6. Draw a circuit diagram of a Radio Beacon transmitter.

7. Why must a Radio compass be calibrated when installed aboard a ship?

8. Name the three classes of aircraft directional Radio devices.

9. Draw a diagram of an airplane receiving circuit used for Radio Beacon signals.

10. What is the advantage of using a vertical pole antenna on airplanes.

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CARRIER CURRENT SYSTEMS
(WIRED RADIO)

Originators of Radio Home Study Courses
••• Established 1914 •••
Washington, D. C.

ACKNOWLEDGMENT

The National Radio Institute wishes to thank the Bell Telephone Company and their officials for their kindness in supplying much of the information, photos and drawings used in this text-book.

Not how much talent have I, but how much will to use the talent that I have, is the main question.

—W. C. Gannett.

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PRINCIPLES OF CARRIER CURRENT SYSTEMS (WIRED RADIO)

Systems have been developed whereby an open-wire line may be increased in efficiency in that additional circuits are provided over the existing wires.

Systems employing these arrangements are called Carrier Systems; Multiplex Telephony; Telegraphy by means of electric waves guided by wires; Line Radio, and more generally, Wired Radio and Carrier Telephony and Telegraphy.

The Carrier Method of sending a number of telephone and telegraph messages at once over one wire is technically one of the most interesting and important of the developments which have been perfected in the art of electrical communication during the past few years. In this text-book we give an explanation of the principles on which this system is based.

The underlying principles of Carrier Current Systems are old in the communication art and indeed go back to the date of the invention of the telephone itself. However, new developments were made possible largely by two devices now indispensable to the communication engineer, the Vacuum Tube and the Wave Filter.

In an ordinary telephone circuit, each frequency component in the voice of the speaker is transmitted by an electrical current of the same frequency. In most cases, the electrical equipment of the circuit is not called upon to transmit frequencies above about 3000 cycles per second. In carrier current operation, however, the voice frequency currents are caused to modulate (vary the amplitude in accordance with the signal) a high-frequency current which thus serves as a carrier for the message. In this way, an additional telephone channel is obtained, using frequencies entirely above those transmitted in connection with the ordinary voice frequency channel. By using other high frequencies, several additional messages may be transmitted simultaneously on the same wires. Each channel occupies a certain range of high frequencies. For example, the words of one speaker may be conveyed by a channel employing frequencies from about 23,500 to about 26,000 cycles per second. At the receiving terminal, the various incoming ranges of the high-frequency current are separated by electrical filters. Then, by demodulation (detection), the original voice frequency currents are produced again and are transmitted over voice-frequency circuits, the transmission over each channel thus reaching the proper listener. In this way, a telephone line already carrying direct current telegraph and voice-frequency telephone services may be multiplexed so as to provide additional telephone facilities. In a somewhat similar manner, the high-frequency range may be used instead to transmit telegraph messages.

The different carrier frequencies which are superimposed on a circuit must differ in frequency sufficiently to separate them from each other at the terminal. This is accomplished by the use of proper electrical circuits. Each carrier may be of either audible or ultra-audible frequency, but its frequency must be higher than the highest frequency represented in the message to which it corresponds. These currents, therefore, are known as carriers, since in a sense, they may be said to carry the telephone, telegraph or signalling current by which they are controlled.

PRINCIPLES OF OPERATION

The underlying principles of Carrier Current Systems will be described in their application to carrier telephony.

First, we will discuss those features which are involved in a **single-way carrier telephone transmission** channel including generation of carrier current, modulation and demodulation or detection. Next, will be considered multiplex telephony in a single direction involving the separation of channels by selective circuits, followed by a consideration of **two-way operation of single and multiplex channels.** Next, will be presented an explanation of another type of system in which no unmodulated carrier current is transmitted over the line and of a special mode of carrier current generation, particularly adapted to this system. Finally, the repeaters used for amplifying the current of carrier frequency at intermediate points, and certain other matters such as ringing and the assignment of carrier frequencies will be discussed.

MODULATION

The process by which the carrier current produced by the oscillator is so combined with the voice current from the telephone transmitter that the variations of the latter are impressed upon the former is known as modulation, and the tube circuit in which this is accomplished is known as the modulator.

The schematic circuit diagram for a single-way carrier transmission system is shown in Fig. 1. The source of carrier frequency is a vacuum tube oscillator; this oscillator generates

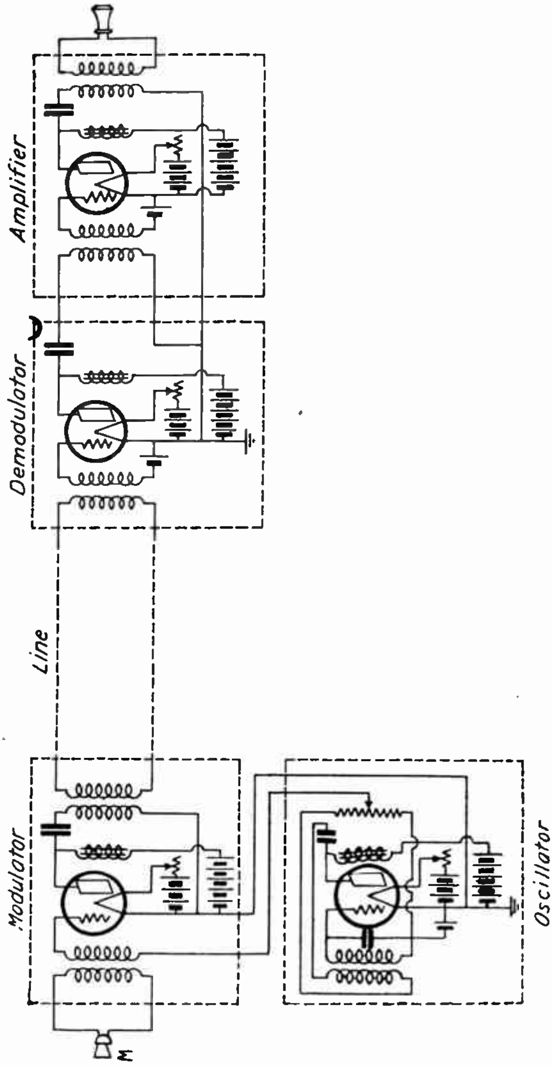

Fig. 1—Schematic circuit diagram of a single one-way carrier telephone transmission channel.

the high-frequency continuous waves capable of receiving impressions of a much lower frequency. In order to impress the signal wave on the carrier, a modulator is employed as shown. Both the carrier and the signal are combined in the grid circuit of the modulator, producing a complex wave in the plate circuit. In a carrier telephone system, a microphone transmitter is used to convert the sound waves into electrical impulses.

The action is as follows: Suppose we wish to transmit a 1000-cycle note, as given by a tuning fork. The fork is sounded before the microphone, M. The modulator transformer induces an alternating potential in the grid circuit of the modulator tube. At the same time, the oscillator tube is adjusted to 20,000 cycles, (the frequency of the carrier wave). The output of the oscillator tube is impressed on the grid of the modulator tube in series with the signal voltage. The characteristic of the modulator tube like that of an ordinary detector tube, is such that a complex wave appears in the plate circuit. This wave contains several components, among which are: the original carrier frequency of 20,000 cycles; the sum of the carrier frequency and the signal frequency, that is, 21,000 cycles, and the difference between the carrier and the signal of 19,000 cycles. The 21,000 cycle wave is called the upper side band and the 19,000 cycle wave is called the lower side band. In general, any tube having such characteristics will combine two input waves; the output wave will have these three component frequencies.

The complex wave now travels along the transmission line to the receiving station. Here, a vacuum tube, called a demodulator or detector, separates the original signal frequency from the carrier-wave and passes it to a low-frequency amplifier. The demodulator possesses the same characteristics as the modulator tube. The complex transmitted wave containing the three component frequencies is impressed on the grid of the demodulator. The plate circuit of this tube contains a wave consisting of similar components—that is, the sum and difference of the input frequencies. In this case, the only audible frequency is the difference between the carrier and side band which is 20,000—19,000 and 21,000—20,000 or 1,000 cycles. The 1,000 cycle wave is now amplified and reproduced at the phones. This action is characteristic of every Wired Radio System or commonly called Carrier System.

The form of a modulated carrier-wave is shown in Fig. 2. Here, curve A shows a modulating wave of irregular form representing the voice current, curve B, the carrier-wave, and curve C, the modulated carrier-wave, whose envelope has the form of the modulating wave.

It is evident that since speech can be reproduced from either side bands alone, there is no necessity for transmitting both. Accordingly, the selective circuit to be described later may be so designed as to transmit only one side band. As this effectively halves the range of frequencies assigned to each channel, its great importance is at once obvious. The effect on the wave

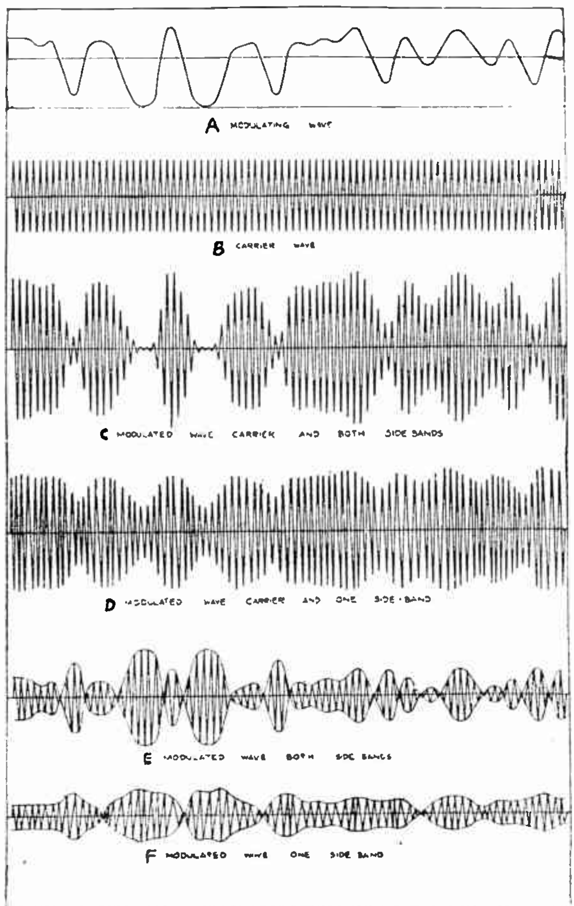

Fig. 2—Illustration showing band of voice frequencies, below, in normal position before modulation; above, in the position adjacent to the carrier frequency to which it is raised by modulation.

form of suppressing the upper side band is shown by curve D, Fig. 2. It is seen that in addition to the form of the envelope being changed, the times at which the current passes through zero are no longer equally spaced.

It is necessary to consider the inter-action between the frequency component of the side band itself, for if, in the case of telephony, the voice wave includes components of more than one frequency, each will be represented by a corresponding component in the side band. The inter-action of these two component frequencies, simultaneously present in the side band, gives rise to a component in the output circuit of the demodulator, the frequency of which is the difference between those of the corresponding two components of the original voice wave. Such currents will have a serious effect on the quality of the reproduced speech, if their amplitude is comparable with that of the reproduced voice current. The amplitude of this distorting component is proportional to the product of the amplitudes of the two side band components, whereas the amplitude of each of the two components of the desired voice current is proportional to the product of the amplitude of its corresponding side band component and the carrier. The reproduced voice current can be made large compared with the distorting current only by insuring that the carrier is large compared with every component of the side band. As a result of this, it follows that in order to secure good quality, it is necessary that the greater portion of the energy applied to the demodulator consist of unmodulated carrier frequency.

The behavior of the receiving apparatus—that is, the demodulating tube to interfering current, such as may be produced by induction from external sources of electrical energy, so-called static interference, etc., can be directly deducted from the above considerations. With properly designed selective circuits, only those line currents whose frequencies lie in the range of the side band being transmitted can reach the demodulator.

It follows, therefore, that in designing a system, it is the side band current in which are preserved the characteristics of the speech, which must at all points along the line be kept large compared with the extraneous disturbing current lying within its range of frequencies.

While the discussion of modulation and demodulation has been made as concise as possible, it is evident from the foregoing that these two are complimentary processes. Modulation may be thought of as elevating the band of essential speech frequencies to a position adjacent to the carrier frequency, and demodulation may be regarded as the process of restoring this band to its normal position in the frequency scale. In Fig. 3, the band of frequencies is shown, below, in its normal position, before modulation, and above, in the position adjacent to the carrier frequency to which it is raised by modulation.

ELECTRICAL FILTERS

When a number of one-way channels of the type schematically shown in Fig. 1, each employing a different carrier frequency, are operated by super-position on a common line, each channel must be connected with the line through selective circuits which transmit only the range of frequencies assigned to that particular channel. Not only must the demodulator assigned to a given channel be prevented from receiving from the line the currents of other channels, but the sending modulator must be prevented from putting onto the line currents of frequencies out-

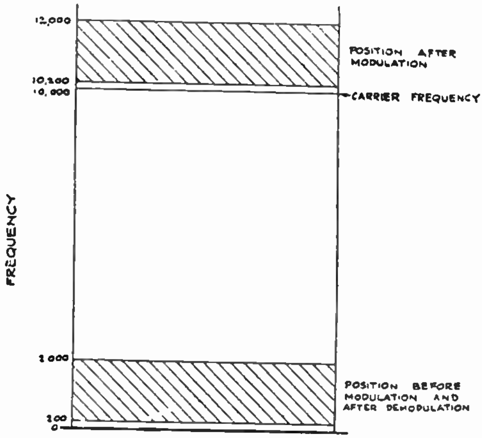

Fig. 3.

side of its assigned band. The general position of the selective circuit in such a one-way Multiplex System is indicated in Fig. 4.

As will be brought out later in the discussion of the behavior of lines with respect to their transmitting efficiency at carrier frequencies and with respect to cross-talk between adjacent circuits on a pole line, the most desirable frequency range is rather limited. For this reason, where it is supposed to secure a maximum number of channels simultaneously operating on a given circuit, it is necessary to make the frequency intervals between the adjacent carrier channels as small as possible. The first limitation to the frequency separation between carrier frequencies is determined by the fact that, as already pointed out, the width of the side band must correspond to the voice frequency range; that is, even with the ideal apparatus, the carrier frequencies must have at least a separation of approximately 2000 cycles per second. The ideal selective circuit that permits this close spacing of frequencies is one which would transmit efficiently this side band, having a frequency range of 2000 cycles, and would absolutely block off frequencies outside of this band. Because it is not physically possible to secure such an ideal circuit, we are obliged to make a greater separation in carrier frequencies than that made necessary by the width of the side band.

The nearest approach to this ideal selective circuit, particularly for carrier operation at moderate frequencies, is secured by the use of what has come to be known as an "electrical filter."

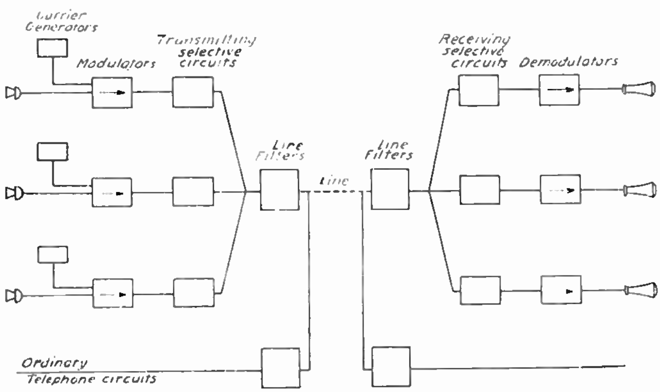

Fig. 4—General position of the selective circuits in a one-way Multiplex System.

This arrangement was invented by Dr. G. A. Campbell even before practical carrier operation was made possible by the perfection of vacuum tubes and the development of their use as oscillators, modulators, and demodulators. Campbell's electrical filter is a net-work composed of inductances and capacities which transmit with a minimum of attenuation current whose frequencies lie in a predetermined range, and attenuate very greatly currents whose frequencies lie outside that range. While these filters may take a variety of forms to meet special needs, they are all alike in that the currents traverse a succession of meshes or sections. The discrimination against the frequencies which it is desired to exclude may be increased in any physically practical value by increasing the number of sections.

TYPES OF FILTERS

Filters may be divided into four general classes: Low pass filters, which pass currents of all frequencies from zero up to a certain frequency called the cut-off frequency and suppress all currents whose frequency is above the cut-off frequency. High-pass filters that pass currents of all frequencies above a definite frequency called the cut-off frequency and suppress currents of all frequencies below this cut-off frequency. Band-pass filters which pass currents whose frequencies are included between two

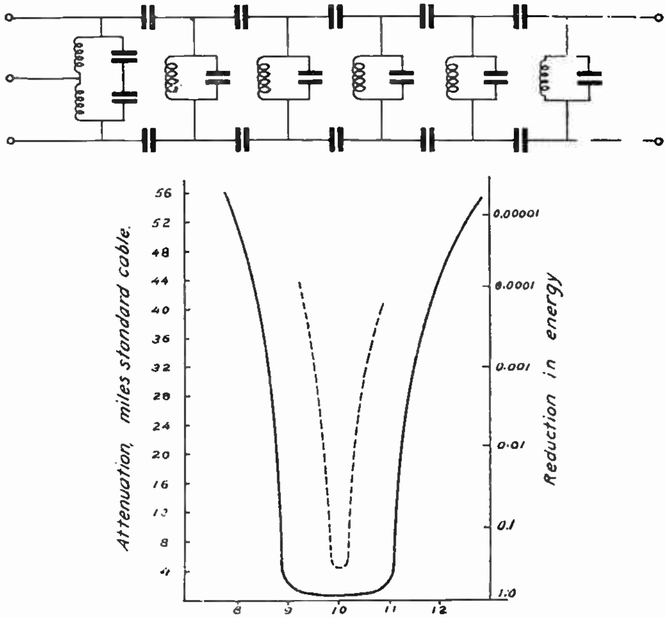

Fig. 5—Type of filter circuit used in carrier telephony.

cut-off frequencies and suppress currents of all frequencies outside of this range. Low and high pass filters or band elimination filter is one that suppresses currents whose frequencies are included between two cut-off frequencies and passes all currents of all frequencies outside of this range.

Figure 5 shows a type of filter which has been used to great advantage in carrier telephony. As this filter transmits a band of frequencies, it has, for convenience, been termed a "band-pass" filter. The transmission characteristics of this filter are also shown in Fig. 6 where the attenuation introduced into a circuit by the insertion of this filter is plotted against the frequency of the applied current. The attenuation is expressed in miles of standard cable. For the convenience also of those not familiar with this usage, there is shown at the right a scale from which may be read for any frequency the fractional reduction of the energy due to transmission through the filter. This particular filter is designed to transmit the upper side band of a carrier of 9000 cycles or the lower side band of a carrier of 11000 cycles.

At this point, it may be instructive to compare the performance of the filter just described with that of a pair of loosely coupled circuits resonant to a frequency in the transmission band of the filter. Attenuation characteristics of such a tuned circuit are shown by the dotted curve in Fig. 5. It is obvious from the attenuations of this circuit in the frequency range of the side band that such a circuit is very poorly adapted to the purpose of carrier telephony.

Referring again to the "band-pass" filter described here, it is of interest to consider the relation between its attenuation characteristics and the operation of the system. The form of the attenuation curve within its transmission range is important from the standpoint of the quality of the transmission of the carrier channel in which the filter is used. If the attenuation is uniform throughout the frequency range which the filter is designed to pass, the effect is nearly the same as that of increasing the length of line by a corresponding amount, and the loss can be compensated for by amplification inserted somewhere in the system. If the attenuation is not the same for all frequencies within the band, as, for example, if it is greater at the edges than at the center of the band, then the difference in transmission equivalent for different components of the side band will introduce a similar distortion in the over-all transmission frequency curve for various voice frequencies, as measured from the modulator input to the demodulator output. Such a distortion will manifest itself by more or less impairment in the quality of the telephone transmission.

Both the magnitude of the attenuation (reduction in power) within the frequency band transmitted and the variation with frequency are dependent upon the dissipation of energy in the coils and condensers, as well as upon the choice of their electrical constants. The problem of securing filters of desired transmission characteristics has been largely one of obtaining reactance elements of high time constant and of high accuracy and stability. For the capacities, mica condensers are largely used. For the inductances, a special core material of finely divided iron has been developed which has made possible toroidal iron-core coils which are superior in time constants to air-core coils for frequencies up to the highest values used in these systems. At the same time, they are more compact and have less stray field. Transformers having similar iron cores are also used throughout the carrier system.

As has been indicated above, the attenuation of the filter outside of its efficient transmitting band, determines the necessary

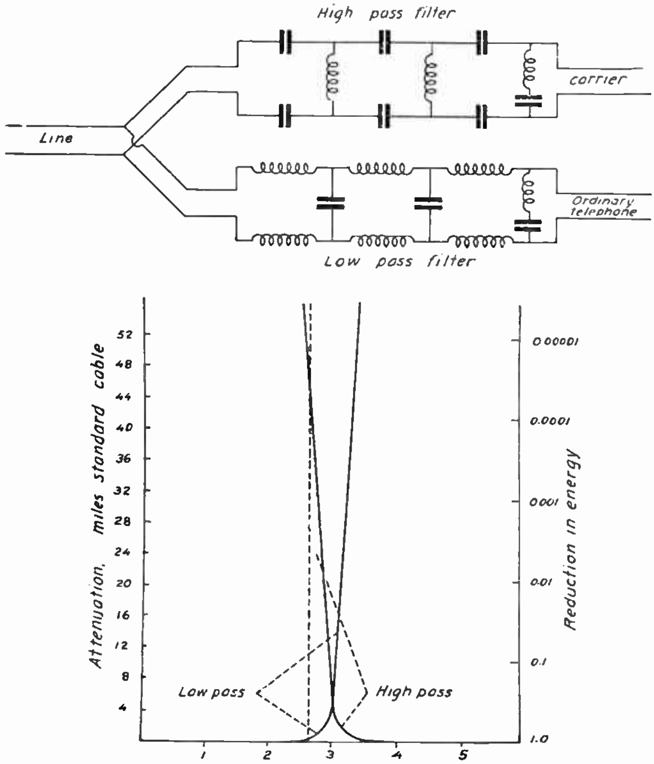

Fig. 6—Circuit arrangement of a combination of carrier line filters with their attenuation curves.

frequency separation between the side bands of adjacent channels and, therefore, to a large degree also the number of channels which may be operated in a given frequency range. For example, if channel A is operating through the filter shown in Figure 5, then the frequency band of channel B must be so chosen in the frequency range that the attenuation of the filter in channel A for currents of the frequencies of channel B is at least as great as some value fixed by the cross-talk requirements imposed on this system.

The attenuation outside of the transmission band is practically independent of the resistance of the coils and the dissipation in the condensers, but is determined almost wholly by the arrangement values of the reactances employed in a section and by the number of sections. Numerous special arrangements have been made for controlling the form of the attenuation curve and for giving to the filter an impedance best suited to the circuit with which it is connected. It has been found practical to design filters which permit operation with intervals of about 1000 cycles between adjacent telephone channels; that is, 3000 cycles between adjacent carrier frequencies.

In addition to separating the various carrier channels from each other, it is found convenient from an operating standpoint to separate within the toll offices the carrier frequencies as a group from the frequencies used for ordinary telephony and telegraphy. For this purpose, the portion of the line which is used in common is connected with the carrier apparatus through a high-pass filter, which transmits all frequencies above a predetermined value (in this case, above 3000 cycles), and suppresses all frequencies below this value (in this case, below 3000 cycles). Similarly, connection is made with the ordinary telephone and telegraph circuits through a low-pass filter, which in this instance passes frequencies below 3000 cycles and suppresses those above. This combination of carrier line filters, sometimes called, a high-frequency composite set, is shown in Fig. 6 together with the attenuation curves of the two filters. Referring to this figure, it will be seen that currents in the multiplex line divide between the low-pass and high-pass filters shown at the top of the figure. The division is determined at any particular frequency by the relative input impedances of these two branches. Accordingly, the high-pass filter is designed to offer a high input impedance to currents of ordinary telephone frequency, and to have an impedance equal to that of the line for currents within the carrier frequency range. Correspondingly, the low-pass filter is designed to offer a high input impedance to currents of the carrier frequency range and to have an impedance equal to that of the line for currents of ordinary voice frequency. The attenuation (reduction in power) of the high-pass filter is small for carrier frequencies and large for voice frequencies, while the reverse is true for the low-pass filter.

The location of these line filters in a carrier system is indicated in Fig. 4. A low-pass filter is also used in the output circuit of the demodulator to prevent currents of frequencies higher than the essential voice range from being transmitted to the subscriber.

ARRANGEMENT FOR TWO-WAY TRANSMISSION

Thus far the discussion has been limited to transmission in one direction. Provision must be made, however, for associating these one-way channels with the connecting telephone lines so as to permit two-way conversation. In many aspects, the problem resembles that encountered in adapting the one-way amplifying element to a two-way talking circuit by means of a telephone repeater. The similarity of the two problems exists not only in the fact that the carrier channel and the repeater element are both unilateral or one-way arrangements, but also that both involve amplification, and, therefore, the same possibilities of singing are present in the case of the carrier as in the case of the repeater. The experience which was gained in the development

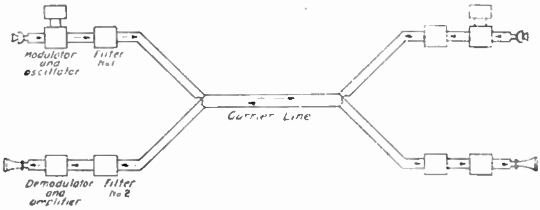

Fig. 7—Drawing showing elementary form of a two-way carrier telephone circuit.

and engineering of telephone repeaters has proved of very great value in connection with the development of carrier current systems.

In Fig. 7, there is shown schematically an elementary form of a two-way carrier telephone circuit. Filters are included in the transmitting and receiving branches, as they are necessary in those branches for multiplex operation. This circuit is entirely operative between two fixed telephone stations. If the same frequency is used for transmitting in both directions, there will be obviously an excess of side tone in the receiver circuit. It is plain that such a type of circuit has very limited commercial application, and it is shown here merely as a starting point for building up the more generally applicable types.

In general, it is desirable to be able to connect any desired telephone trunk or toll line to the section of lines equipped for operation by the Carrier Current Method. It is necessary to adapt a circuit of the type which has been studied for many years by telephone engineers, first in connection with subscriber sets, and second in connection with repeater circuits for connecting these lines together.

Figure 8 shows schematically such an arrangement. At either terminal of the carrier frequency line, the sending and receiving branches, instead of terminating in a transmitter and receiver, terminate in what are in effect conjugate branches of an alternating current bridge. If the impedance of the artificial line exactly simulates the impedance of the voice frequency line, and electromotive force applied between the points A and B, no current will flow in the branch, CD, of the carrier current circuit. This represents a condition of zero coupling between the input and output circuits of the carrier current system; hence,

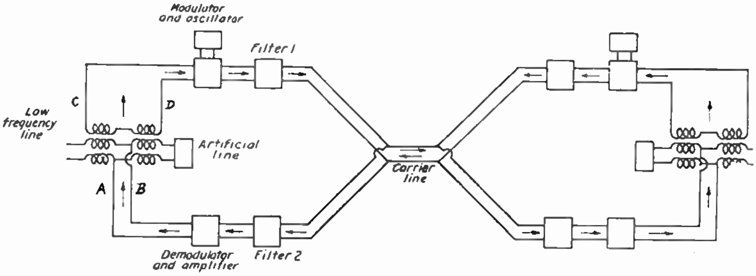

Fig. 8—Drawing showing elementary two-way carrier telephone circuit with connections to subscriber sets and repeater circuits.

persistent oscillations—that is, singing, cannot be set up. If, however, the balanced network does not accurately simulate the low-frequency line, either of two types of singing may occur. In the circuit arrangement in Fig. 8, if the same frequency is used for transmission in both directions, the type of singing most likely to occur would be local singing at either terminal. This occurs because in general the amount of energy applied to the two terminals C and D is largely amplified in the course of passing through the circuit-modulator, filter 1, filter 2, demodulator and amplifier. If the unbalance in the bridge circuit is such that the fraction of this energy which is fed back to the points C and D is as large as that originally supplied, singing occurs.

To avoid this type of singing, different carrier frequencies may be chosen for transmission in two directions. If this is done, local singing cannot be set up for the reason that filter 2 acts as a block to the return of the output current on itself. End to end singing as distinguished from local singing may, however, occur providing the over-all transmission loss of the line and the terminal apparatus is made less than zero, and providing that there is sufficient unbalance between the artificial lines and the low frequency lines at both ends. By transmission loss of less than zero is meant that the attenuation of the carrier line is more than compensated for by amplification introduced either at the terminal stations or at intermediate repeater stations. However, the accuracy of line balance necessary to prevent end to end singing with carrier circuits such as have been used is very much less than would be required to prevent local singing if the same frequency were used for transmission in both directions. It is interesting to note that in both of these types of singing the sustained oscillations in different portions of the circuit are of

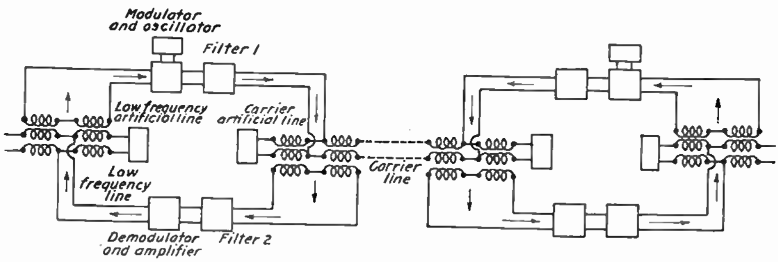

Fig. 9—Drawing showing arrangement of a two-way carrier telephone circuit using different carrier frequencies in the two directions.

different frequencies. Those in the portions used for transmission and voice frequency have some value lying in the voice frequency range. Those in the portions used for transmission of carrier frequencies differ from the carrier frequency associated with that particular channel by the frequency of the oscillations in the low-frequency circuit.

Whereas with the circuit shown in Fig. 8, local singing is prevented by the use of different carrier frequencies in the two different directions; it is possible to prevent this type of singing without resorting to different frequencies by the attendant reduction in number of channels, by the use of the arrangement shown in Fig. 9. In this arrangement, the energy from the output of the modulator is prevented from reaching the input of its associated demodulator by placing the two in conjugate relation in an alternating current bridge, of which the carrier frequency line forms one arm, and a balancing network designed to simulate the line impedance, the other arm.

Both the arrangement shown in Fig. 8 and that shown in Fig. 9 have been successfully employed for two-way carrier current transmission.

We have already discussed quite fully the selective characteristics of filters and their relation to one-way multiplex operation, and have, in the preceding paragraphs, pointed out the fundamental principles of two-way operation. In Fig. 10 is shown schematically an arrangement for two-way multiplex operation capable of giving four two-way carrier conversations in addition to the normal telephone facilities. It will be noted that in this Multiplex System, the basic two-way transmission system of Fig. 9 is employed. A similar two-way Multiplex System could be built up employing the basic two-way Transmission System shown in Fig. 8.

CARRIER SUPPRESSION

One of the systems which has been developed, particularly for use on long high-grade circuits involves certain fundamental principles in addition to those already discussed. It will be recalled that, as stated, the proper operation of the demodulator requires that the side band current by which are transmitted the characteristics of the speech, be accompanied by a relatively large amount of unmodulated current of carrier frequency. When this carrier current is transmitted from the modulator, it is evident that only a relatively small part of the line current is actually used in conveying the characteristic variations of the voice current. If, therefore, this carrier current is supplied to the demodulator from a local source instead of over the line from the sending station, the amount of line current which it is necessary to transmit per channel is very materially reduced for then only the relatively small side bands are transmitted. Curve E, Fig. 2, shows the wave form with the carrier suppressed when both side bands are present; and curve F, Fig. 2, shows the wave form with the carrier suppressed when only one side band is present. In the application of this method, means must be provided for eliminating the carrier current at the sending end and for applying it to the demodulator from a local source at the receiving end.

Elimination of the carrier frequency at the sending end can be accomplished by what is known as a balanced modulator, a schematic circuit of which is shown in Fig. 11. In this arrangement, two tubes are connected in the manner similar to the push-pull repeater circuit. The voice frequency essential is applied differentially to the grids of the two tubes by the transformer T1. The carrier potential is applied through the transformer T2 to the common portion of the input circuit in such a manner that the carrier frequency potentials of the two grids with respect to the filament are at any instant the same. The resultant carrier frequency currents in the plate circuits of the two tubes are then equal, and the fluxes which they set up in the core of the differential transformer, T3, are equal and opposite; hence, no voltage of the frequency of the unmodulated carrier is induced in the output circuit. By a more detailed analysis, it can be shown that the side band currents resulting

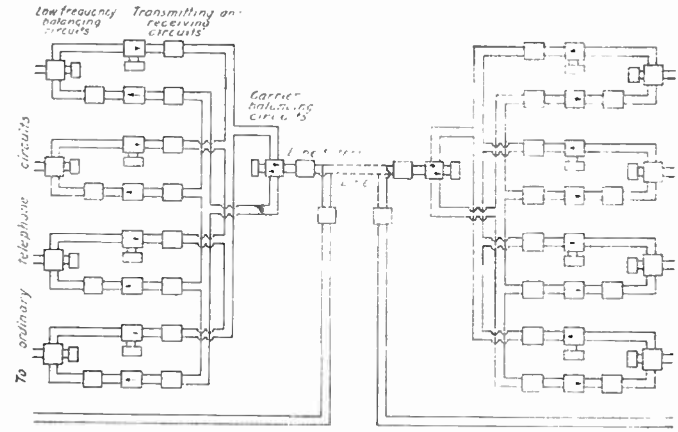

Fig. 10—Drawing showing arrangement for a two-way Multiplex System capable of giving four two-way carrier conversations in addition to the normal telephone facilities.

from the inter-action of the carrier and speech frequency current are not balanced out, but are reproduced in the output circuit. It should be noted that under these conditions, high-frequency current appears in the output circuit only when low-frequency telephone currents are being applied to the input circuit of the modulator.

HARMONIC GENERATOR

In order to insure that the carrier current applied to the demodulator in the above system employing suppressed carrier is of exactly the same frequency as that used for modulation at the sending end, an arrangement has been devised whereby both these frequencies are derived from the same source. For this purpose, at one terminal of the system, a vacuum tube oscillator generates a frequency somewhat above the voice range—say, 5000 cycles. Current of this frequency is applied to the input of another vacuum tube in such a way as to overload it. This harmonic generator as it is termed, is so arranged that the current in its output circuit has a distorted wave form containing permanent components whose frequencies are exact multiples of the applied frequency. The various harmonics of the base frequency (in this case, 10,000, 15,000, 20,000 cycles, etc.), are separated by suitably designed selective circuits and lead into individual circuits where they are amplified and made available for use as carrier currents, each in connection with a different channel. At the same time, current of the base frequency from the controlling oscillator, in this case, 5,000 cycles, is amplified and transmitted over the line to the other terminal. Here it is separated by a filter, amplified and applied to a second harmonic generator, which produces the same series of current frequencies as does the harmonic generator at the controlling station already referred to. These regenerated harmonics may not only be used for demodulating the transmissions received from the controlling terminal, but may also be used in connection with balanced modulators which send in the reverse direction. The demodulators at the controlling station are supplied with the carrier current from the harmonic generator at that terminal.

The Suppressed Carrier System, besides employing smaller line current, has two other important advantages. One is the absence of audible beat notes, resulting from inter-action in the demodulating circuit between the carrier frequency normally present, and others which may be present through cross-talk or lack of perfect balance. Where all of the carrier frequencies are generated separately, these combination frequencies may in certain cases give rise to disturbing tones within the voice range. With the harmonic arrangement on the other hand, the only possible frequencies are differences of the base frequency itself and its harmonics, all of which are above the normal voice range, and accordingly are suppressed by the low-pass filter in the output circuit of the demodulator. As a matter of fact, this harmonic arrangement is practically essential where the same frequency range is used for both directions.

The second advantage rises from the fact that the variations in the attenuation of the line, due to weather changes or other causes, have less effect on the transmission equivalent of the system where the carrier frequency itself is not transmitted.

This will be clear when it is recalled that the magnitude of the voice current in the output of the demodulator is proportional to the product of the amplitude of the carrier and side band currents. If, therefore, the change in line attenuation is such as to increase or decrease the side band current by a given ratio, the carrier current when transmitted will in general also be changed in the same ratio, and the resultant voice current will be changed by the square of this ratio. In the Suppressed Carrier System, the side band is changed as before, and the carrier is increased or decreased not by the change in attenuation which occurs at the carrier frequency, but by the changes, that are much smaller, which occur at the base frequency, affecting the voice current much less in this case.

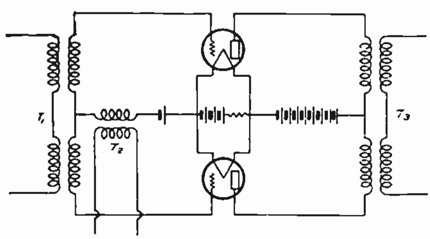

Fig. 11—Circuit diagram of a balanced modulator.

REPEATERS

From the discussion of the transmission characteristics of lines, the very great practical importance of amplifying apparatus at intermediate points on a line employing carrier frequencies will be evident. For this purpose, fortunately, we have available, first, the vacuum tube, and, second, a large variety of methods of applying this tube which have been developed to a high state of efficiency in connection with the voice frequency telephone repeater. While, as just indicated, the same general considerations apply to repeaters for carrier current circuits as to repeaters on circuits operated at voice frequencies, the conditions peculiar to carrier current operation require that repeaters for this service differ quite considerably from standard voice frequency repeaters.

In the first place, on a multiplex carrier current circuit, a single repeater installation may handle the energy associated with a number of independent conversations. This could be accomplished by making the installation include a number of repeaters in parallel with suitably associated filter combinations, but it is at once obvious that it is much preferable to install but one repeater channel capable of amplifying all the carrier transmission. The requirements for the repeater set are made still more severe by the fact that modulation in a repeater tube which tends to increase with the load introduces disturbing factors in carrier operation which are not serious in ordinary repeater operation. The reason for this is that the combination frequencies resulting from the inter-action of the current in two channels may lie in the frequency range of a third, in which case they are transmitted through the selective circuit of that channel and appear as an interfering noise at the subscriber's station. To obtain sufficient energy carrying capacity, and to overcome to some degree this difficulty of inter-modulation, we use a number of tubes in parallel in the so-called push-pull arrangement.

In this arrangement, the input voltage is applied in such a way as to increase the grid voltage of one tube with respect to its filament at the same time that the grid voltage of the other is diminished. The plates are connected with the output circuit by a differential transformer, so that the useful amplified currents from the two tubes are added, while the more troublesome interfering components due to modulation are equal in amplitude and opposite in phase, and hence are balanced out.

In repeater operation at voice frequencies, the amount of amplification which can be secured on a given line and with given types of repeater apparatus is limited by the tendency to sing. The same is true for repeater operation at carrier frequencies. To reduce the tendency of the repeater to sing, the same methods may be adopted as are employed at the terminals; that is, if the same frequencies are used for transmission in both directions, the lines on either side of the repeater must be balanced and the same general type of repeater circuit used as for voice frequency telephone repeaters.

SIGNALLING OVER CARRIER TELEPHONE CIRCUITS

For a carrier telephone channel to form an integral part of an ordinary telephone connection, it is in general desirable to be able to operate the normal signalling mechanism over the channel without the intervention of an operator at the terminals of the carrier section. This is accomplished by two distinct methods in the two types of systems employed. In the type where carrier current is transmitted over the line, an auxiliary rectifier tube is associated with the demodulator in such a manner that the incoming carrier current produces in the output circuit of this rectifier a direct current sufficient to maintain a relay in its operating position. When the operator signals, the ordinary 60-cycle ringing current is received at the carrier terminal. This is made to operate a relay, which disconnects the source of carrier current from the modulator, thereby stopping its transmission over the line. As a result, at the distant terminal, the relay controlled by the rectified current falls back causing an ordinary 60-cycle ringing current to be sent out over the connecting line associated with that particular channel.

In the system where the carrier current is suppressed, the 60-cycle ringing current from the low-frequency line operates a

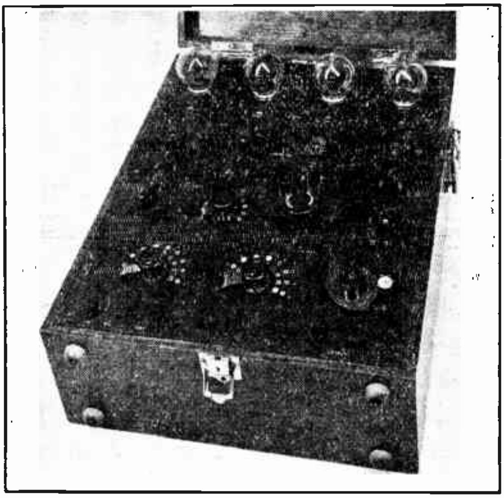

Fig. 12—Photo of a portable high-frequency oscillator designed for testing work.

relay which applies a current of 133 cycles from a vacuum tube oscillator or other source to the modulator through the speech circuit. This current interacts with the carrier current in the modulator to produce a single band current, differing from the current by 133 cycles, which is transmitted to the distant terminal. Hence, it is demodulated and appears in the voice frequency circuit as a current of 133-cycle frequency. This current operates the relay tuned to this frequency, which in turn serves to send out 60-cycle ringing current over the low-frequency line.

TELEGRAPHY

Carrier current telegraphy is based on the same fundamental principles as carrier current telephony, but in actual operation it employs somewhat different typical arrangements, owing to the differences in the nature of the signals to be transmitted and to the differences between the operating conditions met in the two cases.

LINES

General. The electrical design of Carrier Systems is determined in large part by the problems which arise in the transmission of the carrier current over the line wires. The comparatively high frequencies used in carrier transmission attenuate much more rapidly in passing along the line, and have a much greater tendency to cause interference in adjacent circuits than do the ordinary telephone frequencies, but attenuation and interference increase rapidly with increased frequency. Because of this, it has been found most economical to make use of the frequency range commencing immediately above the voice range. The systems which have so far been put into commercial use employ frequencies up to about 30,000 cycles.

LINE MEASURING APPARATUS

To put the lines in proper shape for carrier operation, and to maintain them properly, has necessitated the development of suitable measuring technique and of portable measuring units, including a high-frequency oscillator, high-frequency impedance bridge, detector circuit, thermo-couples, etc. A photograph of a portable high-frequency oscillator designed for efficient work is shown in Fig. 12.

COMMERCIAL APPARATUS AND INSTALLATION

Under this section, there is given a description of the apparatus which has been developed for commercial service and of the manner of employing it in actual installations in the Bell Telephone Plant.

To date, there have been developed and put into commercial use three distinct types of Multiplex Carrier Systems, as follows:

(1) A Carrier Telephone System in which the carrier is transmitted.

(2) A Carrier Telephone System in which the carrier is suppressed.

(3) A Carrier Telegraph System.

There has also been developed a two-way repeater set employing vacuum tubes and suitable for use with any one of these three systems.

CARRIER TELEPHONE SYSTEM EMPLOYING TRANSMITTED CARRIER

The apparatus which characterizes this type of system is indicated in schematic form in Fig. 13 which shows the terminal

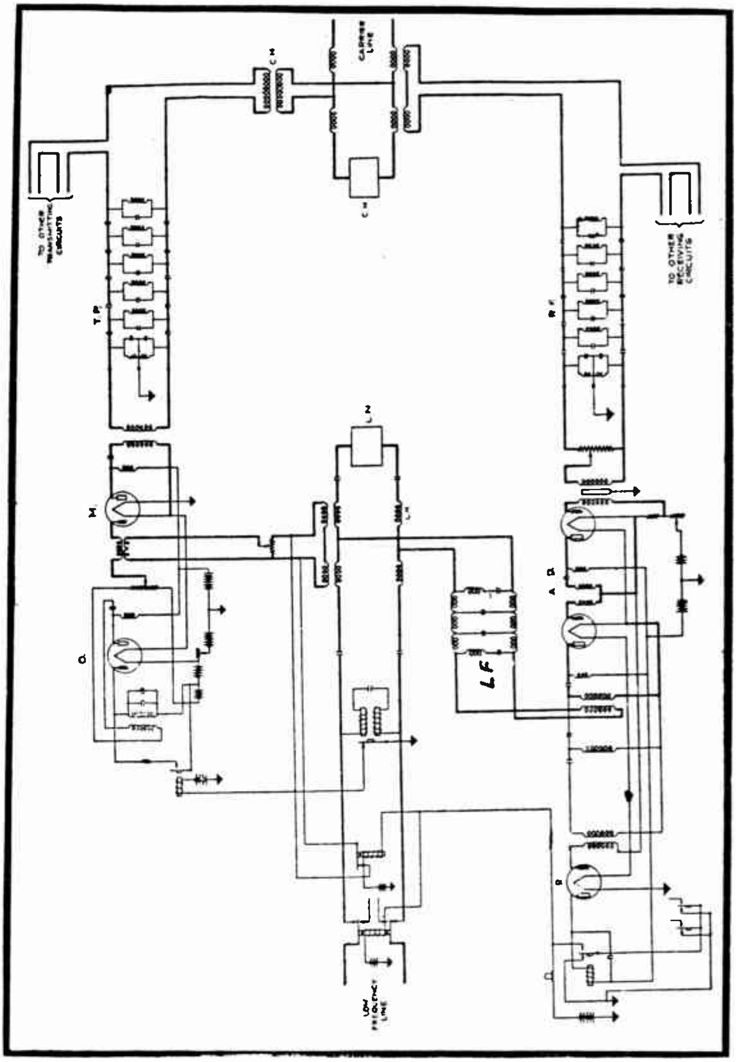

Fig. 13—Schematic circuit arrangement of one two-way carrier telephone channel.

circuit arrangement of one two-way channel. This circuit can perhaps be most simply explained by tracing the path of current involved in telephone transmission, which is shown by heavy lines in the figure. Voice frequency currents originating in the low-frequency line on the left pass through the low-frequency hybrid coil, LH, into the vacuum tube modulator, M. There is likewise fed into the modulator the carrier current from the vacuum tube oscillator, O, shown in light lines. Of the components of modulation appearing in the output circuit of the modulator, the transmitting band filter, TP, suppresses all except one side band, either the upper or lower, as desired, and the carrier, which it transmits or traverses into the circuit common to all the transmitting channels. The transmitting current from this and the other channels then pass through the carrier hybrid coil, CH, and out on the carrier line. The balancing net-

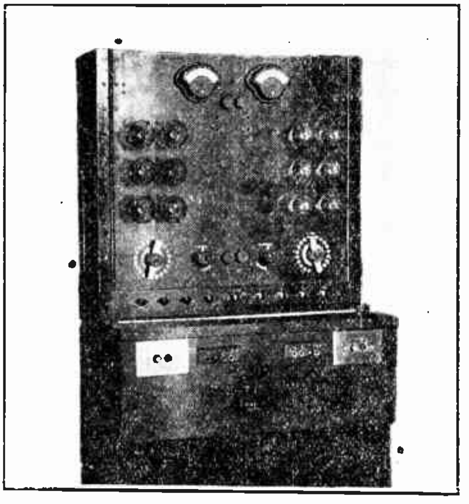

Fig. 14—Photo of a repeater set used with Carrier Current System.

works, LN, and CN, shown in Fig. 13, are important elements in determining the satisfactory operation of the system.

The currents received from the line, as in the case of any given channel, consist of one side band accompanied by its carrier, pass through the carrier hybrid coil and are selectively passed to the earth's appropriate receiving circuit by means of the receiving band filters, one of which is shown at RF. The current passing through the filter, RF, is then amplified and demodulated in the two-stage vacuum tube unit, AD, and the voice frequency currents appearing in the output circuit are selected from the other components of demodulation by the low-pass filter, LF, from which point in this circuit they pass through the hybrid coil, LH, to the connecting voice frequency line.

It should be pointed out that Fig. 13 indicates the points of connection for the transmitting and receiving circuits of the other two-way channels of the Multiplex System, which are led

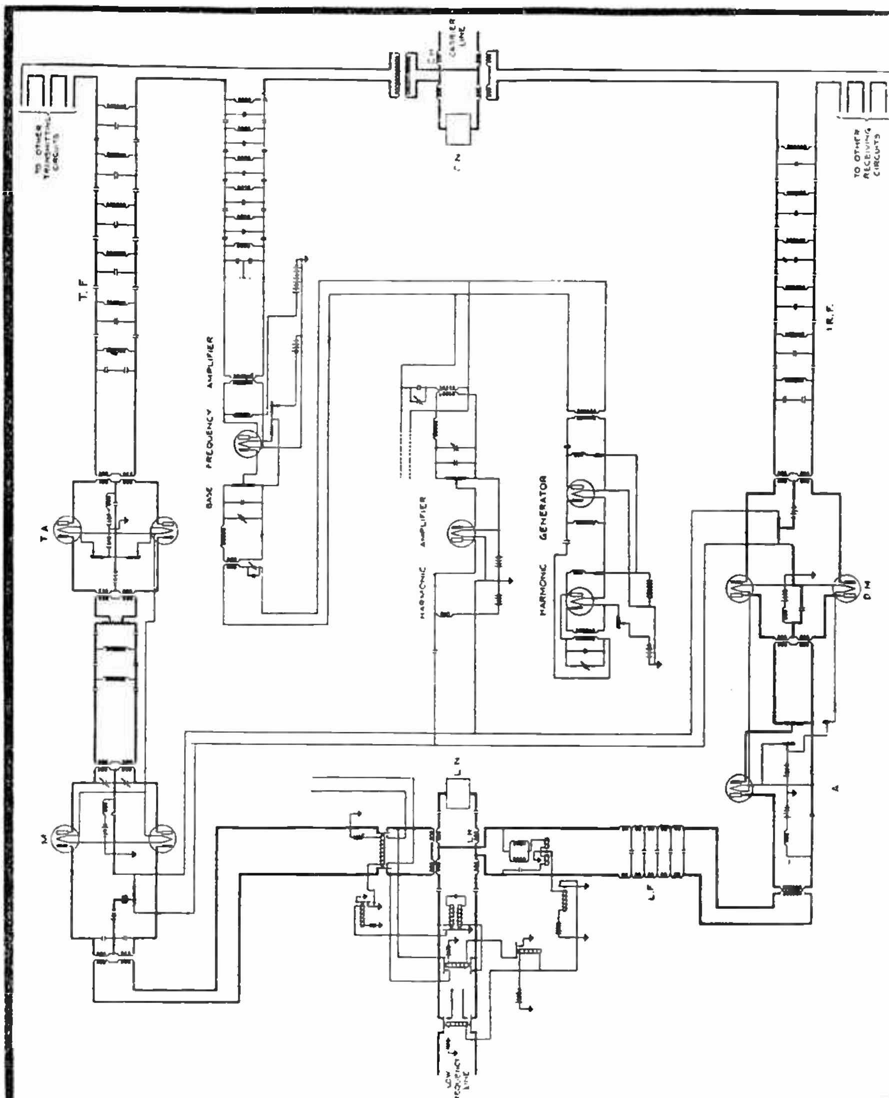

Fig. 15—Circuit diagram of one terminal of one two-way channel and common Carrier Supply System.

to additional low-frequency lines through sets of apparatus which are exactly duplicate to the one shown, except for the modifications necessitated by the use of different frequencies over the different channels. The relays and the rectifier employed in signalling by the methods already discussed are also shown in the figure in light lines.

A front view of an actual set is shown in Fig. 14. This set includes a two stage push-pull amplifier, one for operating in each

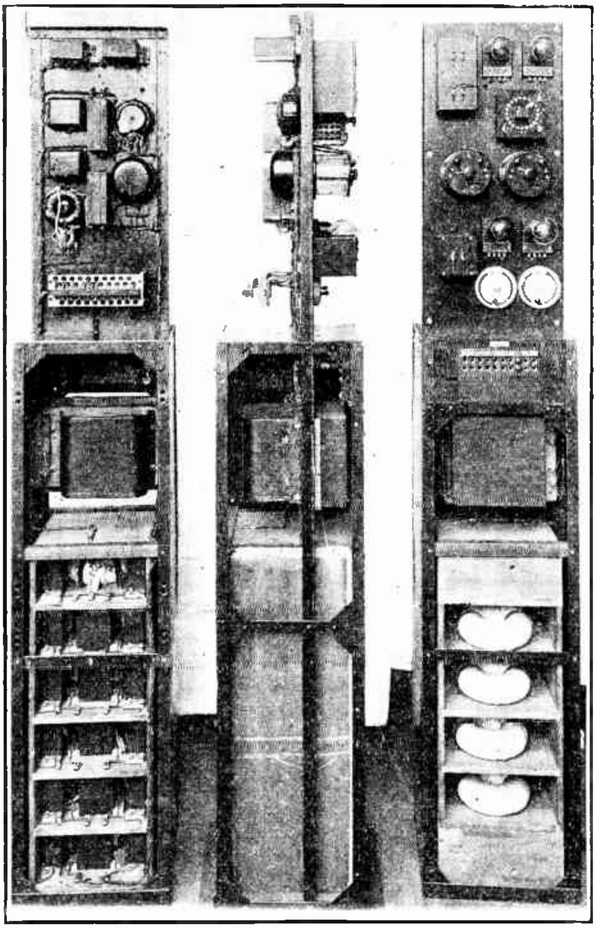

Fig. 16—Sending and receiving apparatus for Suppressed Carrier Telephone System.

direction, and the necessary filters and hybrid coils for associating the set with the line.

An installation of this type is afforded by the Harrisburg-Detroit system, which is planned for New York-Detroit telephone service.

The second type of Carrier Telephone System has been designed to operate on the principle of carrier suppression and harmonic carrier generation. In comparison with the system just described, it is rather more complex and there is more auxiliary terminal apparatus common to all the channels. Figure 15 is a circuit diagram of one terminal of one two-way channel, together with the common carrier supply circuit. As usual, the transmission circuits are indicated by heavy lines, while the light lines show the carrier supply and the signalling. The system indicated is one designed to use the same carrier frequency for both directions of a two-way conversation. Therefore, the harmonic generator is shown as feeding through the same selective circuit and harmonic amplifier, into the modulator, M, and the demodulator, DM. The harmonic generator is supplied with

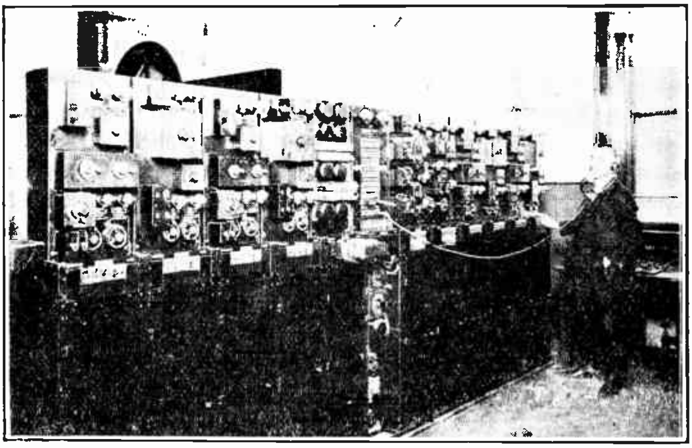

Fig. 17—Photo of carrier telephone suppressed carrier apparatus in Chicago.

the base frequency from the oscillator, and in addition to supplying the harmonics, also supplies the base frequency to the terminals of the base frequency amplifier, which selectively amplifies the frequency and supplies it to the line shown. In the transmission circuit, it will be noted that in addition to the balanced modulator, M, already described, a push-pull amplifier, TA, is used to increase the volume of side band current transmitted. The high-pass filter between the modulator, M, and amplifier, TA, prevents the latter from being overloaded by the voice current in the output of the modulator. The balanced demodulator, DM, serves to prevent the transmission of the local carrier back over the line. The carrier supply apparatus shown includes the harmonic generator, used at the controlling station. At the distant station, the arrangement is modified to provide for amplifying the base frequency received from the incoming carrier line and supplying it to a harmonic generator which supplies the various frequencies through the amplifier to the modulators and demodulators associated with each channel.

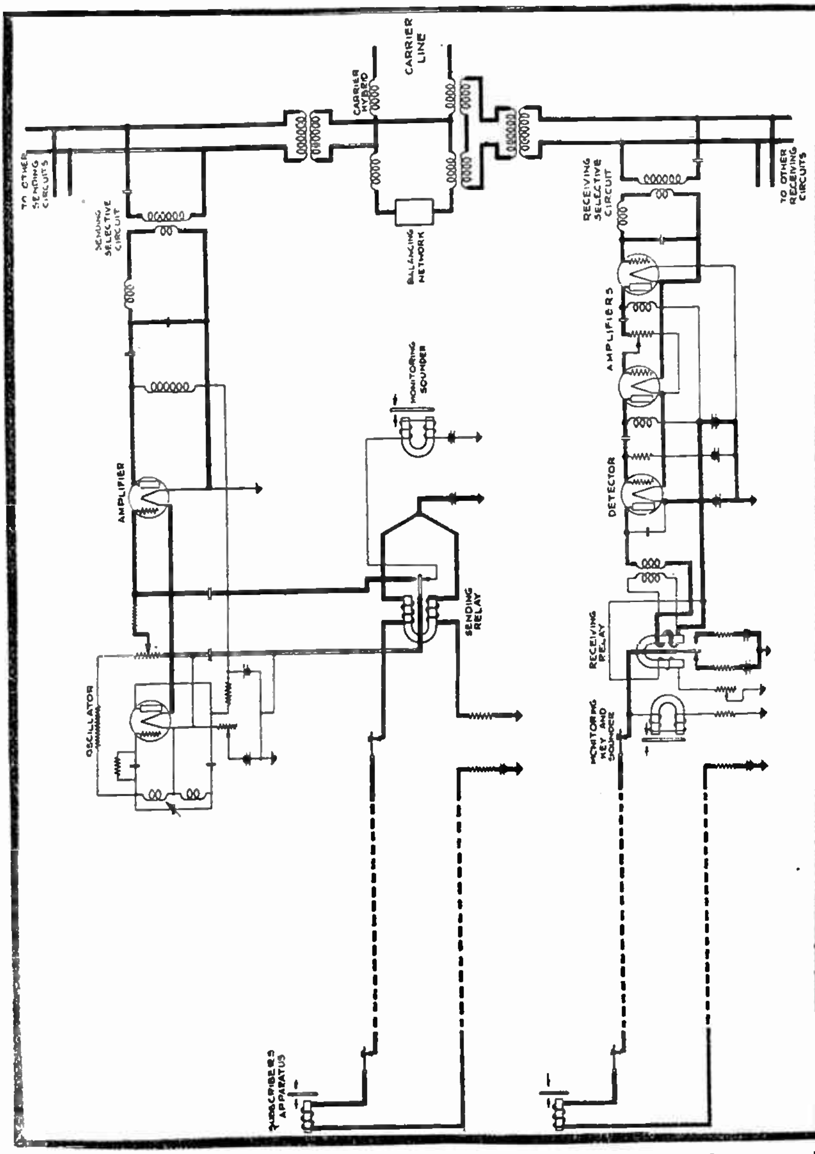

Fig. 18—Circuit arrangement showing one terminal of a duplex carrier telegraph channel.

The apparatus of this system has been mounted on unit racks of self-supporting type. One such unit holds the sending apparatus for one channel and another the receiving apparatus. Illustrations of these are shown in Fig. 16.

This type of apparatus is employed in a Harrisburg-Chicago system, the circuits of which are extended into New York as voice frequency circuits in order to provide New York-Chicago service.

The appearance of the apparatus at the terminal offices is shown by Fig. 17, which is that located at the Chicago terminal. In the center of the group of panels is seen the test panel by means of which the routine maintenance tests of the apparatus and lines are made.

CARRIER TELEGRAPH SYSTEM

Figure 18 shows a circuit for associating ordinary telegraph sending and receiving loops with one terminal of a duplex carrier telegraph channel. It also shows schematically the high-frequency side of the system including the selective circuits and the vacuum tube apparatus. The operation of the high-frequency side of the system will be clear from a consideration of the simplified telegraph circuit and from what has been said of the operation of a very similar carrier telephone apparatus.

TEST QUESTIONS

Number your Answer Sheet 50 and add your **Student Number.**

1. What two devices made possible the developments on carrier current systems?
2. State briefly the difference between an ordinary telephone circuit and a Carrier Current System.
3. What is the advantage of a Carrier Current System?
4. Explain the purpose of the essential parts used in a single-way Carrier System.
5. What is meant by side bands?
6. Can speech be reproduced from either side band?
7. Why are band-pass filters used in Carrier Systems?
8. Draw a diagram of a simple Multiplex Carrier System.
9. What arrangement is used in which the carrier-wave or carrier current is not transmitted?
10. State the advantage of using the Carrier Suppression Method.

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