

SERVICING

by

SIGNAL
TRACING

by JOHN F. RIDER

SERVICING BY SIGNAL TRACING

By

JOHN F. RIDER

AUTHOR OF

*AM-FM-TV-PA Perpetual Trouble Shooter's Manuals,
TV and Radio Text Books for the
Service Industry*

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who is now half-past seven

AUTHOR'S FOREWORD

DURING the past decade the technical problems of the radio serviceman have been increasing in direct ratio to the progress which has been made in receiver and tube design. . . . Engineers' dreams have been many and varied these last few years and their realizations are little short of marvelous when radio reception of today is compared with that of the early 1930's, but unfortunately servicing technique has not kept pace with developments. . . . Far too many servicemen are still using Stone Age testing methods.

It was with the primary idea of giving the servicing fraternity a technique that would be universal in application and as useful when applied to tomorrow's sets as to those of yesterday that we started laboratory research for a testing method that eventually developed into the one described in this book. First of all we cast about to find some one factor that was common to all receivers on which we could base our system of testing and this common denominator was found to be the signal. Trace the signal through a receiver until it departed from normal—and there was the point in the circuit where the trouble originated. That the theory was sound was proved in the laboratory and since its presentation to the radio servicing fraternity it has been acclaimed by thousands of workers in the field—research and design engineers and servicemen—because it has made for speedier and more accurate localization of trouble.

Realizing that a successful application of signal-tracing technique depended upon the knowledge of how the signal behaved in the several circuits of a receiver and how it was affected by the various components which made up these circuits, it was felt that a book describing these subjects was decidedly in order. . . . And

in broad terms, that is what we have endeavored to give you in this book. You will find chapters devoted to the *behavior of the signal* in detectors, amplifiers, coupling devices—and we believe that these will present a new conception of the functioning of these pieces of apparatus to many of you. Bear in mind as you read, that the signal—and *the signal alone*—is the all-important factor.

Strictly speaking, our first thought was the development of a system for testing receivers, but as we progressed in our studies we found that signal tracing could be equally well applied to all forms of communication wherein electronic apparatus acted upon a signal. Thus our scope was broadened to include television, public-address and intercommunication systems, facsimile, sound pictures, aircraft and amateur radio, etc. Fundamentally, many of these different forms of electrical communication are alike and so you will find only the broad viewpoint taken throughout the text. However, if you will think in terms of the signal—its frequency and amplitude—the arrangement of the apparatus through which it passes will make little difference . . . the principles underlying the functioning are the same.

It is our sincere hope that this book will change the cumbersome and haphazard testing methods of its readers to one which is all-embracing in its scope—a technique that is purely functional and dynamic and at the same time is easily and quickly applied and accurate in its findings. We believe that the adoption of such a system is a necessity in view of all the complications in the servicing industry and in view of the future needs in all branches of the communication field.

JOHN F. RIDER.

October 23, 1939.

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Chapter I

WHAT IS MEANT BY SIGNAL TRACING?

WHAT do we mean when we speak of signal tracing in connection with receiver servicing? Essentially it is a system of locating defects in communication systems with the greatest speed, accuracy and convenience. However, as a system, it embraces certain operations. Basically it is a means of locating a defect by observing the performance of the receiver upon a test signal fed into the antenna input system of the receiver. To accomplish this end, signal tracing calls for observation of the presence, absence, and character of the test signal at key points of the receiver system. Supplementing this test is measurement of those control voltages which are in any way associated with the signal. Final conclusions are reached by measurement of the operating voltages in those circuits where the signal tracing process has localized the fault.

The signal test is considered the primary or fundamental test. The secondary tests are those associated with the various voltages already mentioned. Of these two voltages, the control and operating, the former is considered to be the more important, although both are placed in the same category. As a follow-up of the voltage tests, we also employ, when necessary, a d-c resistance test. However, the d-c resistance test is not always employed after the voltage test. If the results of the signal-tracing test localize the defect as being in a certain component, it is possible to dispense with the voltage test and to apply the d-c resistance test to the component in question. Thus the actual routine subsequent to the signal-tracing test depends entirely upon existing conditions.

The sequence of testing expressed in its simplest terms is as follows: The test signal is traced through the receiver until some point is reached where it is no longer normal. Then supplementary tests are made at that point where the signal departs from normal, or in that portion of the system that is related to the particular section of the receiver where the signal first departs from normal. As is to be expected, however, there are instances when this sequence of operation is modified, but such variation does not occur frequently enough to interfere with the identification of the system as being of a certain general character.

When we speak about the signal we include a number of items. Tracing the signal means all of the items to follow, but not necessarily a progressive test to check all of these conditions. For example, it might be necessary to establish whether the signal exists in those circuits where it should exist, whether it is absent from those circuits where it should not exist, and furthermore, whether the signal has the proper level or intensity at certain specific points in the system in accordance with the manner in which the units operating upon the signal are intended to perform. Added to the above are such items as frequency, the presence of interfering signals, distortion, overload, hum, unbalanced signal voltages, etc.

Working with the signal-tracing routine as a means of localizing the defect, we embrace, for a number of reasons to be given later, all of the components utilized in the receiver. This is so because the function of all of the components of a radio receiver is to secure proper operation of that receiver with respect to the signal, and hence, to show some effect, direct or indirect, upon the signal. Therefore, the process of signal tracing makes possible a definite identification of the manner in which individual components function in addition to an identification of the manner in which complete sections of a receiver operate. Signal tracing, therefore, becomes a *functional test* of a complete receiver, of complete sections of a receiver, and of the individual components of a receiver,—*all with respect to the signal*.

Whereas for the past twenty years and even longer, it has not been possible to check certain sections and points in a radio receiver, practically all are opened for investigation by this system of signal tracing. In fact, signal tracing means checking

of the signal at whatever points are desired by the operator. The importance of this is that there is no specific routine which must be employed and from which it is impossible to deviate. Each person can select whatever routine of signal tracing he may desire, although it is true that one particular sequence affords advantages. Individual likes and preferences in procedure are not banned . . . In other words, the application of signal tracing as a means of locating the defect in a receiver is a system of locating a defect based upon securing and interpreting basic information rather than a rigid process of selecting test points.

The Signal Is the Common Denominator

Why do we select the signal as a basis of test? There is one very definite and sound reason for this choice. Expressed in simple words, it is because *the signal is the common denominator of all communication systems*. Strange as it may seem, this fact has been overlooked for many years. Perhaps it was due to its very simplicity, to the fact that it was so basic as to be taken for granted, and therefore not recognized . . . It may be likened to not seeing the forest because of the trees.

Radio communication is the same the world over and while there may be certain small differences in design between receivers or transmitters produced and used in different parts of the world, one thing is common to all: *the signal*. As a matter of fact, recognition of the presence of a radio wave—the original Hertzian wave—was by means of the signal at the receiving end, the spark between two metal balls.

The simplest of all radio receivers has one thing in common with the most complicated of radio receivers. That common factor is the signal. No matter where the receivers are made, whether in China or in New York, both operate upon a signal, and both are considered to be in normal operating condition when the signal output is normal. The two receivers may be of entirely different types, made by different races of people, designed by men who can not converse because they speak different languages, but both operate upon a signal.

The signal is the fundamental basis of determining whether a receiver or transmitter or for that matter any communication system is defective or perfect. A change from a normal to an

abnormal condition in the signal is the means of knowing that a change has developed in the communication system, and this is so irrespective of the locale, the type of service, or the people involved . . . Mr. Jones in New York and Senor Hacienda in Argentina know that something is wrong if the signal output of their respective receivers is not what it used to be. They do not have the slightest idea what defect has developed, but they know that something is wrong because the signal is not normal. The radio operator in a submarine beneath the sea, the operator in a plane miles above the earth, or the operator at a land station, all judge performance and operation by noting the signal.

No matter what the character of the communication service—whether code, speech, music, or picture—the same thing is true in all. *The signal is the fundamental, elemental, basic factor in all of these systems.* Any number of defects may develop in a communication system, but if they do not influence the signal, the presence of the defect will never be known. On the other hand, the simplest defect is instantly noticed if of such character as to influence the signal so that it departs from normal.

There is nothing mysterious about this close relation between the signal and operating condition. It is quite natural since the components used in the communication system—the receiver or transmitter—are employed in order to develop a certain signal. As a matter of fact, the reason why we have a transmitter and a receiver is in order that a signal be transmitted from the sending apparatus to the receiving apparatus. Therefore, it is quite in order to say that the signal is the common denominator for all communication systems and that the signal is the fundamental or basic element in a communication system.

Operating Voltages and Resistance Are Not Fundamental

For years the radio industry at large considered operating voltages and d-c resistance values as the fundamental or basic items associated with radio maintenance or servicing. Today we have come to the realization that such ideas are erroneous. These two items cannot be considered fundamental, if only for two conditions, which no doubt have been experienced by every man who has been in contact with radio maintenance, no matter where he lives.

Analysis of every radio receiver, simple or complex, old or new, domestic or foreign, will show that any number of defects may exist in the system without in any way altering the operating potentials or d-c resistance values present in the system. The reason for this is that every radio receiver or communication network contains components which are not a part of the operating-voltage distribution network or the function of which has no bearing upon either d-c operating voltages or d-c resistance values. For example, some of the components utilized to obtain proper tuning can become defective without influencing operating voltages or d-c resistance values. In fact, certain tube circuits, such as those used with diode rectifiers, are extremely important in the modern receiver, yet operating voltages in particular are entirely absent . . . In other words, it is possible to make the direct statement: *all operating voltages may be normal in a radio receiver, yet the signal may not be normal.*

On the other hand, any defect which causes a departure from normal in either d-c operating voltages or d-c resistance values *will influence the signal.* Because this condition is true and can be proved by any one sufficiently interested, we are justified in making the statement that neither d-c operating voltages nor d-c resistance values can be placed on a level with the signal as a common denominator for radio receiver servicing. This does not deny the fact that many defects can be localized by a d-c operating voltage test and/or by d-c resistance test. It does, however, recognize that the localization of trouble by operating voltage and d-c resistance measurements has too many limitations and does not possess the merits of signal tracing.

The Advantages of Signal Tracing

What makes signal tracing such a superior method of localizing defects? It is possible to answer this question by summing up all of the advantages into three classifications relating to the economic viewpoint, by saying *superior speed, universal application* and *positive identification.* However, such a statement does not fill our needs because it does not present the full and complete picture. In order to acquaint you with the tremendous scope of this method of locating defects, we must of necessity dwell in detail upon all of the salient features of this mode of operation.

Functional or Dynamic Test During Operation

The first major advantage of signal tracing is that the receiver being tested is checked in actual operation or at least under operating conditions. This is of tremendous importance because of the large number of possible defects in a receiver which manifest themselves only when the system is in an operative state. The state of operation may not be productive of a normal signal because of the defect, but in order to be able to locate the defect it is necessary that the receiver power be "on."

Defects of the above variety do not always interfere with the operating potentials or the d-c resistance values in the various circuits, since they are not necessarily associated with open circuits or short circuits . . . All the connections are normal, yet the defect exists. Troubles of this type in the past have been representative of major service problems, essentially because of the absence of a trouble localizing technique which was capable of establishing the location of such defects without interfering with the operation of the receiver.

Examples of the aforementioned types of defects are to be found in any number of abnormal receivers. In a superheterodyne, for instance, the defect may be the presence of an excessively strong intermediate-frequency signal in the audio-frequency amplifier. Or coupling may exist between the second detector tube and the input of the intermediate-frequency amplifier by means of a lead which is a part of the audio system. Still another case may be the development of fading over a portion of the tuning band due to the fact that the tuning condenser rotor wipers do not make perfect contact when the condenser gang is in a certain position.

None of these defects is really complicated, yet its effect on receiver operation is of major importance. For example, such a trifling defect as a shifted coupling lead in an antenna coil or r-f transformer is sufficient to interfere definitely with the normal operation of the receiver, without in any way altering operating potentials or d-c resistance values. Only a functional test of this coupling device will show that it is defective in signal transfer. The coupling lead in such a device is not joined to the secondary and therefore does not short the primary or secondary

windings. Further, the electrical connection between the open terminal of the lead and its primary junction is intact.

We recognize that a visual inspection of such a unit might show the altered position of the coupling lead—that is, if the correct position is known—but since these transformers are frequently within shielded cans and usually in places where access is difficult, visual inspection is not always effective. This is particularly true after a d-c resistance test has shown the primary and secondary to be normal. Furthermore, such a minute visual inspection of all components results in a tremendous expenditure of time, which is entirely incompatible with the rapid servicing required in modern times.

It is possible to devote many pages to a listing of defects of this type, which, in order to be localized with the greatest speed and utmost convenience to the operator, require a functional test. Items such as frequency drift of oscillators, gassy tubes which develop after a period of use, rectification in amplifier tubes, noisy components, signal pick-up in power-supply circuits, modulation of the power-supply voltage, coupling between circuits operating at different frequencies, etc., are seldom complicated in nature, but are exasperating to identify by means of a static test. Signal tracing, on the other hand, being a functional test, makes the location of such defects comparatively simple because all components and circuits are tested in actual use.

Independent of Tube Types

The process of locating a defect by signal tracing is not dependent on the type of tubes used in the radio receiver. No matter what the type of tube—low impedance, high impedance, four, five, six, seven or eight prongs, glass or metal, r-f amplifier, oscillator, converter, rectifier, i-f or a-f amplifier,—signal tracing can be employed with uniform simplicity. No matter how many functions are performed by the tube, a certain orderly performance is still to be found within the tube as far as signal transfer is concerned. No matter where the various tube element contacts are located—the control grid on the bottom, top, left or right side, the plate on top or bottom—contact can be made with these points without having to remove the tube from its socket and the signal tracing process can be applied.

The age of the tubes used in the system being checked is of no consequence. Old as well as new tubes, and even tubes to come are encompassed by the signal-tracing routine. Inasmuch as the system is not dependent on tube types, it is naturally not dependent on the age of the tube, because age has nothing to do with its intended function. Age might interfere with performance merit and, if it does, it can be identified by the signal-tracing test by noting the manner in which the tube amplifies, rectifies, or performs its particular function.

The origin of the tube is likewise of no importance. The tubes made in Holland and used in a Philips receiver, or tubes made in Sweden and employed in a Swedish receiver, or British tubes used in a receiver made in England—all these can be checked as readily as American tubes used in an American receiver.

As far as tubes and tube types are concerned, the factor of obsolescence in testing is entirely removed. In this connection the signal-tracing process of testing tubes is not beset by the limitations to be found when tubes are checked in a tube tester. As a matter of fact, more than one major tube company has gone on record as stating that the final test of a tube is a functional test, that is, its actual performance in the circuit under the conditions of normal use. This is not accomplished in the normal tube-checker test. It is, however, accomplished in the signal-tracing test, for in this test, an r-f amplifier is checked as an r-f amplifier, an oscillator is checked right in the circuit where it is used and over the full frequency range it is supposed to cover, i-f amplifiers are checked as i-f amplifiers, converters as converters of frequency, diode rectifiers as diode rectifiers, voltage limiters as signal-voltage limiters, afc control tubes as afc control tubes, etc.

No matter what the function of the tube in a communication system, the signal-tracing process provides for a test of this tube right in the system without removing the tube from the circuit. Even if a tube is removed for a supplementary test in a tube checker, if such a test is considered necessary by the operator, a tremendous amount of time is saved in the process because the necessity for removing and checking each tube in a tube checker is eliminated. Only the tube under suspicion, as established by

the signal-tracing test, is removed from its regular socket for a supplementary test.

It might be of incidental interest to mention briefly the tremendous superiority of a signal-tracing or functional test of a tube right in its normal circuit rather than the conventional emission or mutual-conductance test. All receivers are not designed in exactly the same manner with respect to circuit constants, and, in many instances, tubes which are exceptionally good for one specific purpose may be unsuited for the r-f or i-f systems because of the regeneration introduced into the receiver. A new tube with slightly higher than normal mutual conductance may result in excessive regeneration and thereby interfere with the normal operation of the receiver. Then again, certain tubes with normal emission and mutual conductance values within the stated tolerance limits may oscillate over a certain portion of the frequency range of the receiver, but not over the complete frequency range. Thus, while the tube checker would show this tube to be normal and good, it still may not be suitable for the receiver in question, and this must be determined by a functional test of the tube in the actual circuit where it is used.

Last, but by far not the least, are those cases of tubes which develop gas after a certain period of use and after the tube has reached a sufficiently high temperature. In some instances this period of use may be ten minutes, while in other cases it may take one or two hours. The routine test of such tubes in a tube checker will not show up the fault unless the tube is allowed to remain in the checker for the required period of time and under the exact conditions prevailing in the receiver. Not knowing which tube is at fault, such tests in a tube checker would require expenditure of hours of testing time, and with doubtful results at that. On the other hand, a functional test made at the time that the final signal output from the receiver indicates the development of a defect, would bring the offending tube into the light in short order. Therefore, not only is this system of signal tracing independent of the tube types, but it affords definite advantages over routine tube tests made with tube checkers.

Independent of Circuit Design

An extremely important advantage of the signal-tracing method of trouble localization over other methods is its complete freedom from limitations due to circuit design. This is a broad statement to make, but it is a fact nevertheless—a fact based upon actual practical experience in various radio fields, at various frequencies up to about 60 megacycles, and embracing all types of radio circuit design used in the communication field. . . .

As far as frequencies above 50 megacycles are concerned, we have confidence in the fact that if a communication system employing resonant circuits can be made to operate upon higher frequencies, signal tracing likewise can be used at the higher frequencies, for after all is said and done the signal is still the fundamental thing. In all of this discussion we wish to reiterate one statement, namely, that what is being said is not theory—it is the result of practice.

When we say that signal tracing is independent of circuit design we cover a great deal of ground because circuit design embraces such items as *type of receiver*, that is, t-r-f, superheterodyne, reflex, etc.; the *age of the receiver*, which means old and new receivers; *number of tubes*, which mean systems ranging from those which employ no tubes as in a crystal receiver to a modern 25- or 30-tube receiver. It also covers the *origin of the receiver*, which means receivers made in any part of the world, because no matter where the receiver is made, the signal still remains the common denominator.

It is possible to supplement the reference to “type” as contained in the foregoing paragraph by including a comment relating to individual specialized control circuits, as for example, automatic frequency control, automatic volume control, automatic bass compensation, automatic volume expansion, automatic selectivity control, and the like. Still another item associated with the comment that signal tracing as a means of localizing trouble is independent of circuit design, is *utility of the receiver*, which means classification of service, as, for example, the frequency range covered in the conventional multi-waveband home broadcast receiver, auto radio receiver, television receiver or facsimile receiver, and whether it embraces the police band, the

commercial aircraft bands, the army and navy channels, carrier telephony, ship-to-shore channels as used by tugs and fishing fleets, etc.

Service experience along routine lines during the past ten or fifteen years has shown clearly that the circuit design and classification of service of the receiver in question had much to do with the ease of servicing and maintaining of these receiver systems in an operative state. Each development in automatic control circuits, which embraced systems wherein operating voltages were absent and control voltages were developed as the result of the signal, greatly reduced the ability of the repair man or radio man to check these circuits with speed and accuracy and keep them in proper repair.

Remove the signal from such circuits as diode detection, automatic frequency control, automatic volume control, automatic bass compensation, automatic volume expansion, and the circuit no longer functions. In other words the very fact that the signal itself is the actuating force has in the past interfered with the servicing technique and introduced definite operating limitations to such an extent as to make servicing virtually impossible. You ask why? . . . Because the tests made were static or because the tests interfered with the operation of the receiver. The trials and tribulations of such operation were enormous and still are extremely cumbersome and costly for the man who does not employ signal tracing as the means of identifying the location of the defect. This is not strange when we realize that the signal is the most important element in these circuits, both as the actuating impulse and as that which is being controlled.

We do not intend these statements as an indictment of the servicing personnel because such condemnation is not justified. On the contrary, servicemen are to be congratulated on their accomplishments, particularly in the light of the difficulties present under the old technique. The manufacturers catering to the servicing industry developed certain testing equipment and propounded certain test methods with the advent of commercial broadcasting. The United States being a leader in radio development, foreign servicemen followed along the lines set forth here in America. The receivers were simple and the number of components in a receiver were comparatively few, so that the serv-

icing technique founded upon d-c voltage and resistance measurements proved entirely satisfactory. This general routine of trouble localization became a habit and has been followed ever since without any recognition of the fact that receivers were becoming far more complex, that each new design introduced servicing limitations, that speed and accuracy were essential for profitable operation, and that radio receiver servicing was not keeping pace with radio receiver developments.

We have repeatedly made the statement that servicing capabilities were years behind receiver design. The years 1938-1939 have proved this statement beyond a shadow of a doubt. The correspondence received from the men who have used our signal-tracing process of trouble localization in actual practice verify our opinions and substantiate our ideas. Once and for all there is removed from the radio servicing field the problem of limitations in servicing operation because of new engineering developments in communication. Whereas it had been customary in the past to improvise tests each time a new circuit development was announced, the need for some basic method of testing founded upon a factor which was the fundamental element in all communication systems still existed . . . Experience during the past year shows that signal tracing is this much needed fundamental system of servicing.

To you as a reader we may seem extremely enthusiastic . . . To tell the truth, we *are* enthusiastic in the fullest sense of the word, because this basic method places all receivers upon a single level! All receivers, all circuits, revolve either directly or indirectly around some sort of a signal voltage, because all components in every receiver, no matter what the nature of the circuit, have some bearing upon the signal passing through that receiver.

It might be well to investigate this statement. It can be described simply by saying that every circuit contains certain test points or locations where information relating to the signal, if not the signal itself, can be obtained. Any change in circuit design, in the number of tubes, in the type of circuit—in general, any difference among receivers—resolves itself into the number of test points or locations and the kind of information desired at these points. Since our system is based upon the signal, we

can say that these test points or test locations are concerned more frequently with the signal and control voltages than with either operating voltages or d-c resistance.

The exact number of points of test created by a change in design, or when one receiver is replaced by a simpler or more complicated system, is a variable since there is no rigid rule concerning the exact number of tests which must be made. This is so because every portion and every component within the receiver, irrespective of type, comes within the province of the signal-tracing test. The determining factor is the type of test to be made and the type of defect to be located. As you no doubt appreciate, there are several types of defects to be found in radio receivers which affect the operation of all of the circuits but, contrary to the general technique that has been used in the past, all components need not be checked. As a matter of fact, one salient time-saving feature of signal tracing is that it is not necessary to check all components, even in that portion of the system where the defect has been localized.

Inasmuch as the components have a definite bearing upon the signal, it stands to reason that if the signal is normal the components in the portion of the circuit embraced by the signal tests are functioning properly and therefore are normal in every respect. And, when we speak of components in this case, we include the operating voltages and tubes as well.

It might be well at this time to illustrate these points with a few examples. Suppose that we consider Figs. 1-1 and 1-2. The former illustrates a comparatively simple superheterodyne receiver. The circuit is simple and few tubes are used. Special circuits are conspicuous by their absence. The latter receiver, however, is more elaborate. The number of tubes is greater, for separate oscillator and mixer tubes are used and an automatic volume control circuit also is incorporated in the system. The number of i-f and a-f stages are increased. In general the receiver in Fig. 1-2 is more complex than in Fig. 1-1.

With signal tracing as the primary test, we have identified the major signal test points or test locations. The input circuits of the respective stages are indicated by the symbol for the grid and the output circuits are indicated by the symbol for the plate. Inasmuch as we are not at this time concerned with the nature

of the coupling between the respective stages, we do not show the coupling units or any tests associated with them. Furthermore, initial signal tests between the output of one tube and the input of the next tube embrace the coupling unit. The tests of individual coupling units are dealt with in detail later in this volume.

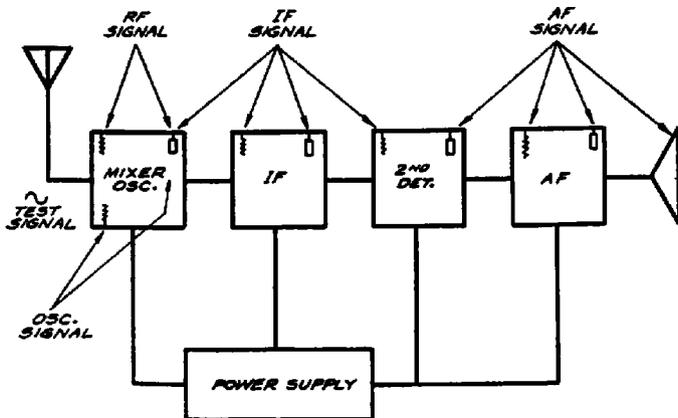


FIG. 1-1. A simple superheterodyne receiver in block form showing the principal signal test points. The input and output of each stage are identified by the grid and plate symbols.

Now, if you compare these two block diagrams, you will note that there is no difference in signal-testing routine. In other words, the increased number of tubes and the change in circuits does not alter the general test locations. All that is changed is the *number of signal test points* at radio frequencies, intermediate frequencies, audio frequencies, etc. Even this statement is subject to qualifications, for while we show the increased number of signal test points, it does not necessarily mean that the signal is checked at each of these points. If you recall, the statement was made that complete sections of a receiver can be checked just as readily as individual components, so that it is possible to check the complete i-f system in Fig. 1-2 by working between the output of the mixer and the input of the demodulator (second detector), a test which is identical to that made in Fig. 1-1,

although the number of tubes and individual test points in Fig. 1-2 is greater than in Fig. 1-1.

The routine of establishing facts concerning the signal is exactly the same in both cases, although the man who works upon the receiver must recognize certain inherent differences between the two receivers. He must recognize, after glancing at

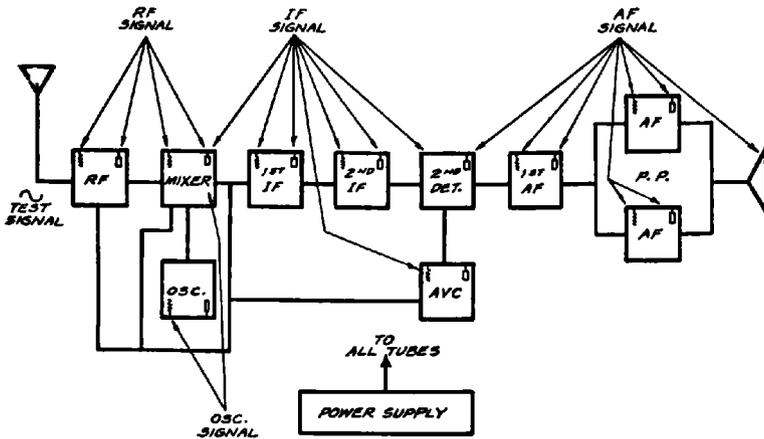


FIG. 1-2. Block diagram of a superheterodyne receiver showing the major signal test points. The r-f, i-f, and a-f sections of the receiver are indicated.

the block diagram which is used in place of the regular schematic, that Fig. 1-2 employs an r-f stage, an avc system, an added i-f stage and a push-pull stage. The reason for stressing this recognition of variations is in order to mention that the operator must know what tests are to be made and what the condition of the signal should be at the various points of test.

In this connection, the man must know that the r-f stage is supposed to provide a certain amount of amplification, that the intermediate-frequency signal actuates the avc tube, that proper operation of the push-pull audio stage means substantially equal signal voltages at the two input grids and likewise at the two output plates of the push-pull stage. He must also recognize the

manner in which the signal voltage varies between the output circuit of say the audio tube and the speaker circuit.

It is, of course, our intention to deal with all of these items later on in this book, but reference is made to them at this time in order to avoid any erroneous impressions. However, as far as the signal-tracing process is concerned, Figs. 1-1 and 1-2 are treated in like manner.

Let us take a still more complicated receiver, one with a greater number of tubes. This is shown in block form in Fig. 1-3. A separate avc amplifier is employed in this system and a push-pull a-f stage has been added. As far as signal tracing is concerned, these additions merely mean just so many more points of test. The avc amplifier adds two additional places where, when necessary, the intermediate-frequency signal may be checked. The added driver stage increases the a-f signal test points by four positions.

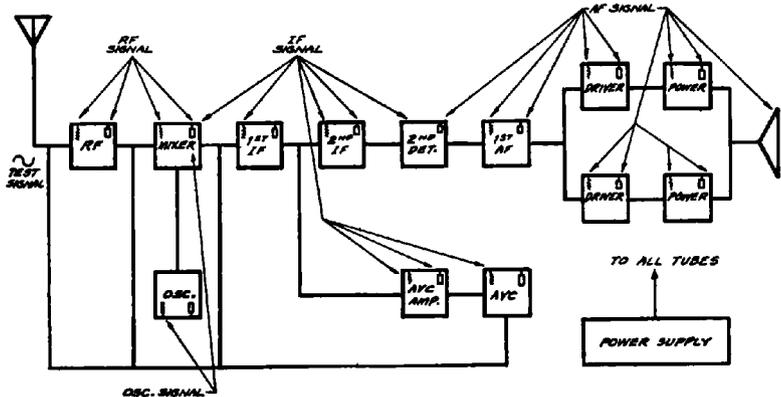


FIG. 1-3. Block diagram of a superheterodyne receiver showing the major signal test points. A separate channel is used for avc amplification.

The special circuit variations represented by the coupling units do not enter into this discussion. This was mentioned before. It does not matter whether the intermediate-frequency transformers are dual winding or triple winding, or whether the audio stages

are transformer-coupled or resistance-coupled, the various portions of the coupling units or the devices employed in conjunction with the various tubes become items of interest only after the test shows a defect in the form of a change from a normal signal.

Another example of circuit structure is shown in Fig. 1-4. This is a double superheterodyne embracing two oscillators, two mixers, an automatic volume control system and automatic frequency control. Despite the major differences between Fig. 1-4 and Figs. 1-1, 1-2 and 1-3, the same general routine of signal tracing applies. The various frequencies designated on the block diagram are purely illustrative and are used to show how, in

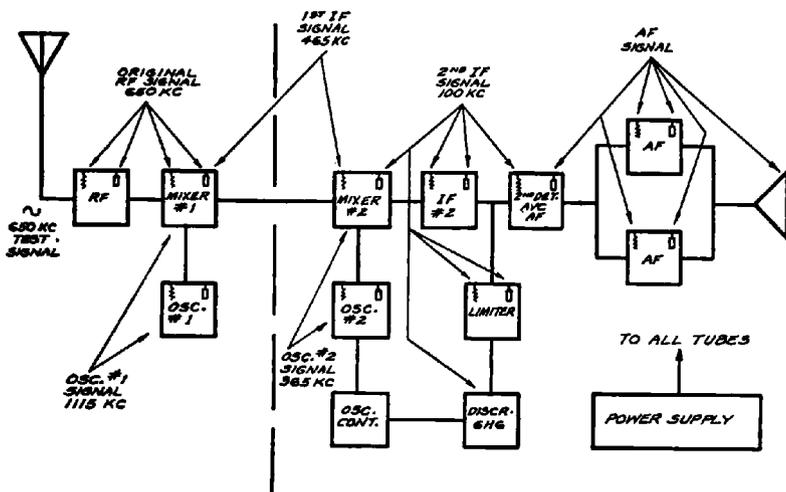


FIG. 1-4. Block diagram of a double superheterodyne receiver showing the major signal test points. The frequency of the second oscillator is automatically controlled by the afc system.

the case of the two intermediate-frequency amplifier sections, the signal is checked at two different intermediate frequencies. Naturally the two oscillators would also be checked at two frequencies, each being in accordance with the frequency of the input signal to the associated mixer and the required i-f peak.

The fact that superheterodyne receivers are used in these examples does not bear any special significance. We show them here because this type of receiver is most popular; however, tuned-radio frequency receivers could be used equally well and if a number of types were shown, the similarity in signal tracing would still prevail.

The moment is opportune to speak of multi-band receivers. As you will note, no special mention has been made concerning the number of wavebands, frequency range, or the classification of utility of the receiver. As was mentioned earlier in this text, no particular discussion is required because the variations mentioned do not in any way change the manner in which signal tracing is applied. As a matter of fact, the number of test points is not even increased when the receiver is of the multiwave type as against the usual single-frequency type, or when an aircraft or police receiver is compared with a home broadcast receiver of equal number of tubes.

By and large, the determining factor with respect to the number of general signal-tracing points is the number of tubes and not the exact circuit. Of course if the occasion arises when it is necessary to backtrack in the coupling unit because proper signal transfer between two tubes is not obtained, then the exact number of test points depends in some measure upon the type of coupling unit. However, due to the similarity between coupling units, such as among the r-f systems, or among the i-f or a-f systems, the possible variations which will increase the number of signal test points are comparatively few. These will be dealt with later. In fact, a portion of the discussion in a later chapter is devoted to the manner in which various types of coupling units operate in different circuits and what is to be expected in the nature of performance from these coupling units and the relation of this performance to the signal voltage.

No matter what receiver you might select, you will find that it is possible to illustrate that receiver in block form similar to that shown in Figs. 1-1 to 1-4, and to establish the various signal-tracing test points in exactly the manner illustrated. As a matter of fact, the man who has had experience reading schematics does not find it necessary to draw such block diagrams. He can instantly determine the various test points by examining the schematic.

In connection with these signal test points, it is of interest to mention that while we refer to signal-tracing test points as being the input and output circuits of the various vacuum tubes in the system, and while we show these test points as being the control grid and plate of the respective tubes, there is no set rule that these tube elements must be used. It is possible to use as an equivalent test point, the junction between the control grid and the component connected to the grid or the junction between the plate and the component connected to the plate. Supplementary to the above, you must also realize that the occasion may arise when the signal should be checked at tube elements other than the aforementioned control grid and plate and also in places other than the actual coupling unit connected between two tubes. This will be discussed in a later chapter.

In each of the diagrams shown thus far, the oscillator appeared as one of the places where the signal was checked. We know, of course, that the function of this tube in a superheterodyne receiver is to *generate* the heterodyning signal. Therefore, when we speak of tracing a signal in the oscillator tube, we are referring to the signal being generated by that tube and not to the test signal fed into the receiver. You no doubt realize that the heterodyne signal generated by the oscillator tube has much to do with the manner in which the test signal will pass through the receiver or the manner in which the receiver will function. As in the case of the conventional test signal, the man who works upon the receiver must be familiar with the usual operation of such oscillators and know what information is desired and how to interpret it. This, like the other facts associated with signal tracing, will be discussed in greater detail later in this volume.

As in the case of the general receiver circuit, variations in oscillator-circuit design and tubes used do not present any limitations. As a general rule, the oscillator tube is one of the items which has rarely been checked in the past. Of course, efforts were made to check this tube by interpreting conditions in other related systems, but direct observations of such items as frequency, stability, or amplitude were seldom made. This is strange in view of the tremendously important rôle played by this tube and particularly when you consider that it may be, and frequently is, defective.

Control Voltage Testing

If you recall, we made mention of the fact that checking the control voltages was a vital function in the process of locating a defect by tracing the signal. Defining a control voltage so as to distinguish it from other d-c voltages found in receivers, we describe it as being *that d-c voltage which is developed as the result of a signal* and is employed to control the amplification provided in a tube or in a section of a radio receiver. Accordingly, we may encounter control voltages and control circuits in every portion of the receiver, as, for example, the radio-frequency amplifier, the intermediate-frequency amplifier and the audio-frequency amplifier.

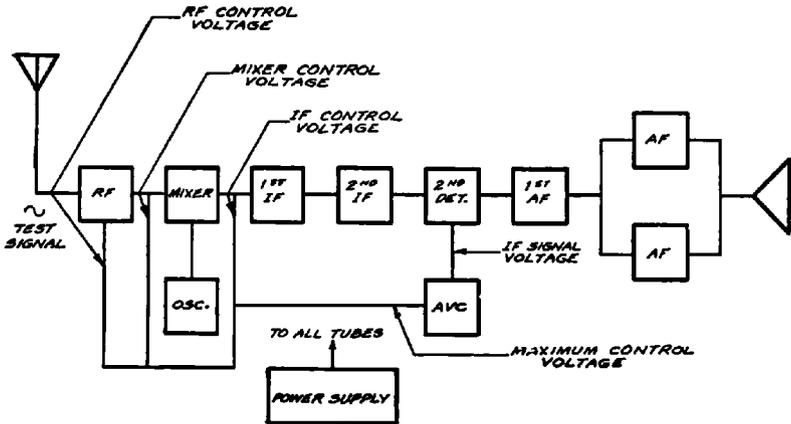


FIG. 1-5. Block diagram of a superheterodyne receiver showing the location of the control voltages.

Figs. 1-2, 1-3 and 1-4 contain various control circuits as they appear in radio-frequency and intermediate-frequency systems. In order to simplify the explanation, we shall repeat Figs. 1-2, 1-3 and 1-4 as Figs. 1-5, 1-6 and 1-7 respectively, but in the second group show the test points for the various control voltages in order to illustrate that all control systems can be checked with equal ease. The process of testing control voltages is identical

to that used to check signal voltages. Of course, there is a difference between the two voltages, the control voltage being of d-c character and the signal voltage being of a-c character, but the process of checking these voltages and interpreting them in terms of the action upon the signal consists of nothing more than establishing four essential facts. These are: (1) the function of the control voltage, (2) the source of the signal applied to the input of the control tube, (3) the control tube itself, and (4) the manner in which the control voltage is distributed to the various control points. This assignment should be within the province of every man who has occasion to work on radio receivers.

As in the previously mentioned cases of signal tracing, variations in control circuits mean nothing more than variations in the source of the signal voltage fed into the tube that develops the control voltage. It might be an i-f signal secured from any number of places in an i-f system and by various coupling means, or it might be an a-f signal secured from some place in the demodulator or audio system. Hence, a variation in the control system means a variation in the kind of signal being checked at the input of the tube which generates the control voltage and the point at which this signal is checked. Also, it may mean a variation in the number of points at which the control voltage developed in a tube is fed to the other tubes. Expressed differently, this would be a variation in the number of places where the control voltage is measured, depending entirely upon the design of the individual receiver.

For example, in Fig. 1-5, a tube marked "AVC" is used to develop the automatic-volume-control voltage. The i-f signal is secured from the second intermediate-frequency amplifier and the control voltage is fed to the r-f, mixer, and first i-f tubes. The exact type of tube being used to develop the avc voltage is of no consequence. The avc voltage is developed at the output circuit of this avc tube and this voltage is then distributed to the various tubes under control. In a circuit such as this, there are four basic control-voltage test points: the source and the three control grids which receive the control voltage. We of course assume, as has been stated before, that the device used to measure these control voltages is of such design as not to inter-

ferre in any way with the normal operation of the circuits, that is, it does not load the circuits. In the event that the control voltage does not appear at the end of the various distribution points, then additional test points may be found in the distribution channels so as to identify the exact point where interruption of the circuit occurs.

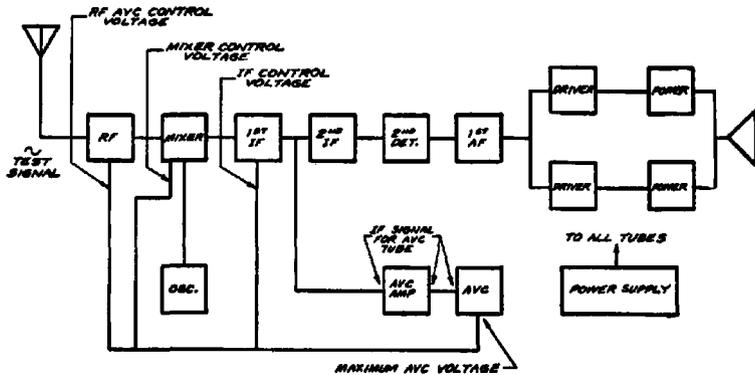


Fig. 1-6. Block diagram of a superheterodyne receiver with a separate channel for avc. The distribution of the control voltages is indicated.

If you now examine Fig. 1-6, you will find that while the number of tubes used in the receiver is greater than in Fig. 1-5, and while a separate amplifier has been provided to feed the avc tube and, further, while the i-f signal for the avc amplifier is secured from a different point in the intermediate-frequency amplifier, the number of control voltage test points in Fig. 1-6 is the same as in Fig. 1-5. In other words, the number of test points does not necessarily change with changes in receiver design. It is possible, as in the case of Fig. 1-6, that the input circuit to the avc tube changes, but the general selection of the test points is governed entirely by where the control voltage is fed.

What is said is true without any modifications in the case of second-detector or demodulator tubes which also include the function of generating the avc voltage. This tube may contain a separate diode which rectifies the i-f signal voltage and

develops the control voltage, or the avc voltage may be obtained from the second-detector load circuit. Whatever system is used, it should be understood that the avc voltage exists at the source, and that the test points, irrespective of the original source of the avc voltage, are those places where the avc voltage is fed to control the tube.

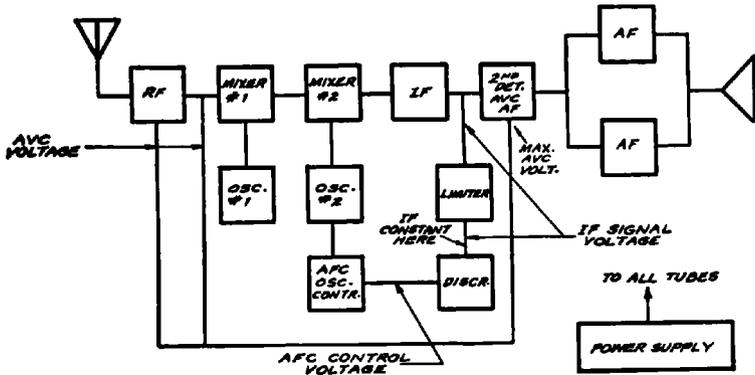


FIG. 1-7. Block diagram of a double superheterodyne showing the distribution of the control voltages. Both afc and avc voltages are shown.

An interesting control system is illustrated in Fig. 1-7. In this double superheterodyne we find both automatic volume control and automatic frequency control as well as a "limiter" tube. Suppose that we start with the automatic-volume-control system. Note, if you please, that the avc tube is also the demodulator and the first a-f tube. This is of no consequence, because in the actual schematic one of the diodes within this multi-purpose tube is the avc diode, and consequently the load circuit of this diode represents the point where the maximum avc voltage is developed. The i-f signal required to actuate this diode is obtained from the stage identified as IF. The tubes which are controlled by this avc voltage are the r-f and mixer No. 1, so that the control grids of these two tubes, being the final destination of the avc voltage, become the control-voltage test points.

You can readily see that the selection of these avc test points is no more difficult in the case of this complicated receiver than in the two simpler receivers already described.

Now for the automatic-frequency-control system. We note that the i-f signal is fed to a tube identified as a "limiter," the function of which is to maintain the i-f signal voltage fed into the discriminator virtually constant irrespective of the signal voltage at the input of the limiter tube. This is accomplished by utilizing a self-biasing action within this tube. At low signal input levels the maximum amplification is secured within this tube and a definite output is fed into the discriminator. However, as the signal input to the limiter rises above a certain value, this tube starts drawing grid current and a voltage is developed across the grid leak in the grid circuit of the tube. The d-c voltage developed across this grid leak as a result of the grid current tends to reduce the amplification provided by this tube and thus tends to keep the output constant.

According to the above, the limiter tube is therefore associated with two types of tests. One of these is to check the level of the i-f signal output for various input signal values and the second is to note the d-c voltage, which we can, for want of a better name, call an automatic control or limiting voltage developed across the grid leak. Hence, the control grid of the limiter tube is a point where we can check this d-c limiter-control voltage. This, as you can readily see, is in exact accordance with the manner in which the tube is supposed to operate. In other words, we are checking the tube in accordance with its function.

Going now to the discriminator, the known function of this device is to develop a d-c (afc) voltage which varies within certain positive and negative limits through zero, in accordance with the frequency of the i-f signal. If, assuming correct tuning in the discriminator circuit, the i-f signal is of the correct frequency, then the output d-c voltage from the discriminator is zero. If the i-f signal fed into the discriminator is off resonance, the discriminator output d-c voltage will be negative or positive, depending upon the discrepancy between the i-f signal frequency and the resonant frequency of the discriminator output circuit. Hence, the basic test point for the afc voltage is as designated, the output of the discriminator.

This afc voltage is fed to the afc oscillator control tube, which controls the frequency of the oscillator, in this case oscillator No. 2, so that the test point in the oscillator control tube circuit is that place to which the control voltage is applied, namely the control grid.

Now, in accordance with the function of the discriminator, the output circuit of this tube is the place where the d-c control voltage is checked to establish correct tuning or incorrect tuning, and also, by establishing the polarity of the d-c control voltage, to determine the direction of the off-resonant state. There is nothing tricky or involved in making this voltage test. The test conforms entirely with the function and purpose of the discriminator tube.

We can go beyond this test of discriminator output and establish the manner in which the afc oscillator control tube varies the frequency of the oscillator. The idea behind the entire system is the variation of the oscillator frequency to produce the correct intermediate frequency in the event that the initial oscillator tuning of the receiver is incorrect. This is done by noting the variation in frequency of the i-f signal developed in the output of the mixer tube, in this case mixer No. 2, with and without afc for the original state of receiver tuning. This test is a function of signal tracing.

You can readily see, from the three examples of control voltage measurement, that in every case the design and function of the control circuit does not complicate the determination of the presence of the control voltage at the various controlled points and the manner in which the control circuits function. In every instance, the tests are made in accordance with the manner in which the various circuits operate. Whatever the design of the system, the control voltage is checked where it is developed and where it is distributed; when desired, its effect can also be checked. For example, signal tracing provides for a simultaneous test of the signal level and the control-voltage level, and thus establishes whether the control voltage applied to a certain tube is actually performing the required controlling action.

This reference to the relation between signal voltage and control voltage levels is extremely brief. Since this subject deserves a more elaborate discussion it will be more completely described in a later chapter.

Audio Circuits

Up to the present time we have devoted very little space to audio circuits. This has been deliberate as we do not deem it necessary to enter upon a lengthy discussion of that subject at this time. Particularly so, when all that need be said now is that the process of signal tracing in an audio system follows along the lines thus far shown. In each and every case the signal test points are selected in accordance with the design of the circuit and the function of the components.

Each and every circuit used in an audio system is checked or tested in accordance with the rôle it plays with respect to the signal as a whole or as regards some of the frequencies or a range of frequencies present in the final audio signal. This latter reference takes care of automatic bass expanders and automatic volume expanders, each of which receive its full allotment of space in a subsequent chapter.

Tubes and coupling elements utilized to secure audio degeneration, phase inversion and the like, are treated entirely from the angle of what happens to the signal. If certain signals of predetermined levels with respect to the level at some other point are supposed to exist at certain places, then these signal voltages are measured quantitatively or qualitatively, whichever may be deemed necessary, in those circuits where they are supposed to appear.

If the design of the audio system is such that specific control voltages developed by weak or strong signals, whichever they may be, are intended to block the amplifier, as, for example, for noise suppression, these circuits are checked according to their function, with the signal and control voltages as the final barometers.

The circuit design utilized in the audio system does not impose any limitations and, as stated earlier in this text, we are not passing lightly over the arduous hours spent in the design of a high-calibre audio system which performs any number of special functions. Audio systems, like radio-frequency and intermediate-frequency amplifiers, are intended to operate upon a signal, and that is how they are checked, inclusive of whatever control actions are supposed to exist or whatever division of frequencies is

supposed to take place in the various channels. Every condition which might develop in an audio amplifier and which will in any way impair the signal comes within the capabilities of signal tracing with utmost ease.

We pass on from this introductory chapter with the hope that we have shown how the signal tracing process of trouble detection or localization is so basic as to be independent of the many factors which contribute to form a communication system and which are subject to variation in accordance with the demands of the industry and the preferences of the men who design equipment.

Chapter II

SIGNAL AMPLIFICATION

Amplification is essential in every radio communication system. Both in transmission and reception vacuum tubes are used as magnifiers or amplifiers of the signal. In the receiver, which is of primary interest to us, amplification is necessary in order to enable the proper reception of weak signals or to provide an output signal which is of the desired strength. As a matter of fact the development of the property of amplification in a vacuum tube is directly responsible for the very existence of modern communication systems of all types. Remove the amplification provided by the transmitting and receiving systems and our present-day communication facilities of the world are virtually at a standstill.

Our interest in amplification is not one of design; that is to say, we are concerned with the practical rather than the theoretical. We know that many millions of radio receivers are in use and that these receivers incorporate amplifying systems. Our attention is focused upon the comprehension of the manner in which these systems function and their correct maintenance. In this connection, the basis is the signal which is being amplified. What happens to the signal during amplification? . . . How is it distributed throughout an amplifier? . . . How can we locate a defect in such an amplifying system most effectively and rapidly? . . . These are the questions we must answer.

Needless to say we cannot omit all reference to the basis of amplification within the vacuum tube. We must of necessity discuss some of the theoretical details, but when we do so, every attempt shall be made to translate the findings into practical terms.

Types of Amplifiers

Speaking in generalities, there are two basic types of vacuum-tube amplifiers in daily use in radio receivers. These are (1) voltage and (2) power. In the former, the design of the amplifier is such as to provide the maximum output signal voltage. Such amplifiers are usually used in cascade, that is, one stage feeding the next, and the highly amplified output voltage of the series is then either rectified or fed to a power amplifier. The power amplifier functions in a manner similar to the voltage amplifier, but with the difference that the amplifier provides maximum power output instead of maximum voltage output.

As far as signal tracing is concerned, both voltage and power amplifiers are handled in like manner. It is simply a matter of interpreting the output under the actual operating conditions and analysis of these operating conditions with respect to the components to make certain that they are conducive to whichever type of amplification is desired. If we recognize that the signal voltage output in a power amplifier is of necessity less than that of an equivalent voltage amplifier, signal tracing calls for the establishment of correct signal voltage conditions, both as to level and character of the signal. This operation is aided very greatly by the fact that power amplification is usually limited to the audio system and then invariably to the final stages.

References to voltage amplifiers in conjunction with audio systems should not be construed as meaning that voltage amplifiers are limited to audio systems. We intend anything but that. Voltage amplifiers are used as radio-frequency amplifiers, intermediate-frequency amplifiers and in audio systems to feed the power stage. As a matter of fact all r-f and i-f amplifiers in radio receivers are voltage amplifiers. This is quite natural in that we want the highest possible signal voltage in such systems because it provides the required sensitivity and further because the output of the voltage amplifiers is fed to the detector for rectification.

In appearance there is very little difference between voltage- and power-amplifier tubes. In general the power-amplifier tubes are slightly larger, but in all other respects they look alike. Intermittently the tubes are also similar in the number of elements or

electrodes, although it is true that the internal structure of the tubes is different. By structure we mean the spacing between the various electrodes, the size of these electrodes, etc. As to the amplifying capabilities, the power amplifiers do not amplify the signal voltage as much as the voltage amplifiers. The extent of this distinction will become more evident as we progress through this discussion.

As far as associated circuits are concerned, the general structure of the input circuits feeding voltage and power amplifiers is similar. This is quite reasonable in that both voltage and power amplifiers are voltage-operated, hence similar types of input circuits are used to supply the maximum signal voltage to the input of the tube. The output circuits of voltage and power amplifiers, while often alike in appearance, constitute the place in the system where differences will be found. Thus, for example, output circuits of power amplifiers almost invariably are low-impedance circuits, which is not true in the usual run of voltage amplifiers. However, it is not always possible to identify one or the other type of amplifier by a quick examination of the schematic of the output circuit. More often, the intended function and tube type number identify its operation as a voltage amplifier or as a power amplifier stage.

So much for the general discussion of the types of amplifiers. We want you to realize this discussion is by no means complete, but in view of what follows later in this volume, what has been said can suffice for the present.

Amplifying Property of the Vacuum Tube

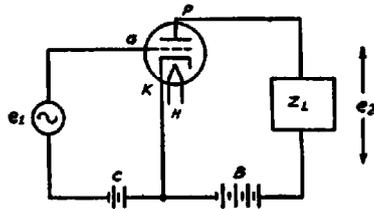
Undoubtedly every man who reads these lines is familiar with the property of amplification possessed by certain types of amplifier tubes. Nevertheless we feel that best interests will be served if a general review of such action is included at this time. It will serve well in explaining not only the action of amplifier tubes in conjunction with signal tracing, but it will also facilitate an understanding of the manner in which detectors perform their functions.

By no means do we intend this as a full and complete explanation of amplifier operation. Frankly, we do not feel that such an explanation must be complete in order to fill our needs. In fact

it would be impossible to do this subject full justice in a volume such as this; it could very easily occupy several volumes of its own. However, it is still possible to convey amplifier information from the viewpoint of signal tracing, which in general is not employed in the conventional text books. In accordance with this belief, we offer the following.

The triode tube is the simplest amplifier; simplest in that it possesses the capability of amplification and yet employs the fewest number of elements. Such a triode tube utilized in an amplifier circuit is shown in Fig. 2-1. The various tube element

FIG. 2-1. A triode used in a simple amplifier circuit. Z_L represents the load across which the output signal is developed.



symbols are conventional and hence require no explanation. The same applies to the batteries. The letters " e_1 " and " e_2 " represent the input signal voltage fed into the grid circuit and the output signal voltage respectively. The letters " Z_L " represent the load impedance in the output circuit of the amplifier, or expressed in other words, the device across which the amplified signal voltage e_2 appears.

The structure of the tube is such that the control grid is located between the cathode and the plate and the operation of the tube is as follows: The heater H causes the cathode K to acquire an electron-emitting temperature. These electrons accumulate in the space between the cathode and the control grid G. If a positive voltage is applied to the plate, it exerts an attracting force upon the electrons emitted from the cathode and current flows between the plate and cathode and through whatever devices, such as Z_L in Fig. 2-1, are connected between the cathode and plate and are external to the tube. The higher the positive voltage applied to the plate, the greater the number of electrons attracted to the plate, and hence the greater the value of plate current. Naturally, the reverse is true; that is, the lower the plate voltage the fewer the electrons that are attracted to the plate. In-

cidentally it might be well at this time to mention that some of the electrons will reach the plate even when no positive voltage is applied to the plate, that is, when the plate voltage is zero. This is due to the fact that the initial velocity of some of the electrons emitted from the cathode is sufficiently great to cause them to reach the plate.

Now, since the control grid is located between the cathode and the plate it is in a position where it exerts an effect upon the emitted electrons and therefore can control the number which will reach the plate. If a negative voltage C in the form of a grid bias is applied to the grid, it will repel some of the electrons emitted from the cathode and prevent their approach to the plate, thereby reducing the plate current. Since the grid is located closer to the source of the electrons than the plate, a small negative voltage applied to the grid can offset a much higher positive voltage applied to the plate. The greater the negative voltage or bias applied to the control grid, the greater the repelling action upon the electrons and the smaller the plate current. Thus a definite relation exists between the grid voltage and the plate current and herein lies the ability of the vacuum tube to amplify.

You will note that we speak of negative grid bias voltages. This is done because practically all amplifiers which employ a grid bias, employ a negative bias. This bias is vital in such systems because it prevents the attraction of electrons to the control grid and hence the flow of current in the external circuit between the control grid and the cathode or filament. In this connection it might be well to point out that there is a distinction between any action on the part of the grid to change the electron flow towards the plate and the attraction of electrons to the grid. Attraction of electrons to the grid is usually undesirable because it causes the flow of grid current with consequent distortion and reduction in amplification.

When the control grid of an amplifier tube is maintained at a negative potential so that it does not attract any electrons to itself, the grid circuit of the tube, that is the input circuit of the tube, becomes the equivalent of a very high impedance. As a result it does not load the device which feeds the input signal to the tube and distortionless amplification is possible, provided that the other proper operating requirements are also fulfilled.

In some instances that we will show later in this volume, certain amplifier tubes operate with zero bias and substantial amounts of grid-current flow. Proper compensation is employed in such circuits to offset the effects of grid current. We make this reference in order to avoid the criticism which would be due if it were omitted and the previous statements were accepted as covering all types of amplifiers.

Plate Current

To comprehend the operation of the amplifier tube properly, it is essential that you understand the part played by the plate current. We made the statement that a positive voltage applied to the plate of the tube, such as that available from the battery B in Fig. 2-1 or from some other plate-voltage source, will attract some of the emitted electrons. The result is the flow of plate current in the plate circuit. In connection with this reference to the plate circuit, we find a number of very significant points. In the first place, the plate circuit embraces a number of tube elements and associated components. For example in Fig. 2-1, the plate circuit includes the plate of the tube, the cathode, the plate-voltage supply B and the load impedance Z_L . Whatever plate current flows in this circuit, flows through all of the parts mentioned. The load Z_L , located in the output circuit and across which the amplified signal appears, can be a resistor, a transformer or a choke without in any way altering the path of the plate current.

The magnitude of the steady value of the plate current is of course controlled by a number of factors, among which are the operating voltages, the design of the tube, which means its characteristics, and the d-c resistance of the load impedance Z_L . By steady value of plate current we mean that value which is the result of the operating voltages and the other factors mentioned in the previous sentence and that which exists without any signal input to the tube. This leads us to a further explanation of the plate current.

When no signal is fed into the amplifier tube, the plate current has a steady value, but when a signal is fed into the tube a change takes place in the plate current. It might seem premature to mention this change now without showing the actual

action, but we cannot omit the reference because we are speaking about plate current. The basis for this variation in plate current will be shown later in this chapter, but let it suffice for the present to say that a signal voltage applied to the grid causes a variation in the plate current from this steady value, thus when a tube is operating as an amplifier, the plate current is a combination of a steady value upon which has been superimposed an alternating current which corresponds in shape or wave-form to the signal voltage applied to the grid. In other words, the plate current is a pulsating current.

In connection with the plate current, one point is of tremendous importance. It is paramount because of the bearing it has upon the application of signal tracing as a means of locating defects in amplifiers. It is the condition that wherever a path exists through which this pulsating plate current flows and this path has some value of resistance, reactance or impedance, an a-c voltage will be developed. This a-c voltage will be a signal voltage . . . This is our basis of operation. It is possible that means are included in the amplifier system to minimize the magnitude of this a-c signal voltage, but basically what we said is true and if remembered will be of great aid in signal tracing. Thus in the simple circuit of Fig. 2-1, where no special precautions are taken, the pulsating plate current flows through the tube, the cathode circuit, the plate-voltage supply, B, and the load impedance, Z_L . Any portion of this complete circuit which contains resistance, reactance or impedance will cause a signal-voltage drop.

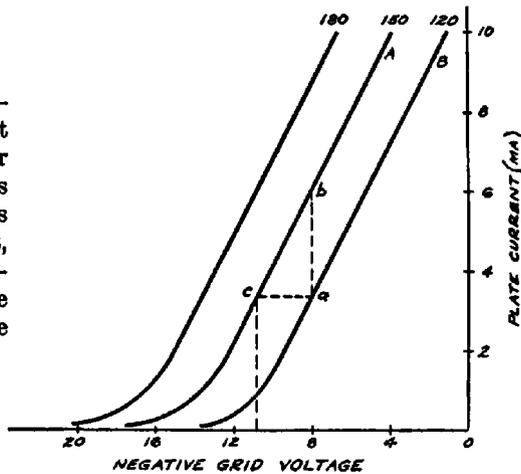
Thus if we assume Z_L to be a resistor and the plate-voltage supply B is assumed to contain some value of resistance, then a signal voltage drop will take place across the terminals of Z_L and across the terminals of the supply B. This description is brief, but appropriate at this time because of the significant nature of the subject.

We said earlier in this chapter that the presence of the control grid between the cathode and the plate and its ability to control the plate current gave rise to the ability of the tube to amplify. Just what is meant by this statement is illustrated in Fig. 2-2. In this graph you can see how a small change in grid voltage has the same effect upon the plate current as a much greater change in plate voltage. Each of the curves is identified with respect to

plate voltage designated at the top of the curves. The vertical axis indicates the plate current and the horizontal axis shows the grid voltage. Thus the three curves represent the plate current—grid voltage relationship for plate voltages of 120, 150, and 180 volts.

Let us now show how the grid voltage is more effective than the plate voltage in controlling the plate current. Starting at point *a* which shows that the plate current has a value of 3.4 ma for a plate voltage of 120 volts and a grid bias of -8 volts, let us as-

FIG. 2-2. The variation in plate current with grid voltage for three different values of plate voltage. As explained in the text, the grid is more effective than the plate in controlling the plate current.



sume that the plate voltage is raised to 150 volts without any change in the grid bias. The new plate current, as represented by point *b* will then be 6 ma. To determine the effectiveness of the control grid, we must now find the amount by which the grid bias must be changed to offset exactly the increase in plate current brought about by the increase in plate voltage from 120 to 150 volts. If you will refer to the curves, it will be clear that the grid bias must be increased to 10.8 volts, as shown by point *c*, in order to bring the plate current back to its original value of 3.4 ma. Thus, an increase in grid voltage from -8 volts to -10.8 volts is just as effective in controlling the plate current as is an increase in plate voltage from 120 volts to 150 volts.

The amplification factor of a tube deals with the relative effec-

tiveness of the grid and plate voltages in controlling the plate current, and as we should expect, the amplification factor is equal to the ratio between the change in plate voltage and the corresponding change in grid voltage which is required to produce the same change in plate current. In the example above, a change in plate voltage of 30 volts produced a change in plate current which was offset by a change in grid voltage of 2.8 volts. The ratio between 30 and 2.8, $30/2.8 = 10.7$ thus indicates that the grid is 10.7 times as effective as the plate in controlling the plate current and therefore the amplification factor of the tube is said to be 10.7.

This relation between the grid-voltage change and its effect upon the plate current is not characteristic of the triode tube alone. All vacuum tubes—triodes, tetrodes, pentodes—all tubes capable of amplification and used in communication systems act as amplifiers because of this action between the grid and plate circuits. In fact all such tubes capable of amplification bear an amplification-constant rating denoting this amplifying ability.

The exact value of 10.7 used in the example is purely illustrative. In some tubes this factor is much higher, sometimes amounting to 1500 or more and in other types it may be very low, such as 3 or 4. Tubes intended as voltage amplifiers generally have higher "μ" ratings than tubes intended for use as power amplifiers.

The importance of the amplification factor μ is that it expresses the maximum amount of amplification obtainable with the tube in question. That is to say, a tube rated at a μ of 7, is capable of a maximum gain of seven times the signal fed into the tube, provided that the requirements for distortionless amplification are fulfilled. A tube rated at a μ of 100 is capable of amplifying a signal a maximum of 100 times, etc.

However, there is a tremendous difference between the value of amplification indicated by the amplification factor and the value actually realized in the complete stage, including the tube and its associated external components. The maximum theoretical amplification is never realized in practice but it is nevertheless important to know what this maximum value of amplification is, because it enables the determination of the actual amplification being obtained. When we speak of the actual value of ampli-

fication we mean the relative gain or increase in signal level between the input to the tube and the output secured *across the load impedance*. What we get *out* of the tube is far more important in practice than the possible amplification indicated by the value of the amplification factor.

Plate Resistance

Supplementary to the amplification factor, there is another tube constant which has a definite bearing upon our subject. This is plate resistance. Plate resistance is the opposition offered by the tube structure to the flow of plate current. This phenomenon takes place within the tube, within the space between the electron emitter and the plate and is essentially a function of such items as the spacing between the electrodes, the area and number of the electrodes, etc., but it is also influenced by the operating voltages. However, for any one set of operating voltages, the tube structure is the determining factor. Plate resistance is measured in terms of ohms.

A general relation exists between plate resistance and amplification constant. Although it is not invariably true, it is generally the case that the higher the amplification constant, the higher the plate resistance, which means that as a rule, voltage amplifiers have higher values of plate resistance than power amplifiers. This applies to all types of tubes: triodes, tetrodes, pentodes, etc. Associated with the subject of plate resistance is plate current. The higher the plate-resistance of a tube for a given set of operating voltages, the lower is the plate current. This is only natural in view of the usual relation between resistance and current when the voltage is fixed.

The plate resistance of a tube, indicated by the symbol r_p , is the a-c plate resistance and should not be confused with the d-c plate resistance. As the name implies, the d-c plate resistance is equal to the d-c plate voltage divided by the d-c plate current and it indicates the resistance of the tube to the passage of *direct* current. On the other hand, the a-c plate resistance, with which we are primarily concerned in this book, is a measure of the opposition which the tube offers to the passage of the *signal*. In all computations which involve the signal, it is the a-c plate resistance that is important since it is this value which determines

how much of the maximum possible amplification will be obtained. The plate resistance value appearing in tube tables is ordinarily the a-c plate resistance unless otherwise stated.

You will see later that a definite tie-up exists between the load impedance Z_L in Fig. 2-1, the plate resistance and the amplification constant. For any one particular tube, the higher the ratio of the load resistance to the plate resistance, the higher is the amount of voltage amplification realized with the stage.

Mutual Conductance

Mutual conductance is the last of the three major tube constants. Identified as " g_m " and expressed in terms of micromhos (the mho is the reciprocal of the ohm), it is a measure of the amount of amplification obtainable under actual operating conditions. More specifically, it expresses the microampere change in plate current for a unit change in grid voltage; consequently it embraces the structural features of the tube, the amplification constant, the plate resistance and the operating voltages.

The greater the mutual conductance of a tube, the greater will be the change in plate current for a given change in grid voltage. Thus a tube having a mutual conductance of 800 micromhos will produce a change in plate current of 800 microamperes when the grid voltage is changed by 1 volt; a tube having a mutual conductance of 5000 micromhos will produce a change in plate current of 5000 microamperes (5 ma) when the grid voltage is changed by 1 volt. It should be kept in mind that the change in plate current expressed by the value of g_m assumes that the load resistance is zero. For any value of load resistance, other than zero, the change in plate current will be proportionately smaller as the load resistance is increased.

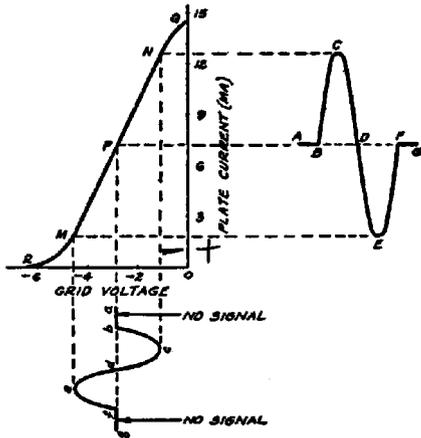
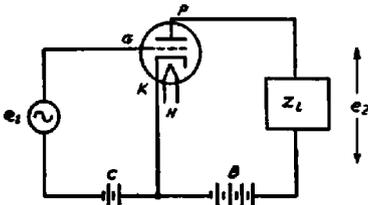
Of importance is the fact that the value of g_m does not indicate the maximum amplification which can be obtained from a given tube. Thus one tube having a lower g_m than another tube may provide a considerably greater value of signal or voltage amplification. We will explain the reason for this condition in detail later in this chapter.

Process of Amplification

Having discussed some of the highlights of amplifier tubes, we

are ready to investigate the process of amplification. How does the amplified signal appear in the plate circuit of the tube? The answer to this question will explain the presence of the a-c or signal component of the plate current.

We said that a change in grid voltage will cause a change in plate current. Let us analyse this statement and use the simple triode circuit shown in Fig. 2-3 and illustrate the action by means of a graph, which is shown in Fig. 2-4. You will note that the



FIGS. 2-3, 2-4. A simple triode amplifier circuit is shown in Fig. 2-3, above. When a signal is applied to the grid, the plate-current variations follow the grid voltage variations as shown at the right.

vertical axis in the latter is identified as plate current and the horizontal axis is identified as grid voltage. To the right of the plate current axis is the plus or positive region of grid voltage and to the left of the plate current axis is the minus or negative grid-voltage region. You will also note a sloping line *QNPMR*. This is the grid voltage-plate current characteristic, and it shows the variation of plate current with grid voltage when the plate supply voltage is fixed.

Further examination of the grid voltage-plate current characteristic shows that this sloping line has a fairly straight portion and that the two limits are curved. The portion between *M* and *N* is the straight or linear portion and is the useful portion of the characteristic. It is over this region that the plate-current variation is uniform or linear with respect to changes in grid voltage. However between *N* and *Q*, the plate-current variation no longer

is uniform and the same is true between M and R ; hence operation over these portions will be non-linear and result in distortion.

Now in order to provide operation over the linear portion of the characteristic it is necessary to select a certain point along this characteristic which will permit uniform variation in plate current over a range of input signal voltages. This point is determined by the magnitude of signal voltage which is to be applied and also the length of the characteristic as determined by the plate voltage. For our illustration, P is the operating point and it is established by the use of a negative grid-bias voltage of approximately 2.8 volts. With this amount of grid bias employed, we can apply a signal voltage and cause the plate current to increase and decrease equally in both directions around the operating point P . If this point P is projected to the plate-current axis, it identifies the no-signal steady plate current as being approximately 7.2 milliamperes. This is the value of plate current which is assumed to flow through the entire plate circuit of Fig. 2-3 without any signal input to the control grid.

Directly below the negative region along the grid-voltage axis is shown a single cycle of a-c voltage. This is the signal voltage and for convenience we assume that its frequency is so low that the variations in amplitude can be followed. What is the effect upon the plate current of this variation in grid voltage?

Inasmuch as it is customary to consider the half cycle above the zero reference line of an a-c voltage to be positive, such a voltage applied to a grid which is biased negatively will have the effect of offsetting the bias by an amount equal to the peak value of the a-c voltage. This is the equivalent of reducing the effective bias, and hence increases the plate current. Let us now assume that the line $a-b$ represents no-signal input and that the line $A-B$ adjacent to the plate current axis represents the steady no-signal value of plate current; then if a signal voltage corresponding to $b-c$ is applied, the plate current will increase from the steady value as shown by line $A-B$ to point C and the plate-current variation $B-C$ then will correspond to the grid voltage variation $b-c$.

When the signal voltage applied to the grid decreases from c to d , it is the equivalent of an increase in bias because the amount of signal voltage which offsets the bias decreases from its

peak value to zero at d . The result is a decrease in plate current throughout the entire plate circuit and the corresponding change in plate current is shown by the plate-current variation $C-D$. Thus, during the half cycle of grid voltage change, a corresponding change has taken place in the plate current—starting from the no-signal value, reaching a peak, and then returning to the no-signal value.

When the negative alternation of the signal voltage is applied, it is the equivalent of increasing the effective bias, so that the net result is a decrease in plate current, starting from the no-signal value. The negative signal-voltage alternation $d-e-f$ results in an equivalent change in plate current $D-E-F$, which of course takes place throughout the plate circuit of Fig. 2-3. You can readily see that under the ideal conditions which we assume to exist in this circuit, the plate-current variation caused by the change in grid voltage corresponds in waveform with the signal-voltage applied to the grid.

We spoke about ideal conditions. What do we mean by ideal conditions? First, if you will examine Fig. 2-4, the magnitude of the positive half of the signal voltage wave is less than the grid bias applied, which means that the grid voltage swing does not exceed that permitted by the limits of the linear portion of the grid voltage-plate current characteristic. If the peak positive half of the input signal voltage wave exceeds the grid bias,—the grid will go positive, attract electrons, grid current will flow, and distortion will result. As we stated earlier in this text, certain types of amplifier operate with grid current. These will be discussed later.

Referring once more to Fig. 2-4, you should understand that once the correct operating point has been established with respect to the maximum grid swing, any value of signal voltage less than this maximum can be used, because it will result in operation upon the linear portion of the grid voltage-plate current characteristic.

In addition it might not be amiss to mention that the type of amplification being discussed is identified as Class A, wherein the output waveform is a faithful reproduction of the input signal voltage; the grid is never driven positive and the plate current as read upon a d-c meter remains the same with or without signal

input. Voltage amplifiers are almost invariably operated as Class A amplifiers.

Plate-Current Variation and Signal Voltage

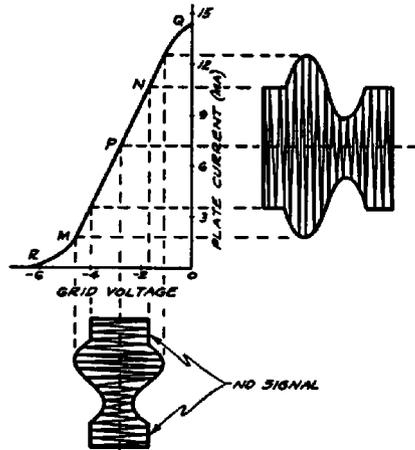
Having seen how the signal voltage applied to the grid causes a variation in plate current, you might ask about the development of the signal voltage in the plate circuit. This is quite simple in that the plate-current variation takes place throughout the entire plate circuit, consequently through the load impedance, no matter what its type. If the circuit structure of the amplifier resembles that of Fig 2-3, wherein the d-c component flows through the load impedance, two voltage drops develop across this load impedance. One of these is that due to the d-c component of the total plate current, which is the equivalent of the average value of the varying plate current. This is the voltage drop which could be computed by placing a d-c meter in the plate circuit, noting the current indication, and multiplying this value by the d-c resistance of the load impedance. The other voltage drop is the a-c voltage drop due to the varying current through the load; this signal voltage is the product of the a-c or signal component of the current and the impedance of the load at the frequency of the plate-current variation. Naturally in a class A voltage amplifier, the frequency of the a-c voltage in the plate circuit is the same as that of the signal voltage applied to the grid. This reference to frequency is not as strange as it might seem because under certain conditions we will discuss later the output circuit can contain frequencies which are multiples or harmonics of the frequency of the input signal voltage.

The process of amplification as outlined in Fig. 2-4 is applicable not only to the triode, but it is substantially the same in all types of voltage amplifiers and in many types of power-amplifier tubes. In those types of power amplifiers where it differs, the variation takes place in the shape of the grid voltage-plate current characteristic, which of course is not a fundamental change. Thus when working with triodes, tetrodes, pentodes and the like, the process remains the same.

The sine-wave input and sine-wave output shown in Fig. 2-4 are purely illustrative. The output will not always to be a sine wave. It depends entirely upon the waveshape of the input signal

voltage and the operating conditions. Assuming correct operating conditions, the output current variation will be an amplified reproduction of the input signal voltage so that if the input signal voltage is distorted, then the output will be distorted in the same

FIG. 2-5. When a modulated r-f signal is applied to an amplifier, the plate-current variations have the same form as the input signal.



way. If the input signal is a modulated r-f or i-f carrier, as shown in Fig. 2-5, then the amplified plate current variations will assume the shape of the modulated r-f or i-f carrier.

Phase Relations

We have already seen that when a signal voltage is applied to the grid, a corresponding amplified signal voltage is developed at the plate of the tube. If we take the case where a resistive load is used in the plate circuit of the tube, then we arrive at some important relations which are called the phase relations between the signal voltages at the grid, plate, and cathode.

To arrive at these phase relations, let us first consider what takes place when a more positive voltage is applied to the grid. As a result of this more positive grid voltage, there is a corresponding increase in plate current. Similarly, when a more negative voltage is applied to the grid, the plate current decreases. Thus the plate current is said to be *in phase* with the grid voltage since both go through their positive and negative peaks at the same time.

If we investigate the phase relations between the signal voltage at the plate and the input grid voltage, then we find that these two voltages are *out of phase*. Thus a positive increase in grid voltage causes an increase in plate current; this increased plate current causes the plate voltage to drop below the steady value which it has with no input signal. Similarly a more negative grid voltage than the steady value causes the plate current to decrease so that the voltage at the plate increases as a result of the decreased drop in the plate-load resistor. Thus the signal voltage at the grid is exactly opposite in phase to that at the plate since the one signal goes through its positive peak at the same instant that the other goes through its negative peak.

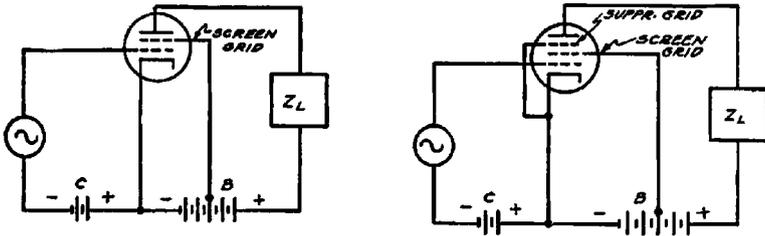
If a cathode resistor is used to supply the grid bias, the varying plate current will also develop a signal voltage across this resistor, unless the resistor is by-passed by a condenser. As a result of the direction of current flow, the signal voltage developed at the cathode is exactly in phase with the signal voltage at the grid. Thus at the instant that the input signal makes the grid more positive, the increased plate current flowing through the cathode resistor also makes the cathode more positive with respect to its steady value. As we shall see later, this tends to reduce the net signal voltage effective between the grid and the cathode and thus reduces the amplification which is obtained. This effect will be discussed in connection with inverse feedback in a later chapter.

Tetrode and Pentode Amplifiers

So far we have mentioned the triode amplifier. All of us know that as radio progressed, the screen-grid, or tetrode, and pentode tubes were developed for use as amplifiers. These tubes differ from triodes in a number of respects, such as the number of elements and the operating characteristics, but as far as signal tracing is concerned, there is very little difference between the triode and these other tubes. Perhaps the added elements augment the number of test points under certain conditions, but in general we can consider them in the same way.

As far as the process of amplification is concerned, tetrodes and pentodes function in a manner similar to the triode. The change in grid voltage causes a change in plate current and the

effect of the grid circuit upon the plate circuit is to produce an amplified signal in the plate circuit. The facts mentioned in connection with the ideal performance of the amplifier, that is, freedom from grid current, an input signal voltage which is limited by the grid bias, the plate current change being an enlarged image of the grid voltage change—all of these are true in tetrode and pentode tube circuits. However, the increased number of



Figs. 2-6 (left), 2-7, (right). The use of tetrode and pentode type tubes does not change the input and output circuits of the amplifier stage, which are similar to those for a triode stage.

elements changes the conventional amplifier circuit and examples of basic tetrode and pentode circuits are given in Figs. 2-6 and 2-7. If you compare them with Fig. 2-3, you will find that the variations are introduced by the added electrodes, and that the input and output circuits of the amplifiers are identical.

As to the difference between the triode and the screen-grid tube, our primary interest lies in the plate current. The actual functions performed by the added grids are not important here because in practice these elements are connected or operated in accordance with prescribed instructions and this information is available for comparison. With the plate current, however, we are concerned because of what was said in connection with the relation between the plate current and the appearance of signal voltage drops in the various portions of the system where the plate current flows. Accordingly, it is of special interest to mention that in the screen-grid tube, the total cathode current is made up of other currents in addition to the plate current. Thus in the tetrode, the cathode current, which is also the current drawn from the B-supply, is equal to the sum of the screen current and

the plate current. Because of the structure of the screen and the plate and the relative voltages applied, the current in the plate circuit is several times that in the screen circuit; but you should remember that whatever variations are introduced in the space current by the signal applied to the grid, these are present in the screen current as well as in the plate current. As it happens, the circuit is generally arranged to nullify the effect of the a-c or signal component of the screen current, so that only the plate current is effective in developing the signal in the output of the amplifier, but we cannot ignore the fact that the screen current also contains a signal component.

In the pentode we have a somewhat similar situation. The total current from the B-supply is equal to the plate current plus the screen current and wherever the current exists a signal component will be found, which is either permitted to become effective or is nullified. Thus the a-c or signal component of the screen current, due to the application of a signal to the control grid, is rendered useless, whereas the signal component of the plate current is caused to develop the amplified signal voltage in the plate circuit. As is shown in Fig. 2-7, the suppressor grid is usually connected to the cathode, so that whatever voltage is present at the cathode will also be applied to the suppressor grid.

The primary reason why we explain these points is that under certain conditions found in defective amplifier stages, the signal components of the plate and screen currents in both tetrodes and pentodes will result in signals where they should not exist and the means of establishing the nature of the defect is by interpreting the presence or absence of signal-voltage drops in some of the circuits. We will show just how this is accomplished later.

Factors Controlling Amplification

Recognizing the fact that a vacuum tube is capable of amplifying a signal is not sufficient. It is equally important to appreciate that certain factors associated with the tube display a tremendously important influence upon the attainment of the correct amount of amplification and the correct kind of amplification. The following is a brief description of these conditions:

Electron Emission. It stands to reason since the operation of the amplifier tube depends upon the flow of electrons, that this

electron flow must be of the required amount. This means that the filament or cathode must be capable of emitting the required number of electrons. Any deficiency in electronic emission is naturally going to affect the amount and character of the amplification. In other words, not only will the amplification be reduced, but it will be accompanied by distortion and other undesired conditions. If the electron emission is sufficiently small, the tube will not function and hence must be replaced.

Plate and Screen Voltages. The operating characteristics of a tube depend upon the presence of certain operating voltages on the respective elements, in this case the plate and screen, or just the plate if the tube is of a type that does not have a screen. If these operating voltages are incorrect, the amplifying capabilities of the tube are altered. This does not mean that no variation from the stated values may be tolerated. As a matter of fact, a variation as much as 20 percent is permissible, and in fact will be found to be a commonplace condition. However, major discrepancies in plate or screen voltages will impair the operation of the tube. This applies equally well in both directions; that is, when the voltages are too high as well as when they are too low.

The fact that we speak collectively about plate and screen voltages does not mean that both must be incorrect. If either is incorrect, a defective state exists and it affects both the amount and the character of amplification. Since the final effect depends upon the correct operating voltages in all of the circuits, all applied operating voltages must be properly related to produce the desired results. Excessive values are just as harmful as low values, in that an unbalanced state results in distortion which is just as undesirable as reduced amplification due to low operating voltages.

It might be well at this time to point out that the presence of correct operating voltages does not necessarily mean that the signal is correct, or even that the signal is present. Just why this is so will become evident as you read on in this chapter.

Control Grid Voltages. As you no doubt appreciate from what has been shown so far, the control-grid voltage displays the greatest effect upon the amplifying characteristics of a vacuum tube. While not always critical in value, the grid bias is nevertheless more critical with respect to performance than either the screen

or plate voltage. This is so because of the amplified effect of the grid-voltage change in all of the other circuits of the tube.

The grid bias displays a major effect upon all of the constants of an amplifier tube and consequently upon the amplifying capabilities. For example, variation of the grid bias alters the plate resistance as well as the mutual conductance of the tube and this is utilized as a form of volume control. Variable cathode bias and automatic volume control are examples of the application of a variable control-grid bias voltage as a means of reducing amplification, and thereby effecting control of volume. Increasing the negative bias increases the plate resistance and reduces the mutual conductance, and thereby reduces the amplification.

The application of excessive bias, regardless of the other operating voltages, is capable of converting an amplifying tube into a rectifying tube. You might recall this condition as a major problem years ago before the development of "remote-cutoff" or "variable-mu" tubes. Although solved by the development of these tubes, the condition still exists at times because of the development of a high bias as the result of a defect elsewhere in the system. The harmful effects of an excessive negative grid bias are not only the reduction of the signal level, as the consequence of reduced amplification, but also rectification of the signal. Such action results in a distorted signal because rectification is taking place where undistorted amplification should exist.

Insufficient grid bias, on the other hand, also tends to reduce amplification after a certain level has been reached, as the consequence of overloading of the tube. Such action causes distortion, variation of the tuning properties of the amplifiers, etc.

Gassy Tubes. Excessive gas content in a vacuum tube will alter the amplifying characteristics of the tube and in general will produce many undesirable effects depending upon the particular circuit in which the tube is used. To secure proper operation the defective tube should be replaced.

External Influences. When speaking about factors which control the amplifying capabilities of a vacuum tube, it is necessary to include external influences, although it is true that when such external influences are added, we are really passing beyond the limits of the tube. Yet we cannot ignore such external influences because in the final analysis the tube is used as a part of a com-

plete stage which includes the tube and devices external to the tube.

Defects in these external devices will materially affect the amount of amplification obtained in the stage. This does not mean that the amplification always is reduced below the normal value. In some instances as a result of a defect the amplification is increased sufficiently above normal to cause excessive regeneration. This is just as harmful in the final result as insufficient amplification and often is more troublesome to correct.

These external influences alter what can best be described as the overall result of the tube operation. They manifest an effect upon both the magnitude of the signal and its character.

So much for the general discussion of factors which control the amplifying capabilities of vacuum tubes. As you no doubt note, we are not specifying any particular type of service or application of the amplifying tube or any one type of tube. What we have said is applicable to all types of amplifiers, r-f, i-f, a-f, voltage and power.

Transfer of Signal Voltage From Triode Tube to Load

Having examined the general operation of the vacuum tube, let us now investigate more closely the manner in which the load or output circuit affects the amplification which can be obtained. This is important because it is the signal voltage developed across the load circuit which determines the amplification. It is this same signal voltage across the load circuit which is coupled to the succeeding stage and plays the all-important part in the operation of the system.

It is here in the development of the signal across the load circuit that we meet a number of very interesting conditions relating to signal transfer. It is important to understand these conditions because they provide the key to the nature of the defects which exist in amplifiers. The statement has been made that operating voltages are not always indicators of defects, and the reasons why will become evident as you read these lines concerning the effect of the load circuit on the operation of a tube as an amplifier.

Once the operation of a tube as an amplifier is understood, it is possible to visualize that tube in another form, a form which en-

ables further investigation of amplifier operation and a clearer interpretation of the signal in terms of the plate current. For example, we can say that an amplifier tube is a generator of a signal voltage. This is made possible by the fact that if a signal voltage numerically equal to the amplification constant of the tube is introduced into the plate circuit of an amplifier tube, the plate current which will flow will be the same as if a unit signal voltage were introduced into the grid circuit. Hence the plate circuit of the amplifier can be considered to be a generator of a

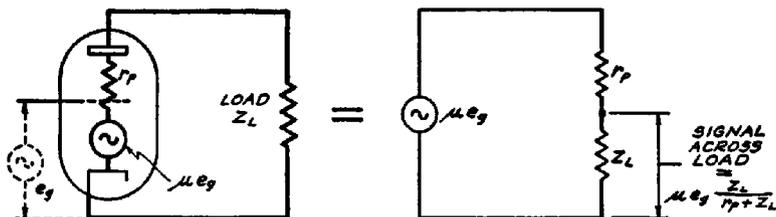


FIG. 2-8. A triode used as an amplifier can be considered as being equivalent to a generator in series with an internal resistor equal to the plate resistance of the tube. The manner in which the signal voltage divides between the internal plate resistance and the load impedance is shown at the right.

signal voltage equal to μ times the signal voltage at the grid. The internal plate resistance of the tube becomes the internal resistance of the generator. Thus if a tube is rated at an internal plate resistance of 20,000 ohms and a μ of 10, the generator form of representation would bear the constants of 20,000-ohms internal resistance and of 10 volts output voltage. Working along such lines we can say that the simple triode amplifier circuit of Fig. 2-3 finds its equivalent in the generator circuit of Fig. 2-8, wherein μe_g is the output voltage, r_p is the plate resistance and F_L is the load resistance.

Suppose that we investigate the various voltage relations which exist in this equivalent circuit of a triode amplifier. The load can be assumed to be a resistor, such as would be found in a conventional resistor-coupled audio amplifier. However, what will be said about voltage distribution is true regardless of the form taken by Z_L . At the present moment it is far more important to

consider the effects of various values of load rather than the effect of the different types of load. The problem at hand is to establish what portion of the maximum voltage available in an amplifier tube will appear across the tube load; in other words, what portion of μe_g in Fig. 2-8, will appear across Z_L . You will note that the load is in series with the internal resistance r_p and that the total signal voltage is available across this series combination. This means that the signal voltage across the respective resistances (or impedances) will divide in accordance with their respective values. The ratio

$$\frac{Z_L}{r_p + Z_L} = \frac{\text{load impedance}}{\text{plate resistance} + \text{load impedance}}$$

expresses the fraction of the total signal voltage which appears across Z_L .

As is evident, when $Z_L = r_p$, the full signal voltage divides equally between the two resistances, and thus one way of securing the maximum signal-voltage drop across Z_L is to make the load many times the value of r_p . The higher the value of Z_L with respect to r_p , the greater is the amount of amplification actually realized in a voltage-amplifier stage and the smaller is the signal voltage lost across the internal plate resistance r_p . However, the value of r_p is a determining influence in establishing what portion of the available signal voltage will be obtained across the load, because if we set $10 \times r_p$ as being a satisfactory value for Z_L so as to obtain about 90 percent of the available signal voltage, this is practical only when r_p does not exceed about 50,000 ohms. The higher the value of r_p , the higher must be the value of Z_L and consequently the greater must be the B-supply voltage so as to provide the required voltage at the plate of the tube. This is a limitation which plays a very important part in the actual d-c resistance value of Z_L . In fact, it is a general limitation, and you will find that the majority of voltage amplifiers employ a ratio between the load impedance and the internal plate resistance such that approximately fifty percent of the maximum possible amplification is obtained.

To summarize what has been said, it is evident that in a voltage amplifier the higher the load impedance with respect to the internal plate resistance, the greater is the amplified signal voltage

developed across the load. This can also be expressed by saying that the greater the load impedance with respect to the internal plate resistance, the greater the amplification obtained in the stage.

Let us now examine this arrangement with respect to frequency. Suppose that Z_L is a winding of some kind, the primary of an audio transformer or a choke. How does this affect the signal transfer from the tube to the load with respect to frequency? Naturally, it is going to vary, depending upon the frequency of the signal voltage and the impedance of the load at that frequency. The higher the impedance of the load at any one specific frequency, the greater the signal voltage developed across the load with respect to that lost across the internal resistance r_p . Naturally the reverse is also true; the lower the impedance of the load at any one frequency, the lower the signal voltage transferred and the lower the amplification in the stage. Thus if the frequency of the signal voltage varies and the load impedance is of such character as to vary with frequency, the signal voltage developed across the load impedance will vary with frequency. As to the amount of amplification obtained in such a voltage amplifier system, the following equation applies:

$$\text{Amplification} = \mu \frac{Z_L}{r_p + Z_L}$$

From what has been said so far it is obvious that some value of signal voltage will be developed across the load impedance, no matter what its value, provided it is greater than zero; but whether or not the signal voltage so obtained is what it should be depends naturally upon the conditions in the circuit. For example, if some condition exists which tends to reduce the load impedance to a very low value, then only a very small signal will be present across the load.

Such a condition might arise in the case of a tuned r-f transformer used in conjunction with a triode tube. In other words Z_L might be a tuned r-f plate winding, the load impedance being supplied by this winding and parallel resonance being used to develop a high value of impedance at resonance. At resonance, a signal voltage drop would develop across the tuned winding; but if the tuned circuit were not resonated to the frequency of

the signal voltage, the impedance would be low and the signal voltage drop across the winding would be correspondingly small.

Amplification in Tetrodes and Pentodes

All voltage amplifiers are not triodes. Tetrodes and pentodes also are used very extensively, and while the basic facts as outlined herein concerning the transfer of the signal from the tube to the load are not changed, the method of calculating the signal transferred from the tube to the load is different. This is brought about by the fact that the plate resistance of tetrodes and pentodes is very much higher than that of triodes, in fact very much higher than the usual load impedance. As a result the signal current which flows in the plate circuit has a constant value regardless of the load impedance used.

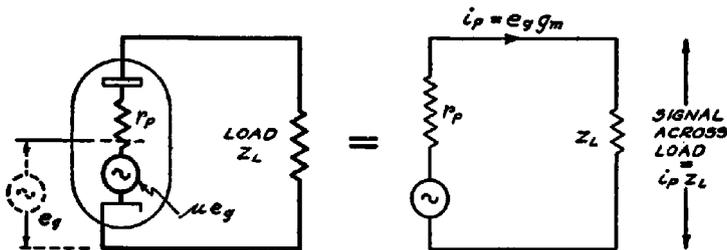


FIG. 2-9. In screen grid tubes, the internal resistance is so high that the same value of current flows through the load regardless of the value of load impedance.

Instead of calculating the voltage across the load impedance in terms of the relative drop across the load impedance and the internal plate resistance, it is convenient to make use of this fact that a constant signal current will flow in the plate circuit as the result of a signal voltage applied to the grid. This you will recall is expressed by the mutual conductance which gives the change in the plate current per unit change in the grid voltage.

Knowing the magnitude of signal current per unit signal voltage on the grid, we can easily establish the signal voltage developed across the load impedance, which then equals the actual amplification being obtained. The generator equivalent of the pentode is shown in Fig. 2-9, and as you can see it is virtually identical

to that of the triode shown in Fig. 2-8. The only difference is that the signal component of the plate current is not affected by the load impedance because the plate resistance is large in comparison with the load impedance. Referring to Fig. 2-9, it is clear that the signal plate current i_p is equal to $\mu e_g / r_p$, which in turn is equal to $e_g g_m$ since the mutual conductance is equal to μ / r_p . The signal voltage developed across the load can be computed readily by multiplying the value of signal current by the load impedance. Thus the signal across the load is equal to $e_g g_m Z_L$ and the amplification is equal to the product of g_m and Z_L . The larger the mutual conductance, the greater is the amplification; and similarly, the larger the load impedance the greater is the amplification.

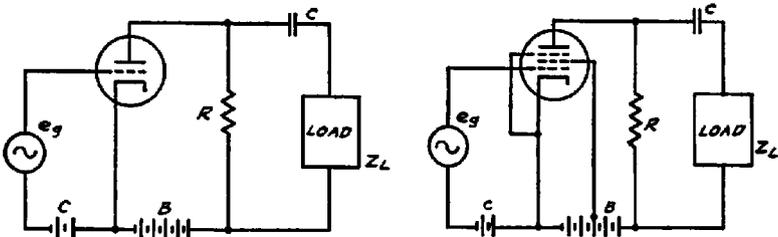
In computing the amplification as explained in the preceding paragraph, it is important that the mutual conductance and plate impedance be expressed in the proper units. A convenient set of units to use is to express the mutual conductance always in micromhos (microamperes per volt) and to express the load impedance in megohms. The amplification will then be equal to the product of g_m and Z_L expressed in these units.

The following example will make this clear. Suppose we take the case of a 6K7 which is working into a parallel resonant tuned circuit. If a signal is applied to the grid at the resonant frequency of the tuned circuit, then the tuned circuit will act as a resistance of say 50,000 ohms. This value is commonly found in intermediate-frequency amplifiers. Thus the load impedance for the tube is 50,000 ohms or .05 megohm. The mutual conductance of a 6K7 is about 1400 microamperes per volt. Hence the amplification is equal to $1500 \times .05$ or 75.

The illustration employed for the pentode is applicable to the tetrode without any change and for that reason we show just the pentode. As you can see, the higher the load impedance, the greater is the actual voltage developed across the load impedance, or the greater is the amount of amplification obtained with the stage. The fact that the tetrode and pentode circuits are more complicated does not alter matters. All that was said with respect to frequency of the signal voltage and variation in load impedance is applicable to the pentode and tetrode as well as to the triode.

Series and Parallel Connection of Load Impedances

Up to the present time we have spoken about signal transfer between the tube and its associated load with respect to the amount of amplification obtained in the stage. In the two illustrations showing the triode and the pentode, the load impedance was so wired into the circuit that it carried the d-c as well as the a-c components of the plate current. Lest this type of connection, which is called *series feed*, be accepted as standard without any alternative, we want to devote some space to a short discussion of *parallel-feed* arrangements which make use of a shunt connection of the load device.



FIGS. 2-10, 2-11. A triode, left, and pentode amplifier stage, right, using a parallel or shunt feed arrangement of the load. No d-c flows through the load.

In many instances the design of the circuit is such that the d-c component is not desired in the coupling unit or load device. In other words, the nature of the unit used as the load impedance is such that better results are obtained if only the a-c or signal component of the plate current flows through the unit. Such is occasionally the case in audio amplifiers. Then again certain r-f and i-f circuit arrangements are improved if the load impedance or coupling device is not subjected to a d-c voltage. To accomplish these ends, shunt feed is used as shown in Figs. 2-10 and 2-11.

These two illustrations are very much like Figs. 2-6 and 2-7. The essential difference is the fact that the load circuits in each case are connected *in shunt* with the device which feeds the plate voltage to the tube, and the load devices are isolated from the d-c supply by means of a blocking condenser C . As to the device

which completes the d-c path in the plate circuit, it is not always the resistor R shown in Figs. 2-10 and 2-11. In some instances this unit is a choke.

No special comment is made concerning the nature of the load impedance. They can be of any type in common use without in any way altering the fact that such circuit arrangements are known as shunt feed and only the a-c or signal component of the plate current flows through the load. However, it is very significant to note, in view of what will follow later, that the resistor R carries both the d-c and a-c components of the plate current, and hence a signal voltage drop takes place across R as well as across the load Z_L . As a rule, the design of such circuits naturally provides for the maximum signal voltage drop across the load Z_L . As to the relation between the load impedance, the tube plate resistance, and the amount of amplification obtained, the use of shunt feed does not change the computations or the process of operation. However, what must be remembered is that the impedance of the feed circuit, in these two cases the resistor R , is in shunt with the load and therefore influences the final value of impedance present in the plate circuit.

Signal Distribution In Voltage Amplifiers

Having covered the preliminaries relating to amplification and the manner in which the signal is transferred through the tube to the coupling device, we are now ready to speak about the distribution of the signal in a voltage amplifier stage. What happens to the signal during the process of amplification? Where in a voltage amplifier does this signal exist? The answers to these questions will show the process of signal tracing and the possible means of isolating a defect in a voltage amplifier stage by means of signal tracing.

Inasmuch as there are many types of voltage amplifiers, types which differ because of the kind of coupling device used between stages, it would seem necessary to deal with several systems. There are of course certain definite similarities between all of these amplifiers because after all is said and done, the tube structure is the same in all types of amplifiers which employ the same tube. However, we do find sufficient differences in certain types of coupling devices to require recognition and discussion.

In order to present the subject properly it is essential to consider an amplifying stage from two angles: First, the basic amplifier circuit without any by-passing; and second, with all of the additional components added. By so doing we can best investigate the path of the signal and present the subject in such a manner as to enable the simplest interpretation of conditions existing in all types of voltage amplifiers.

Radio-Frequency Voltage Amplifiers. Let us start with the triode used in a single tuned-radio-frequency stage. True, such amplifiers are now no longer made, but many are still in use. The basic schematic of such a system is shown in Fig. 2-12. The sig-

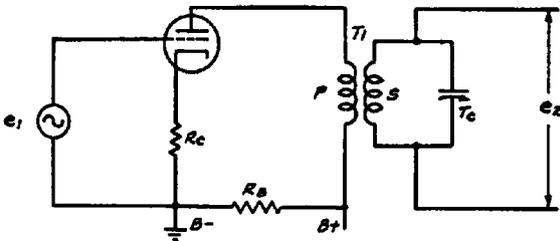


FIG. 2-12. A triode used as a radio-frequency amplifier. The amplified output signal appears across the tuned secondary winding.

nal voltage e_1 is fed into the input circuit of the tube. The coupling device is a conventional radio-frequency transformer with tuned secondary. The amplified signal which would normally be fed to the succeeding amplifier stage normally appears across the terminals of the tuned secondary circuit and we designate this signal voltage as e_2 . We shall assume for the sake of illustration that the frequency of the signal is 1000 kc.

The control grid bias for the tube is secured by means of a cathode bias resistor identified as R_c . The plate voltage is secured from a power-supply unit. As you well know, the voltage divider employed in such power-supply units is a resistor and this resistor is identified as R_B with the positive and negative terminals as shown. Take note of the fact that all by-pass condensers have been omitted. This is deliberate at this time in order to show later, after the by-pass condensers have been added, how

the path of the signal currents is changed and what happens to various signal voltage drops in the circuit.

Let us now trace the path of the plate current in this circuit. It is through the primary winding of the transformer, through the tube from plate to cathode, through the bias resistor and through the B supply. As to the respective d-c voltage drops across these various resistances, they mean very little to us because we are not concerned with d-c voltages. However, what does interest us is that if the signal e_1 is introduced, the plate current will contain an a-c as well as a d-c component. Thus when the signal is applied, we find that an a-c or signal voltage drop appears across all of the devices which carry the d-c plate current. As is to be expected, the frequency of these signal voltages which appear across the various resistances in the circuit is the same as that of the input signal, or 1000 kc. However, in connection with this signal-voltage drop, we must comment upon the r-f transformer primary. The impedance of this winding by itself is very low, so that the signal voltage drop at 1000 kc across P would be very small. However, when we consider the primary winding as a part of the tuned transformer and the secondary winding is tuned to the signal at 1000 kc, an entirely different condition is created.

The entire transformer, primary and secondary windings now act as one, so that an effective impedance appears in the plate circuit of the tube, an impedance which is many times greater than the impedance of the primary itself. In other words, the condition of resonance in the secondary of the r-f transformer makes the entire transformer act as a high impedance present in the plate circuit, so that a substantial signal voltage will appear across the primary of the transformer. Let us for the moment say that the effective impedance of the primary is equal to 10,000 ohms.

What is the status of the signal voltages in Fig. 2-12? Since the signal currents flow through all of the components, a signal voltage will be developed across the r-f transformer primary. In addition a signal voltage will be produced across the power-supply voltage divider R_B and also across the cathode bias resistor R_c .

How do these conditions affect our operations? In the first place it is important to remember that the major objective is to secure the maximum signal voltage across the load impedance, in this case the r-f transformer. Second, we must minimize all signal-voltage drops other than that across the load impedance, so that the maximum signal will be obtained across the load impedance. This means that the signal-voltage drop across the bias resistor R_c must be kept at a minimum and the signal-voltage drop across the power-supply resistor R_B must also be kept at a minimum. If this is done, then the available signal voltage will divide between the internal plate resistance and the load impedance.

Now, since no means for minimizing or eliminating the signal-voltage drop across certain portions of the amplifier have been incorporated, we find that with the ground as the reference point, a signal voltage will exist between ground and the cathode. A signal voltage will also be found between ground and the plus end of the B-voltage supply or the low end of the r-f transformer primary. Naturally signal voltage exists between ground and the plate of the tube. Of all these signal voltages, that which is available across the terminals of the r-f transformer primary is the only one of use to us. In each case the magnitude of the signal voltage is equal to the value of the a-c component of the plate current times the impedance of the element through which this signal current flows.

Assuming that the aforementioned signal voltages exist, what is the effect of their presence? Are they harmful at any point? Do they afford certain information? What can be done to minimize those signal voltages which are not required? Let us answer these questions in the order in which they are given. The effect of signal voltages in circuits or across devices where they do not belong cannot be stated as being harmful in every instance, because that condition which might be stated as being undesired in one case, might be actually wanted in the next. For example, the signal voltage which is built up across the cathode bias resistor is at times desired and then at other times it is entirely unwanted. For the present moment let us assume that it is not wanted and see what happens.

If you recall what was said concerning the effect of the grid

voltage upon the plate current, you can readily understand that since the grid is located between the cathode and the plate, a definite relation exists between the voltages on the grid and those on the cathode. If, for example, a signal is applied which at any instant makes the grid less negative and results in an increase in plate current, this increased plate current naturally flows through the cathode circuit. Since the cathode circuit contains the resistor R_c , an increased voltage drop takes place across this resistor and the cathode becomes more positive with respect to the grid. This tends to offset the change in voltage of the grid because the net difference in voltage between the grid and the cathode is reduced.

If during the operation of an amplifier an a-c signal voltage is applied to the grid, causing a change in plate current in accordance with this change in grid voltage, and the development of a corresponding signal voltage is permitted across the cathode resistor,—then this signal voltage across the cathode resistor will tend to offset some of the signal voltage applied to the control grid of the tube. Expressed differently, the signal voltage developed across the cathode bias resistor by the a-c component of the plate current is out of phase with the signal voltage applied to the input of the tube, and hence a degenerative condition is created. This degenerative condition tends to reduce the signal output from the amplifier because it tends to reduce the effective signal between the control grid and the cathode.

The elimination of such a degenerative condition is simple. It means the removal of the signal voltage developed across the cathode bias resistor. It stands to reason that this cannot be accomplished by removing the cathode bias resistor, for if this is done, it becomes impossible to obtain the required d-c bias. Hence the solution must be some means whereby the impedance of this cathode bias resistor is reduced to a minimum without altering its d-c resistance. The answer is a by-pass condenser connected across the cathode bias resistor as indicated by $C1$ in Fig. 2-13.

The value of this condenser $C1$ is such that its reactance over the range of frequencies of e_1 is very low in comparison with the d-c resistance of the cathode bias resistor. Thus while the correct bias is developed across R_c by the steady component of the

plate current, a very low impedance path is offered by $C1$ to the a-c or signal component of the plate current and the degenerative voltage built up across the condenser is negligible.

It is of course true that the magnitude of signal voltage built up across the cathode bias resistor when the by-pass condenser is absent is ordinarily not very great, but it is still sufficiently great to be used as an indicator to establish that there is improper by-passing caused, for example, by an open-circuited by-pass condenser, or one which has such a high internal resistance that its

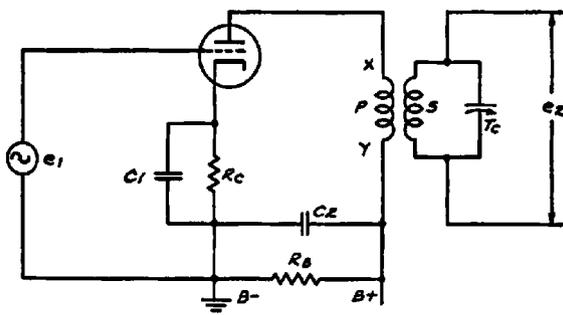


FIG. 2-13. A triode used in a radio-frequency amplifier stage. Note the condensers which are used to by-pass the cathode and plate-supply circuits.

by-passing effect is not very good. Normally the average by-pass condenser has such a low reactance at the normal run of signal frequencies, that the cathode is virtually at ground potential with respect to the signal. Thus a test for the signal voltage between ground and cathode is a test for the condition of the by-pass condenser which is connected across the bias resistor. Any such signal voltage test between ground and cathode would be made at the frequency of the signal voltage fed into the tube, namely the frequency of e_1 .

What has been said should not be construed as being limited only to radio-frequency amplifiers. It is just as true in intermediate-frequency and in audio-frequency amplifiers. At the same time, examples can be found wherein this by-pass condenser

is deliberately omitted in all of the classifications of amplifiers named.

It is also significant to note that the conditions described are not limited to triodes. Perhaps it is premature, in view of the fact that tetrodes and pentodes will be mentioned later, but it can be said that the significance of signal voltages between cathode and ground in triodes is similar in screen grid tubes.

We have spoken about the development of a signal voltage across the internal impedance of the power supply. What is the effect of signal voltage across this impedance? As stated earlier, it reduces the voltage which can be effective across the normal load impedance because it tends to reduce the magnitude of signal plate current flowing in the plate circuit. How can this be overcome? By inserting a low-reactance path across the B supply; in other words, by-passing the plate circuit so that the a-c or signal component of the plate current finds an easy path around the B-supply unit. This path is provided by the by-pass condenser C_2 in Fig. 2-13. The reactance of this condenser, being very small in comparison with the impedance of the power supply, places the low end of the r-f transformer primary at ground potential as far as signal voltages are concerned. Thus a test for the signal voltage between ground and the low end of the r-f transformer will establish whether the by-pass condenser C_2 is functioning.

A supplementary condition associated with the plate by-pass condenser requires mention. When a number of stages of amplification are operated from the same plate power supply, the impedance presented by this power supply is naturally common to the plate circuits of all of the stages. If, as a result of improper by-passing, a substantial signal voltage is permitted to build up across this common impedance, it is very apt to cause regenerative interaction between the stages and possibly oscillation of the amplifier.

Returning again to Figs. 2-12 and 2-13, a summary of signal conditions in these circuits shows the following: As a result of normal operation and with normal precautionary measures instituted, the input signal e_1 appears at the control grid between grid and ground. In fact all signal voltages are most conveniently measured with respect to ground. An amplified signal should of

course be present at the plate; a test between plate and ground is the equivalent of a test across the terminals X and Y of the primary winding because C_2 effectively places point Y at ground potential. The signal is also present across the secondary terminals of the r-f transformer. If all conditions are correct, there will be no signal at the cathode or at the B-plus end of the transformer primary.

As to the signal voltage between plate and ground or across the primary of the r-f transformer, two conditions must be mentioned. While it is true that we show a triode amplifier, wherein it was customary in the past to employ r-f transformers with very low-impedance primaries and wherein the signal voltage appears across the primary only when the secondary is properly resonated, it is necessary to mention that if the primary of this r-f transformer were of the high-impedance type, a maximum signal would exist across the primary winding when the secondary is resonated, but a certain amount of signal voltage would still exist across the primary when the secondary was detuned. The difference between the two conditions is at all times sufficient to be able to distinguish when the secondary is in or out of resonance with the input signal. The reason for the existence of such a signal across the primary when the secondary is off resonance is that the impedance of the primary itself is substantially high. In the case of the low-impedance primaries, there would be practically no signal at the plate off resonance because the low-impedance primary would be almost a short circuit as far as the signal is concerned.

As to the signal e_2 , shown across the secondary terminals of the r-f transformer, this naturally is a maximum when the secondary circuit is correctly tuned and decreases rapidly for an off-resonance state, eventually reaching zero. The rapidity of decrease of the signal voltage across the r-f transformer secondary depends upon the selectivity characteristics of the transformer. The more selective the transformer, the more rapidly will the signal voltage across the secondary winding reach zero as the circuit is tuned off resonance with the frequency of the input signal.

The use of a tetrode or pentode tube in place of the triode does not alter the comments made in connection with the triode. All that happens is that the added tube elements increase the com-

plexity of the circuit and introduce one or more additional circuits which are subject to the signal test. For example, Fig. 2-14 shows the pentode tube used as an r-f amplifier. The circuit structure is very much like that of Fig. 2-13, except for the added tube elements and the fact that the screen-grid circuit contains another by-pass condenser, C_3 . This capacity C_3 places the screen at ground potential with respect to the signal and in this way removes the possibility that the signal component of the screen current will cause the development of a signal voltage across the impedance of the B supply. Thus the presence of a signal voltage between the screen grid (point Z) and ground,

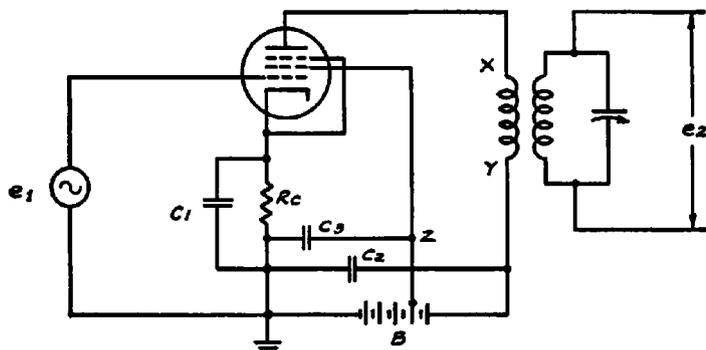


FIG. 2-14. A pentode tube used in a r-f amplifier stage. Condensers are used to by-pass the cathode, screen, and plate-supply circuits in order to prevent the development of signal voltages at these points.

establishes that proper by-passing is not being accomplished. All other statements concerning the signal in the control grid, cathode, and plate circuits in triodes apply to the pentode and tetrode tubes. Since the tetrode is similar in circuit structure to the pentode, except for the omission of the suppressor grid, it is not necessary to show a schematic of the tetrode r-f amplifier.

Making the amplifier more complicated by the use of filter networks so as to confine the signal currents to certain paths, does not in any way alter any of the statements made so far. For example resistance-capacity filters are shown in a pentode stage in Fig. 2-15. RS is the plate-circuit filter resistor and $R\#$ is the

screen-circuit filter resistor. The respective by-pass condensers are $C3$ and $C2$. The process of amplification remains unchanged. The signal test points remain the same as before, namely the control grid, the plate, and points Y and Z to establish whether the low-impedance paths to ground for the signal component of

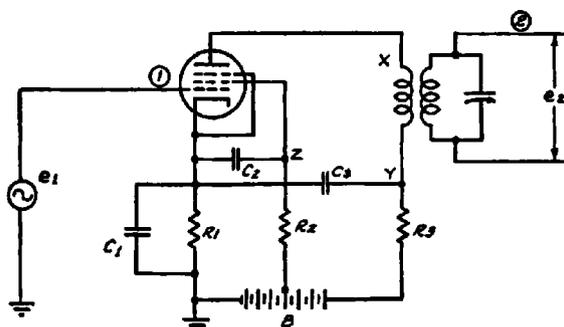


FIG. 2-15. A pentode tube used in a r-f amplifier stage. Resistance-capacity filters are used to prevent the screen and plate circuits from developing signal voltages at the power supply.

the screen and plate currents are functioning properly. The fact that the by-pass condensers $C2$ and $C3$ join the cathode instead of connecting directly to ground is unimportant since the condenser $C1$ provides the required low-impedance path from cathode to ground.

As to operating voltages, the presence of filter resistors and condensers increases the possibilities of incorrect operating voltages, due either to some variation in the values of $R2$ and $R3$ or to leakage in the condensers $C2$ and $C3$. Leakage in the screen and plate by-pass condensers, with the connections shown, will increase the operating bias and in that way reduce the amount of amplification obtained with the stage. However, if proper signal amplification is obtained, it is reasonable to assume that the operating voltages in the stage are correct.

Changing the type of load impedance does not in any way alter the distribution of the signal in an amplifier stage. For example, Fig. 2-16 shows a typical i-f amplifier stage in which the signal

is provided by a tuned input circuit, the secondary of *T1*. The plate winding is tuned and the secondary of *T2* also is tuned and feeds the succeeding amplifier stage. The remainder of the circuit is very much like those shown in preceding illustrations.

As far as actual operation of the amplifier tube itself is concerned, the principal item is the operating voltages, but as far as operation of the amplifier stage with respect to the signal is concerned, we find that the signal from *T1* is important and the signal developed in *T2* is important. Assuming that *T1* is properly resonated to say 470 kc, the signal which is supposed to be amplified, this signal is present across the secondary circuit between the control grid and ground. However, you should remember that this signal will be present even if the amplifier tube is entirely inoperative because of any one of a number of reasons. As long as the input transformer circuit is complete and there is no short circuit, the signal will be present across the grid-to-ground circuit.

As to the amplified signal in the plate circuit, that is, between plate and ground in Fig. 2-16 or between *X* and *Y* in the same illustration, it depends upon the tuning of the resonated primary winding. Whether or not it appears across the tuned winding, depends entirely upon the impedance of this winding. As stated before, since parallel resonance is used, the impedance is a maximum at resonance and falls off on both sides of resonance. If the circuit is badly detuned, very little signal voltage will be present in the plate circuit. For example, in a typical case where an i-f stage using a pentode was checked, a maximum signal voltage existed when the transformer was tuned to 470 kc. When the transformer was detuned by 5 kilocycles, the signal voltage between *X* and *Y* dropped by 50%. When the transformer was detuned by approximately 20 kilocycles, the signal voltage dropped to only 5% of its original value.

It stands to reason that any condition of incorrect resonance in the primary circuit will influence the signal in the secondary circuit. Thus if the primary is greatly mistuned, very little signal will be produced across the secondary. Possibly there might be some signal due to stray signal pickup, but this is very much less than would exist when the transformer is properly tuned.

Speaking about the signal present in the output circuit, it

stands to reason that under normal conditions the frequency of the signal in the plate circuit is the same as that applied to the grid circuit. Furthermore, under normal conditions, the character of the signal in the plate circuit corresponds to the signal applied to the grid circuit. Thus if a modulated carrier of 470 kc, 1000 kc or 30,000 kc is applied to the grid circuit, the signal in the plate circuit will be 470 kc, 1000 kc or 30,000 kc, respectively, and it will retain the modulation characteristics of the signal fed into the grid circuit.

These examples of frequency are purely illustrative. In practice they can be lower or higher, as for example in the commercial band just above the audio band, or in the television band. Furthermore the character of the signal is of no consequence as far

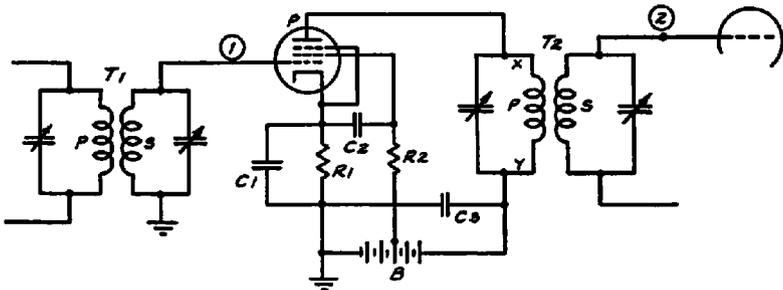


FIG. 2-16. An amplifier stage with both the input and output circuits tuned. The dependence of signal transfer upon the tuning of these circuits is described in the text.

as amplifier operation is concerned. Possibly one type of signal might be more difficult to check than another, but neglecting the testing procedure for the moment, what has been said concerning the distribution of the signal remains unchanged. For example, if e_1 is a conventional unmodulated carrier, the distribution of the signal through the amplifier is exactly the same as if the signal were an amplitude-modulated carrier or a frequency-modulated carrier. The exact method of establishing the presence or the level of the signal at various places might be more complicated with one type of signal than with another, but the distribution remains the same and the test points remain the same.

Amplification in Tube and Transformer

We have spoken about the tube as an amplifier, but actually the tube itself does not constitute a complete stage of amplification. It is a part of the stage, but the entire stage of amplification includes the output coupling unit. This means that if we consider the schematic of Fig. 2-16 as a typical example, the amplification of the stage is that which exists between the control grid of the tube, point 1, and the grid of the succeeding tube, point 2, in Fig. 2-16. These references to test points mean that the test is made between these points and ground in each case.

With reference to the distribution of gain or amplification in a complete stage of this type, it is divided between the tube and the coupling unit. As a general rule, the modern receiver is of such design that very little if any gain is obtained in the coupling unit, that is, in the interstage r-f or i-f transformer. The gain usually is obtained between the grid and plate of the tube. The coupling device enables the transfer of the signal from the plate to the grid and also provides selectivity,

However, in the older receivers employing triode tubes, the gain was divided between the tube and the coupling unit, so that both contributed the final amount of amplification. The exact distribution of gain between the tube and the coupling unit does not justify detailed discussion, if only because so few of such receivers are in use, but at any rate we can say that the tube contributed very little to the overall stage gain. Practically all of the voltage gain was provided by the transformer because of the step-up ratio between the primary and the tuned secondary winding. Thus if you refer to Fig. 2-12, the level of the signal at the control grid and plate would be about the same, whereas the signal voltage e_2 across the secondary of the r-f transformer would show the increased voltage as a result of the gain in the transformer. It is of course possible that in certain particular instances, the gain obtained in the tube would be greater than unity, but by and large the majority of these stages operated in such manner that most of the amplification was obtained in the transformer.

When tetrode or pentode type tubes are used as r-f and i-f amplifiers, we find that just the reverse of what has been said

about triode amplifiers is true. Practically all of the gain is obtained from grid to plate, so that at resonance the signal at the plate of the tube is greater than the signal at the grid of the tube by practically the amount of gain provided by the stage. As far as the transformer is concerned, the signal level at the plate of the tube and the signal level at the grid of the succeeding tube or point \mathcal{Z} in Figs. 2-15 and 2-16 is approximately the same if not a slightly lower. In other words, the gain through the transformer at resonance is approximately one. This applies to r-f as well as i-f transformers.

These details relative to gain in r-f and i-f transformers with triodes, tetrodes and pentodes are extremely important in signal tracing, because as you can see the normal conditions differ in accordance with the type of tube used. There are two points of difference in r-f and i-f amplifier systems which should be mentioned at this time, if only briefly, because they are discussed at greater length in a separate chapter. We are referring to the antenna transformer and the transformer which couples the last i-f stage to the diode detector. For the present let it suffice to say that a definite amount of gain is available in the average antenna transformer and that this gain varies with the class of receiver in which it is used. Also, the i-f transformer which feeds the diode usually shows a loss in voltage, that is, it acts as a step-down instead of a step-up transformer.

Audio-Frequency Amplifiers

The distribution of the signal in an audio-frequency amplifier system is the same as in a r-f or i-f amplifier, with the exception of course that the signal frequency is lower. True, the general structure of the circuit is slightly different, occasioned by the fact that audio-frequency coupling devices are used, but when we consider the tube alone, it still remains an amplifier and when we add the coupling unit, that which is in the plate circuit is still the load impedance. For example, in Figs. 2-17 and 2-18, we show a resistance-capacity coupled triode and pentode stage respectively.

The audio signal e_1 is present across the grid leak $R1$, which means that it is present between the control grid of the amplifier tube and ground. This signal is assumed to originate someplace

ahead of the blocking or coupling capacitor $C1$. The plate current during amplification contains the signal component which has the same frequency as e_1 . Since this plate current flows through the bias resistor $R2$ and since it is desired to develop only a d-c voltage (the bias) across this resistor, the by-pass capacitor $C2$ is made sufficiently large so that it offers a low-impedance path to the audio signal. As you can readily understand, the capacitance of such a by-pass capacitor must be greater when working with audio frequencies than with radio or intermediate frequencies.

In connection with such bias resistor by-pass capacitors, the amount of by-passing accomplished is not always sufficient to

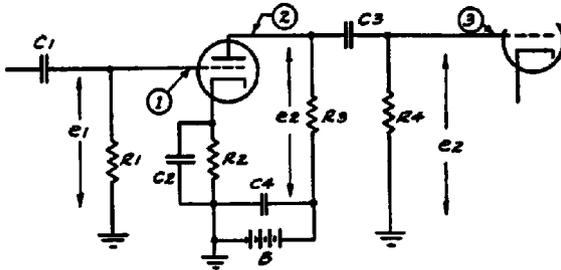


Fig. 2-17. A triode amplifier stage using resistance-capacity coupling. $R3$ is the plate load across which the amplified signal voltage is developed.

prevent entirely the development of an audio signal across the cathode resistor; this means that under certain conditions, particularly at low audio frequencies, a signal will be observed between the cathode and ground. In connection with the audio signal developed across the cathode resistor, some amplifiers deliberately omit the bias resistor by-pass capacitor in order to secure a definite amount of degeneration. In such cases a strong audio signal is present across the cathode resistor. In other cases you might find that this bias resistor is made up of two units, one of which is by-passed and the other is not. That which is not by-passed is intended to develop an audio signal for degenerative purposes or for deliberate feedback to some other portion of the amplifier. Examples of such feedback will appear later in this volume.

As to the signal in the plate circuit, the signal current flows through the load resistor R_3 and a signal is developed across this resistor, so that a signal exists between the plate and ground. The by-pass condenser C_4 serves the same purpose in an audio stage as the plate-supply by-pass condenser in an r-f or i-f amplifier.

Whatever the signal voltage developed across the load resistor R_3 , that signal voltage also appears across R_4 , which is the grid

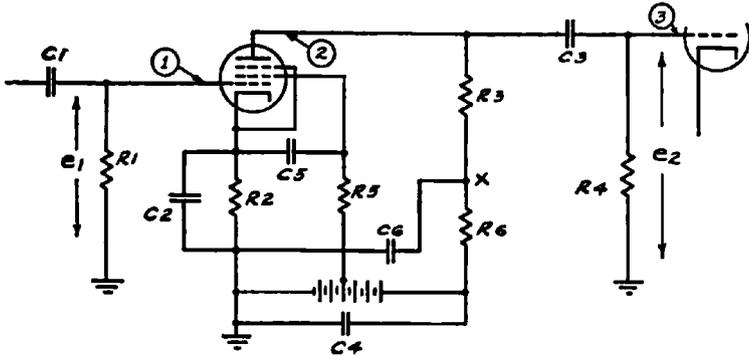


FIG. 2-18. A pentode amplifier stage using resistance-capacity coupling. The distribution of signal voltages is described in the text.

leak for the succeeding stage. The blocking condenser C_3 serves the purpose of keeping the d-c voltage at the plate of the amplifier tube from reaching the grid of the succeeding tube. Its value is such that it ordinarily does not attenuate the signal, so that in amplifiers of this type, the signal level at the signal grid of the following tube, point 3, is virtually the same as the signal level at the plate of the preceding tube, point 2 in Fig. 2-17.

Speaking about attenuation or reduction of signal level, such amplifiers do show a marked drop at the low frequencies, due to the increased reactance of the blocking condenser C_3 . At the higher frequencies the amplification also drops off as a result of the shunting effect of the tube and wiring capacitance. Usually, designers try to arrange the constants of these components in such manner that the amplification is substantially flat over the entire audio range. This matter of attenuation is more important

when overall frequency response is being considered than when a single-frequency test signal is fed into the amplifier. As far as the actual value of amplification is concerned, this depends upon a number of different factors such as the type of tube, the load resistance, the coupling or blocking condenser and the grid leak used for the next stage. However, since we are concerned solely with amplifiers already designed, we need not discuss the part played by each of these components.

The use of tetrode or pentode tubes in place of the triode does not essentially alter the operation. All that happens, for example in the circuit of Fig. 2-18, is that the added tube elements increase the number of connections and the number of components in the circuit. The signal distribution in the system is in line with what has been said before about pentodes used as voltage amplifiers. The test points shown in Fig. 2-18 correspond with the numbers shown in Fig. 2-17, with the addition of the screen grid.

Speaking about the screen grid in the pentode tube, it is interesting to note that if the screen circuit is not by-passed, a signal voltage will be present at the screen grid, between the screen grid and ground. The signal voltage applied to the control grid will cause a signal component to be present in the screen current and this will develop a signal voltage across whatever impedance or resistance may be present in the screen circuit. In this instance, it would be resistor $R5$.

As to the distribution of gain in such audio amplifiers, all of it is provided by the tube. The coupling unit, in this case $R3-C3-R4$, contributes nothing. Nevertheless, when considering the total amplification provided by such a stage, it is determined by the increase in signal between e_1 fed into the control grid of the tube and e_2 available across the grid leak of the succeeding tube.

Fig. 2-18 contains a variation in the plate circuit. Although shown only in this schematic, it is used not only with pentode tubes but also with other types of voltage amplifiers. We are referring to the use of the plate-circuit filter resistor $R6$. $R3$ is in series with $R6$ as far as the steady plate current is concerned, but as far as signal current is concerned, only $R3$ acts as the plate load. This is true because the by-pass condenser $C6$ provides a low-reactance path to ground, a path which does not include $R6$

and the plate power supply. If, however, $C6$ were open-circuited or for some reason did not perform its by-passing function, then the plate load would be the sum of the two resistances $R3$ and $R6$. With operation normal no signal voltage is present at X , the junction of $R3$ and $R6$; but if $C5$ is open, a signal voltage will be present across $R3$ and between X and ground. This would also be true if $R3$ were a choke and $R6$ a resistor.

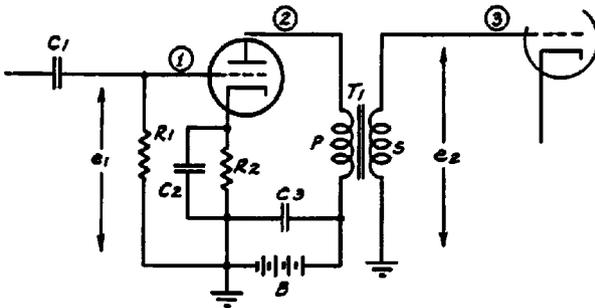


FIG. 2-19. A triode amplifier stage using transformer coupling in the load circuit. Signal voltages are present at points 1, 2, and 3.

Variations of circuit components used in voltage amplifiers do not alter the process of amplification. For example, the grid leak $R1$, the plate load $R3$ and the grid leak $R4$ need not be resistors. They can be chokes such as are used in impedance-capacity coupled amplifier systems. As far as that is concerned, the system shown in Fig. 2-18 need not be used for audio amplification. It can just as readily be used at higher frequencies with chokes replacing the various resistors or different combinations of chokes and resistors. While it is true that the type of component utilized as the coupling device can change the number and location of the signal test points, replacement of a resistor by a choke in an amplifier system does not introduce variations in the basic operation of the tube or in the distribution of the signal.

Of course the type of coupling unit will influence the magnitude of signal at various points in the system. Thus in the transformer-coupled amplifier stage shown in Fig. 2-19, the essential

difference between this circuit and that of Fig. 2-17 is in the output coupling device. Whereas in Fig. 2-17, the signal level is the same at the plate and the succeeding grid, in Fig. 2-19 the signal level at point 3, the succeeding grid, is usually greater than at point 2, the plate of the amplifier, because of the step-up in $T1$. As you can see, proper interpretation of signal distribution must be accompanied by an understanding of the function of the various components with respect to the signal. This subject of functions of various types of coupling devices and their relation to signal level and signal distribution is dealt with in detail in the chapter devoted to coupling devices.

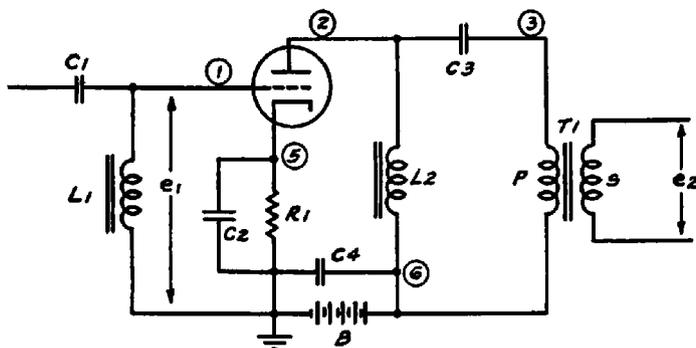


FIG. 2-20. Various methods of coupling the signal can be used in the input and output circuits. In this stage, choke coupling is used in the input and choke-transformer coupling in the output circuit.

Examples of variations of these basic circuits are shown in Figs. 2-20 and 2-21. Various combinations of input and output coupling devices are shown. In each case, you will see that the basic circuit remains the same and hence the operation of the amplifier is the same. Likewise the basic signal test points remain unchanged. Where the number of components is greater, the number of test points is greater; however, certain points remain common to all systems because they are an integral part of the basic tube circuit.

condition responsible for this type of signal be corrected, but that is not a major problem. . . . The problem is the determination of the cause of this condition.

We previously mentioned hum as a possible exception to the general statements made herein. Now, there are a number of places where hum can originate, but since we are now concerned with the process of amplification, we need consider at this time only those conditions which cause hum in connection with a stage of voltage amplification. It is of course true that those conditions which will cause hum in a voltage-amplifier stage also will cause hum in a power-amplifier stage, so that what is said here can be kept in mind for future reference.

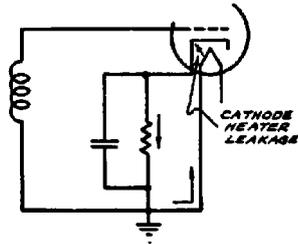
One item which is of interest if only because it is generally difficult to solve, is hum due to cathode-heater leakage in the indirectly heated type of tube. In high-frequency circuits this type of defect may modulate the carrier and thus become noticeable, whereas in audio-frequency amplifiers, it becomes a part of the signal. Basically it is due to the presence of a small leakage current which flows between the heater and the cathode and therefore flows through the cathode bias resistor. Being of low frequency, it is often inadequately by-passed by the cathode by-pass condenser and consequently builds up a hum voltage across the cathode resistor; this tends to vary the voltage between cathode and control grid and therefore creates a hum signal component in the plate current. A diagram of this condition is shown in Fig. 2-22.

There are a number of other conditions associated with the heater which might tend to cause hum, all of which, like the first example, are items associated with the tube structure and not with operating potentials. It is true, however, that excessive heater voltage can aggravate the condition previously mentioned. Of interest to us is the fact that the remedy for such difficulties is tube replacement which is much simpler than the addition of a higher value of by-pass capacity across the cathode bias resistor. Although adding capacity across this resistor reduces the a-c impedance across which this hum voltage is developed and thereby reduces the hum, the former method is by all means preferred. As to methods of identifying the existence of this condition, they consist of checking the signal at the grid of the

tube, trying a replacement tube, and checking for the presence of hum in the various operating voltages supplied by the power supply. In general, where the tube is suspected as a cause of hum, the quickest method is the substitution of a tube known to be in good condition.

We might repeat at this time that we are omitting items which are outside the stage itself, as for example modulation hum. This is discussed elsewhere in this volume. The subject of improper filtering of voltage-supply circuits is discussed in connection with regenerative conditions in voltage-amplifier stages. Two of the items mentioned below may not seem extremely important, but they are especially important in high-gain audio amplifiers. These are imperfect grounding and stray coupling between adjacent components and wiring. In this connection coupling between leads running close together are often a source of trouble.

FIG. 2-22. Leakage between the cathode and heater produces a hum voltage across the cathode resistor.



Distortion

Distortion is quite an extensive subject and in this process of signal tracing is checked in two ways: (1) by listening to a broadcast signal and (2) by visual observation or examination of the signal waveform. At the moment we are not concerned with which method is used.

You will remember we said that distortionless voltage amplification calls for a faithful reproduction in the plate circuit of the signal voltage applied to the grid. When this is accomplished, either the listening or visual test will enable detection of distortion.

Incorrect operating voltages are a very frequent cause of distortion and this applies to all types of voltage amplifiers. The determination of such contributing causes, as you can readily

understand, is very simple. It is the measurement of the operating and control voltages at the tube elements during operation of the amplifier stage. By operation we mean with signal input. It is not sufficient to check operating voltages only, because distortion may be due to the control voltage which is present only when the signal is applied to the receiver. Furthermore, these measured voltages should be the actual voltages, which means that they must be checked with such measuring equipment that will not load the circuits. In general the measuring equipment must have an input impedance sufficiently high so as to enable measurement of the actual voltages across the high resistances and tuned circuits present in the system.

Since the measurement of operating and control voltages is not difficult, we do not consider it necessary to enter upon a lengthy discussion. As to the normal voltages to be expected, service manuals containing the electrical specifications of the various receivers invariably state the correct operating voltages. It should be understood, of course, that these values may vary as much as plus or minus 20% from the value specified because of variations in resistors, tubes, and other component parts. In this connection, it might be well to add that service notes often specify the values of operating voltages as measured with comparatively low-resistance voltmeters, such as those of the 1000-ohms-per-volt type. This means that the measured voltage is often much less than the actual operating voltage. However, more and more receiver manufacturers in the United States are making a change in their tabulations and are stating the actual voltage effective at the various tube elements. The voltage values so designated are those which would be indicated by an electronic or vacuum-tube voltmeter of very high input resistance. It is our belief that in time to come all voltage tabulations will specify the actual operating voltages rather than the lower values obtained when a lower-resistance voltmeter is used.

Leaving operating voltages for the present, distortion can be divided into a number of classifications. Hum has already been considered. What is left? In a general way we can list them as including (1) overloading, (2) rectification, (3) frequency distortion, (4) phase distortion, and (5) regeneration. Let us examine the significance of these various items. What do we mean by

overloading? Basically it means that the signal voltage applied to the tube is greater than it is possible for the tube to handle. This applies equally well to all types of amplifiers.

Overloading. If we are speaking about overloading of the input circuit it means that the signal voltage fed into the tube is in excess of that permitted by the grid bias. You may recall the statements made earlier in this chapter that in amplifiers operated with grid-bias, one of the requirements for proper operation is that the grid remain negative at all times. If, however, the amplitude of the signal applied to the tube is such that it exceeds the grid bias and permits the grid to swing positive and attract electrons, then a direct current will flow between the grid and cathode and the signal in the plate circuit will be distorted. The

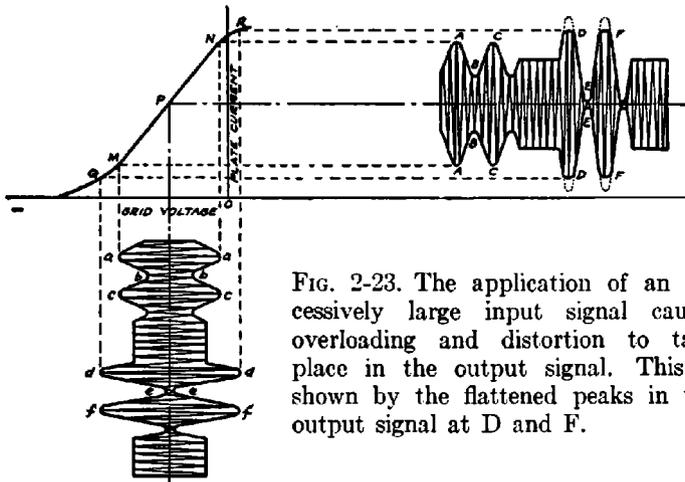


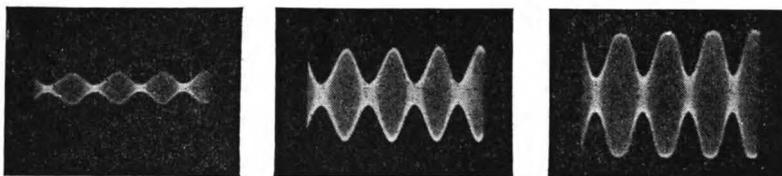
FIG. 2-23. The application of an excessively large input signal causes overloading and distortion to take place in the output signal. This is shown by the flattened peaks in the output signal at D and F.

distortion is caused by the fact that the grid-voltage change due to the signal follows the waveform of the signal only over that part of the cycle before the grid goes positive; consequently the plate-current waveform is a true amplified reproduction of the grid-voltage waveform only over that range of grid-voltage swing which is below the level where the grid swings positive. This is shown in diagrammatic form in Fig. 2-23.

The sloping line *QMPNR* is the grid-voltage-plate current characteristic of the amplifier tube. The applied signal voltage

is shown as the modulated wave *abc-def*. You will note that two amplitudes are shown for the modulated input signal: that represented by *def* is greater than that represented by *abc*. The operating point *P* on the grid voltage-plate current characteristic is assumed to be such as to accommodate the maximum amplitude of signal input. Between points *M* and *N*, the characteristic is linear. Beyond these two points the characteristic bends.

Proper amplification of the weaker of the two input signal voltages is shown by the plate-current variation *ABC* corresponding to the grid-voltage variation *abc*. When the amplitude of the

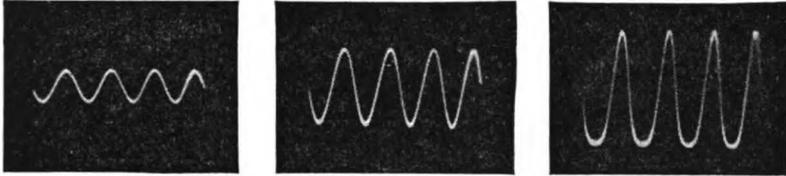


FIGS. 2-24, 2-25, 2-26. The input and output signals are shown at the left. When the input signal is further increased, the signal becomes distorted as shown in the oscillogram at the extreme right.

input signal voltage is increased to correspond with *dd-ff*, the input voltage now swings the grid voltage over the non-linear portion on both the positive and negative alternations. The positive alternations swing the grid positive because the peak amplitude of the signal exceeds the grid bias. The result is that the plate-current curve no longer remains a faithful amplified reproduction of the input signal voltage curve. Instead it flattens over that curved portion of the grid voltage-plate current characteristic which lies above *N* and also below *M*. The dotted portions of the plate-current curve at *D* and *F* indicate the shape of these peaks if there were no distortion. The same condition is shown in the three oscillograms of Figs. 2-24, 2-25 and 2-26. The first is the input modulated-carrier signal. The second is a correctly amplified signal and the third shows overloading. The flattened peaks can be clearly seen. The equivalent condition in an audio amplifier is shown in Figs. 2-27, 2-28 and 2-29.

Let us continue with the investigation of such a condition in a typical stage which is amplifying a modulated wave similar to the one we have been discussing. Suppose that we take as our

basis, the amplifier shown in Fig. 2-30. We shall call the input signal e_1 , and the output signal e_2 across the secondary of T_2 . What happens during such a condition of overloading? Where in this circuit is the signal normal and where is it distorted?



FIGS. 2-27, 2-28, 2-29. The input and output audio signals are shown in the two oscillograms at the left. When the input is further increased, overloading takes place and the output signal becomes distorted as shown at the right.

For the usual conditions of overloading encountered in r-f and i-f amplifiers, the input signal across the tuned circuit will be found undistorted, which means that the signal at the control grid is undistorted. With further reference to the grid circuit, the

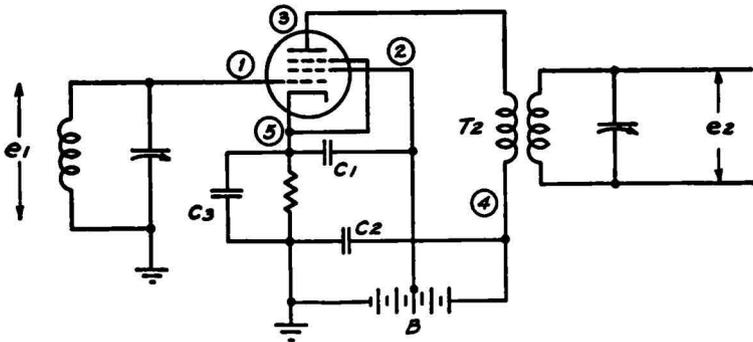


FIG. 2-30. A typical amplifier circuit which is used in connection with the description of distortion in the text.

comment that the signal is not distorted when the grid draws current should not be interpreted as being true in every single case. It is generally true in the case of r-f and i-f amplifiers, also in the case of some a-f amplifiers—but not in all a-f amplifiers. In transformer-coupled a-f amplifiers, a great deal depends upon a number of factors, such as the output impedance of the winding

which supplies the grid of the tube being overloaded, the amount of overloading, and the amount of impedance reflected from the grid winding back to the plate circuit of the preceding tube. However, since we are interested solely in r-f amplifiers at the moment, we can repeat that the modulated signal at the grid will generally be undistorted despite the fact that the signal in the plate and screen circuits is distorted.

As is to be expected in accordance with what has been said concerning the effect of grid voltage variations upon the plate current, the presence of grid current affects all of the circuits which are associated with the electron stream. In other words, a check of the signal, if it exists in the screen circuit of a tetrode or pentode tube, will show the same general type of distortion as exists in the plate circuits. If for the moment we forget the presence of the by-pass condensers $C1$, $C2$, and $C3$ in Fig. 2-30, the signal at points 2, 3, 4 and 5 would be distorted. In other words, wherever the varying plate current causes the development of a signal voltage, the signal voltage will carry the distortion caused by the presence of grid current or overload of the grid circuit during certain portions of the input signal cycle. Naturally, the signal e_2 developed across the secondary of the transformer $T2$ will be distorted.

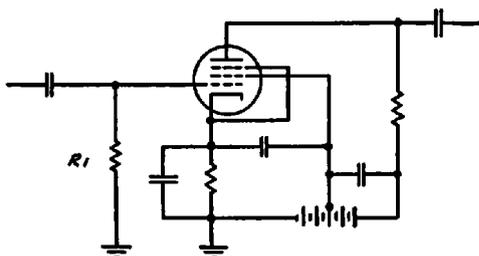
Continuing the discussion of this distorted signal, the time is opportune for the introduction of another subject associated with such distortion in amplifier circuits. This subject is the development of harmonic frequencies as a result of such nonlinear operation. Without attempting to discuss the subject at great length, one of the results of operation along the nonlinear portion of the grid voltage-plate current characteristic, the creation of a flattened plate-current wave, is the introduction within the tube of frequencies which are not present in the output—namely harmonic frequencies of the signal input. Thus if the input signal e_1 is 1000 kc and the described condition of overloading exists, there will also be present across the terminals of $T2$, harmonic frequencies of 2000 kc; 3000 kc, etc. Of course the amplitude of these harmonic voltages is small in comparison with the fundamental frequency, especially since the plate circuit is tuned to 1000 kc, but they are present and this should be borne in mind. Any signal-tracing device connected to $T2$ and resonated to the

harmonic frequencies will show their presence under the conditions mentioned. However, this should not be accepted as a positive statement to the effect that these harmonic frequencies always will be detected; if the extent of overloading is not excessive, the amplitude of these harmonic frequencies may not be sufficient to be detectable.

What has been said as being true in r-f and i-f systems is also true in untuned circuits such as those in a-f amplifiers. In other words, the development of such harmonics is essentially a result of the overloading, and does not depend directly on the type of load circuit used or the frequency of the input signal. Where the plate circuit is untuned, as for example in a-f amplifiers, stronger voltages at the harmonic frequencies will be built up because the plate load circuit responds to the harmonics as well as to the fundamental. In contrast to this, the tuned load circuit used in r-f and i-f amplifiers tends to suppress the harmonic frequencies because of its low impedance at these frequencies.

You may recall a previous reference to the effect that when grid current flows a voltage drop is developed across whatever resistance exists in the grid circuit. Accordingly a check for overloading is more easily effected in Fig. 2-31 than in Fig. 2-30

FIG. 2-31. When overloading in the grid circuit takes place, grid current flows through R_1 and develops a negative voltage at the grid.



because of the presence of the high-resistance grid leak R_1 . A high-resistance d-c voltmeter, preferably a vacuum-tube voltmeter, connected across this resistor between grid and ground, will show the d-c voltage developed as a result of the flow of grid current. This test is not done as easily in Fig. 2-30 because of the comparatively low d-c resistance of the tuned winding; this is true even if the transformer is an i-f unit. However, if the circuit is such that a high resistance, for example a filter resistor,

is in the circuit as is R_1 in Fig. 2-32, a test between points 1 and 2 will show the presence of grid current by the development of a d-c voltage across this resistor. If overloading is taking place point 2 will become negative with respect to point 1.

In all cases the grid current present when the grid circuit is overloaded develops a voltage across whatever resistances are connected in the grid circuit between the grid of the tube and the return point of the grid circuit to the cathode. This statement applies to all types of circuits, and is repeated to emphasize its importance.

Naturally the input signal does not have to exceed the negative grid bias before distortion will take place. It is only necessary

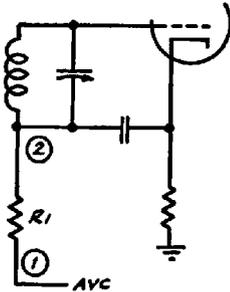


FIG. 2-32. The grid return circuit of a typical amplifier. When grid current flows, point 2 becomes negative with respect to point 1.

that the input signal be large enough so that the plate-current variation under the operating conditions is not linear—that is, is not proportional to the grid voltage variation. In cases of this type, the output signal will be distorted as a result of the excessively large swing. However, the input signal will in all instances be free from distortion since the signal is not sufficiently large to cause the flow of grid current.

Further consideration of the subject of amplifier overloading brings to the fore the fact that not only is the signal distorted, but in addition the output which can be obtained from a given stage is limited. In other words, increasing the signal input to an amplifier stage to the point beyond that at which overloading takes place does not produce a proportionately stronger signal than the amount of output obtained just before overloading begins. That is, each and every amplifier operated at certain voltages is subject to definite signal-carrying capabilities. Con-

sequently an amplifier stage can handle just so much signal and no more. Putting more in will not produce a greater signal in the output.

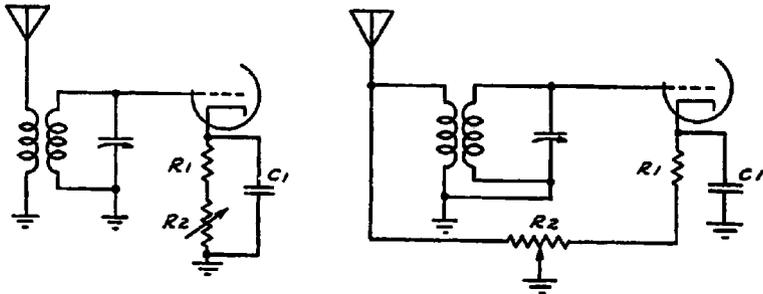
The type of distortion produced by overloading is often described by the term *amplitude distortion*, because the amplitude of the output signal is not proportional to, or does not follow, the amplitude of the input signal.

With reference to the application of signal tracing to determine the point where the distortion originates, it stands to reason that it is between the point where the signal is normal and the point where it first appears distorted. To establish this point the serviceman's knowledge of circuit operation must be applied. As to the points where such distorted signal can be checked they are the various tube elements, such as the control grid, screen, plate, cathode, or the junctions of component parts connected to these points. Such test points have been identified in a general way in the preceding chapter and elaboration of technical details does not alter the test points. Although it is true that in the past it has not been possible to make measurements directly at such points as control grids and plates, modern-day signal tracing with proper equipment removes these limitations.

Rectification. Another cause of distortion in an amplifier is operation of the amplifier tube as a rectifier rather than as an amplifier. This comes about as the result of incorrect operating voltages, usually the control-grid bias, and is to be found in all types of amplifiers regardless of frequency range. Usually it appears when a strong signal is applied, and it is caused by an excessive value of grid bias; this biases the tube to such an extent that the negative half of the input signal voltage alternation is cut off, so that it does not appear in the plate circuit. Consequently the required linear relation between the input signal voltage and the output signal voltage is not maintained, and the output signal is distorted.

This problem of distortion due to cut-off was quite commonplace years ago before the development of special types of r-f and i-f amplifier tubes. The original run of r-f and i-f amplifier tubes were of the sharp cut-off variety, that is, the grid voltage-plate current curve was very steep. Increasing the bias decreased the plate current very rapidly. This in turn decreased the

amplification very rapidly. With the then commonplace methods of volume control in receivers—the use of negative bias—any attempt to attenuate a strong signal, such as that from a local station, resulted in the application of a high negative bias and in a change in the operating characteristic of the tube from an amplifier to a rectifier. The result was distortion. To correct this condition, the remote cut-off or variable- μ tube was developed, wherein the plate current and mutual conductance decreased gradually over a very high range of negative grid-bias values and operation as an amplifier was retained over the full range of bias values required to give volume control. Such tubes are used today in automatic-volume-control systems as well as in those simpler circuits wherein volume control is accomplished by the use of variable cathode bias resistors operated with or without associated antenna volume controls. An example of both types is given in Figs. 2-33 and 2-34.



Figs. 2-33 left, 2-34 right. Two methods for controlling the transfer of the signal. At the left, the gain of the stage is varied by varying the bias. At the right, the coil is shunted in addition to the bias control.

It is important to note that the effects of rectification and overloading are similar in many respects. Although, as we have seen, rectification produces distortion of the negative peaks while overloading produces distortion of the positive peaks, the overall effect is essentially the same: in both cases, the signal in the output circuit is distorted and the defective condition must be corrected. Both rectification and overloading are examples of amplitude distortion to which we have previously referred.

Frequency Distortion. Another kind of distortion which may be found in all types of amplifier systems is known as *frequency distortion*. This term designates unequal amplification of the various frequencies which make up a signal voltage. For example, in an r-f system a complex modulated signal is made up of a number of components, essentially the carrier frequency and the side-band frequencies. If, for example, the modulating voltage is that developed by music produced by an orchestra, which might mean a frequency range of from 30 cycles to 7500 cycles, proper operation would call for uniform amplification of these sidebands extending over a range of 7500 cycles on either side of the carrier. However frequency distortion would tend to cut the amplitude of the upper limits of the sidebands. Similarly, in the case of an audio amplifier, frequency distortion is the unequal amplification of the various audio frequencies being passed through the amplifier system.

Now, it so happens that the vacuum tube is capable of nearly equal amplification over a wide range of frequencies so that frequency distortion, if present in a system, is usually due to some condition associated with the coupling device rather than with the amplifier tube itself. For this reason frequency distortion will be discussed in the chapter devoted to coupling units. This is especially desirable since frequency distortion in r-f, i-f and in some a-f systems is very closely associated with the performance of tuned circuits. No doubt you recall comments heard at different times about the need for flat-top adjustments of i-f transformers, broad-band tuning, etc. All of these are for the purpose of minimizing or controlling the amount of frequency distortion.

One possible exception to the above is feedback. That is to say, feedback in an amplifier, and not necessarily associated with the coupling device, may be one reason why frequency distortion is present. This subject is discussed in detail in the paragraphs which follow.

Feedback in Amplifiers. Feedback plays an extremely important part in the operation of all types of amplifiers. In certain instances it is responsible for the introduction of distortion and then again in other cases it is responsible for the elimination of distortion. It all depends upon its undesired presence in one case and its deliberate introduction in the other. No doubt you are

familiar with its use as a means of increasing the sensitivity of a receiver, in which case it is called regeneration.

Feedback in a communication system can best be described as the returning of a portion of the signal present in the output circuit of an amplifier to the input circuit of the same amplifier. Although the amplifier may consist of a single tube or a complete system, since we are discussing single tubes, it might be best to first speak about feedback in a signal stage.

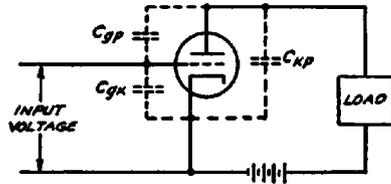
When such feedback exists and is of such character as to aid the input signal, it results in an amount of amplification from that stage which is in excess of that which would normally be calculated from the constants of the circuit; this action is called positive feedback or regeneration. On the other hand, if the feedback is of such character as to buck the input signal, then the amplification present in the system is less than that which would be determined by the constants of the circuit; this action is called negative feedback or degeneration.

Suppose that we start with feedback which is favorable to operation, that is, feedback which increases the signal. We recognize that maximum gain consistent with performance is always desirable in the average stage of amplification, but, if for some reason high gain causes instability, it is of little practical value and the amount of amplification must be reduced. As to the reason for lack of stability in an amplifier stage, it can readily be associated with certain definite conditions in the circuit. Just what these conditions are depends entirely upon the system, but in general it is due to stray coupling of one kind or another. In some cases this coupling may be through the grid-to-plate capacitance of the tubes used in the amplifier; in other instances it may be due to insufficient shielding of the input and output circuits.

The relative importance of these two contributing factors depends upon the type of tubes used and the type of amplifier. For example, both tube capacities and shielding are of importance in amplifiers operating above audio frequencies, whereas the tube capacities are not usually of very great importance in audio amplifiers. As a matter of fact it is important to mention that inter-electrode tube capacities were of much greater importance in the past than they are at present. This is due to improvements

in tube design and the development of the screen-grid tube, in which the grid-plate capacity, which was most troublesome in the triode, has been reduced to a point where it does not cause feedback between the grid and plate currents. However, since triodes are still in use in many receivers all over the world, it is desirable to consider them at this time.

FIG. 2-35. A triode showing the capacities between the three elements of the tube.



In order to comprehend the manner in which these tube capacities come into play, let us examine the typical triode in Fig. 2-35. Three capacities are shown: C_{gk} , that between the control grid and the cathode; C_{gp} , that between the control grid and the plate; and C_{kp} , that between the cathode and the plate. That such capacities exist within the tube is quite natural, since the various tube electrodes are metal surfaces located near each other. True, the surface areas are comparatively small, but small as they may be, they nevertheless form miniature condensers in which each electrode acts as one of the plates.

All of these capacities are important, but of the three the most important is C_{gp} , the capacity between the control grid and the plate. In fact we can dismiss the control grid-to-cathode capacity by saying that in tuned circuits it becomes a part of the tuning capacity which shunts the grid circuit coil and in audio systems it simply shunts the input circuit connected across the control grid-cathode circuit. This capacity has the effect of decreasing the amplification of the higher frequencies in audio and video amplifiers, but by no means is it as important as the control grid-plate capacity. The capacity between the cathode and plate likewise is of interest in connection with frequency distortion in audio and television amplifiers. However, let us investigate first the control grid-plate capacity.

This capacity provides a path whereby some of the signal present in the plate circuit can find its way back into the grid circuit, in other words feedback can occur from the output circuit

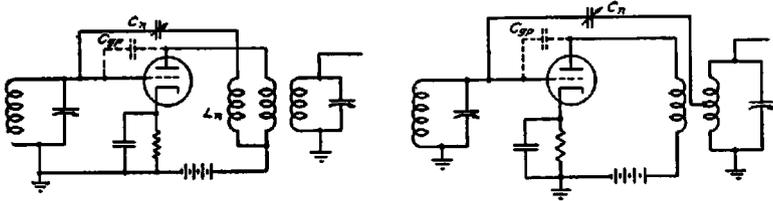
of the tube to the input circuit of the tube. This feedback voltage is again amplified through the regular action of the tube and a portion of the signal voltage in the plate circuit of the tube is again fed back into the input circuit. If this feedback action is permitted to exist and reaches a sufficient magnitude, sustained oscillations are developed and the stage is no longer useful as an amplifier.

Two methods were widely used before the introduction of the screen-grid tube to overcome the effects of the signal voltage fed back from the plate to the grid circuits through the grid-plate capacity. One of these was the use of grid-suppressor resistors placed close to the control grid of the tube. These resistors absorbed sufficient energy as a result of signal voltage drop across them so that the amplification was reduced and oscillation prevented. The second method, which was very widely used, was the method of neutralization which we shall now discuss. While these systems of neutralization are very old, there are still a large number of receivers which use neutralized triode stages of amplification in both r-f and i-f amplifier stages. It is therefore worth discussing these systems from the viewpoint of signal tracing.

The basic principle in the operation of a neutralized stage is the introduction of another signal voltage which cancels the voltage fed back through the grid-plate capacity. Two examples of such systems, both of which were used in numerous r-f amplifiers, are shown in Figs. 2-36 and 2-37. In Fig. 2-36, the signal voltage is secured from the plate circuit, through the winding L_n and this signal voltage is applied to the control grid through the neutralizing capacity C_n . This neutralizing voltage is equal in magnitude and out-of-phase with that fed back from the plate circuit to the grid circuit through the grid-plate tube capacity C_{gp} . In this way the feedback is cancelled and maximum amplification is obtained without oscillation. A later modification of the first neutralizing system is shown in Fig. 2-37. In this circuit, the voltage is secured from the secondary of the tuned transformer which feeds the tube following the neutralized stage. The basis of neutralization is the same as previously stated.

A basic method of checking and adjusting neutralized receivers by means of signal tracing depends upon an indirect measurement of the neutralizing voltage. The first step in the neutralizing pro-

cedure is to insert a dummy tube in the stage being neutralized; a dummy tube is one which is of the same type as the tube used in the stage, but which has an open filament or heater. With this dummy tube in the socket, a signal should be fed to the antenna post of the receiver and the signal voltage measured at the control grid of the dummy tube. This value should be noted. Next the dummy tube should be removed and the regular tube inserted.



FIGS. 2-36 (left), 2-37 (right). These figures show neutralized r-f amplifier stages and illustrate two different methods of obtaining the neutralizing voltage.

Again the signal voltage at the grid should be measured without making any changes in the tuning or in the setting of the signal generator. If the stage is perfectly neutralized, then the signal at the grid will have the same value as it had with the dummy tube in the socket. If the signal voltage at the grid is greater than that measured with the dummy tube in place, then this means that not enough signal is being fed back through the neutralizing winding to cancel the voltage reaching the grid through the grid-plate capacity. Similarly, if the signal at the grid is less than that with the dummy tube, then too much neutralizing voltage is being fed back. In both cases, the neutralizing condenser should be adjusted so that the signal voltage at the grid remains unchanged when the dummy tube is replaced by the regular tube; when this condition exists the neutralizing voltage exactly cancels the feedback voltage through the grid-plate capacity and the stage is therefore neutralized.

As stated earlier, neutralizing systems are still in use in old receivers but have not found much application in modern receivers because of the development of the tetrode and pentode tubes. The very low control grid-to-plate tube capacity of screen-grid tubes

has eliminated the need for such balancing systems because the amount of signal voltage fed back from plate to grid within the tube is so low as not to cause such regenerative troubles. However, improper shielding or isolation of the various components which carry such high-frequency currents is still important and cannot be neglected. This is true with all types of tubes and includes not only possible electromagnetic coupling between components and connecting leads, but also electrostatic coupling between such items as sections of tuning condensers.

We may point out here that isolation of the various signal currents in the tube so that they are confined to their respective circuits is extremely important, as will be shown later in this chapter. The development of signal voltage across points which are common to more than one circuit will create a regenerative condition, with results which are similar to feedback between the plate and grid circuits, although the exact contributing causes are not the same as those outlined.

Regeneration of such extent as to cause sustained oscillations in a tuned stage of any kind impairs the operation of that stage as an amplifier of the original signal. When such a condition exists, amplification is still being obtained, for without it there would be no state of oscillation, but proper signal transfer between stages is not being accomplished. Of course, it is not essential that a signal be fed into the amplifier in order that it develop sustained oscillations. If sufficient feedback takes place between the output and input circuits, sustained oscillations will be developed in the stage.

The presence of oscillations can be checked by means of signal tracing by considering the oscillating tube as a generator of a signal without any external signal input to the stage. The problem of locating an oscillating stage in a multi-stage amplifying system is somewhat more difficult, and is described later in this volume.

Regeneration can be due to conditions other than feedback through the tube capacities or induction between components and their connections. It can be created as the result of an impedance which is common to more than one circuit. To present this subject properly it is first necessary to speak about multi-stage voltage amplifiers.

Multi-Stage Voltage Amplifiers

What is meant by a multi-stage voltage amplifier? As the name implies, it is an arrangement whereby the amplified signal from one stage is fed to the next stage and so on until the signal level is sufficient to meet the requirements for rectification or for conversion from voltage to power as in the case of the audio system. Thus any type of amplifier which contains more than one stage, whether r-f, i-f or a-f, is a multi-stage amplifier.

Typical examples of such multi-stage amplifiers are to be found in commercial receivers of all types. In all such systems the total amplification available with the system is equal to the product of the respective amplification values of each stage. Thus if a two stage r-f amplifier is being considered, and the first stage provides an amplification of 10 and the second stage provides an amplification of 15, then the overall amplification in the system is 10×15 or 150. These figures are purely illustrative and not to be accepted as an indication of the gain of any one particular radio-frequency amplifier. If, for example, a two stage i-f amplifier has individual stage gains of 50 and 70, the total gain is 50×70 , or 3500.

As far as operation of a multi-stage amplifier is concerned, it is no different from that of the individual stages. All that has been said about the individual stages separately is true of the individual stages of a complete amplifier system. The relation between the tube and the load impedances, the factors determining distortion, the function of the respective components, the distribution of the signal in the separate stages—all these are similar to conditions in a single amplifier stage.

There are of course a number of differences between the performance of a single stage and a multi-stage amplifier. One of these is regeneration, which will be discussed later. It is extremely difficult to minimize regeneration in a complete system to a value as low as that which prevails in a single stage used by itself. Invariably some signal feedback is present in a complete system and this tends either to increase or decrease the overall amplification, so that the total amplification is more or less than the product of the individual stage gains. It all depends upon the direction of the feedback, that is, whether it aids or bucks, whether it is regenerative or degenerative.

To point out the similarity between single stage and multi-stage amplifiers, we show in Fig. 2-38 a typical two stage tuned r-f amplifier. Note that the individual stages are identical to those which we have previously considered and that a common power supply is used for each of the separate stages. The input voltage to the amplifier is e_1 at the control grid of the first tube, and the final output signal voltage is e_2 which is present across the tuned winding which feeds the diode rectifier.

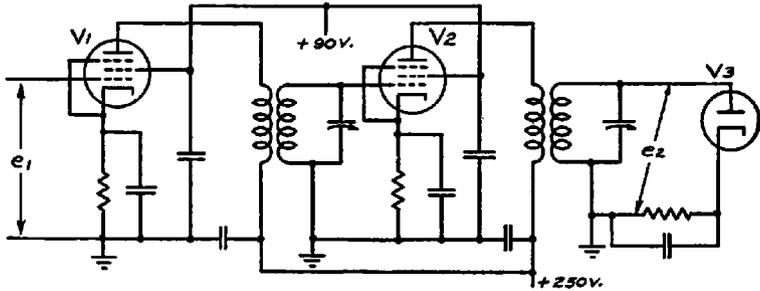


FIG. 2-38. A typical two stage tuned r-f amplifier. The overall amplification of the signal is obtained by multiplying the gain of the two stages.

The overall gain in this system is that which is obtained between the control grid of the first tube and the diode plate of tube $V3$. The gain of the first stage is that between the control grid of tube $V1$ and the control grid of tube $V2$. Similarly the gain in the second stage is that between the control grid of tube $V2$ and the diode plate of tube $V3$. In the event that some other tube were used in place of the diode, the gain of the last stage would be measured by taking the signal level across the output winding.

You should of course realize that there is nothing rigid in these statements concerning the manner in which the amplification or gain of the system is calculated. In general, the gain can be measured between any two points and the measurements continued in this way until the output of the amplifier is reached. Thus in the circuit of Fig. 2-38 the gain can first be measured between the grid and the plate of the tube $V1$, and then this

measurement can be followed by a measurement of the gain between the primary and secondary windings of the transformer. As you can readily see, the first measurement gives a measure of the performance of the tube, while the second measurement describes the functioning of the transformer.

Previously we pointed out that one essential difference between multi-stage amplifiers and single-stage amplifiers is the possibility of interaction between the several stages with a resultant increase or decrease in the overall gain. As we shall see in the following chapters, a number of different methods are used to minimize this interaction. Since amplifiers almost invariably use the same common power supply, interaction through the power supply is a common cause of feedback. To eliminate this feedback through the power supply, it is general practice to decouple or isolate the power supply leads which feed the d-c voltages to the electrodes of each of the individual stages. Generally, these decoupling units take the form of by-pass condensers and filter resistors which prevent a signal voltage from being built up across the power supply.

It is unnecessary at this point to discuss at length the manner in which signal tracing is carried out in multi-stage amplifiers. This is covered in detail in the other sections of this book which deal with the various types of receiver circuits.

Signal Tracing in Power Amplifiers

With certain modifications, which will be covered in this section, signal tracing in power-amplifier circuits follows along the same lines as in voltage amplifiers. In general the circuit impedances are lower and the signal levels higher. Both of these effects tend to simplify signal tracing because there is less possibility of reacting on the circuit and because the higher signal levels simplify picking up the signal.

A typical power amplifier stage is shown in Fig. 2-39. Insofar as the circuit connections are concerned, the stage is similar to a voltage amplifier stage. However, the operating conditions and circuit constants of power amplifiers differ from those of voltage amplifiers because the function of the voltage amplifier is to deliver the maximum *voltage* across the load, while the function of the power amplifier is to deliver the maximum *power* to the

load. Unlike the conditions met in voltage amplifiers, a large value of load resistance does not provide the maximum amount of power and is therefore undesirable for use with power amplifiers. Actually it turns out that the maximum amount of power is delivered to the load when the resistance of the load is equal to the plate resistance of the tube. This is but another application of the broad principle that a generator of any type will deliver the maximum amount of power when the load impedance is "matched" to the internal impedance of the generator. How-

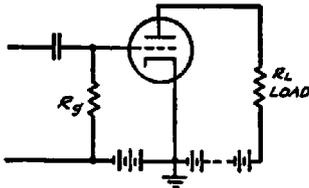


FIG. 2-39. A basic power amplifier circuit. The power is developed across the load R_L .

ever, as we shall see later in this chapter, this principle of matching the load and plate impedances is often modified so as to decrease the distortion.

In a typical triode output stage using a type 45 tube, the load resistance recommended is equal to 4600 ohms, although the plate resistance of the tube under the operating conditions is equal to only 1700 ohms. This illustrates the point that in practice the load resistance is often made somewhat greater than the plate resistance of the tube in order to minimize distortion. Of course, the use of this higher load resistance does lower the efficiency of the amplifier somewhat, but because of the straightening effect which it has on the tube characteristic, it makes possible a higher power output with less distortion.

The average gain from the grid to the plate of power amplifiers is of interest because it provides an index as to the operation of the stage. For a single stage using a type 45 tube, the average gain from grid to plate is about 2.7. In other words, with a 10-volt signal at the grid of the tube, the signal at the plate should be equal to about 27 volts. This amplification may seem quite small, but it should be kept in mind that the tube is functioning as a *power* amplifier and not as a *voltage* amplifier.

In the operation of pentodes as power amplifiers, the difference in choice of load resistance is again evident. In a typical pentode

output stage using a type 6F6 or 2A5, the recommended value of load resistance is 7000 ohms whereas the plate resistance of the tube is about 80,000 ohms. As in the case of triodes, the load resistance is not made equal to the plate resistance because of distortion considerations. It is found that the distortion can be decreased by using a value of load resistance which is about one-tenth that of the plate resistance. Although this low value of load resistance reduces the voltage amplification, the power output is maintained at a high value. For a typical pentode output stage using a 6F6, the amplification from the grid to plate is about 16. In other words, a 5-volt signal at the grid will produce an 80-volt signal at the plate of the tube. Note that the voltage amplification for pentodes is appreciably higher than that for triodes.

Coupling to Speaker

In practice the impedance of the average speaker voice coil differs widely from the values of load resistance recommended for power output tubes. Thus the average speaker voice coil resistance is several ohms, whereas in order to transfer power efficiently from a power amplifier stage, a load resistance measured in thousands of ohms is required. Some method is required

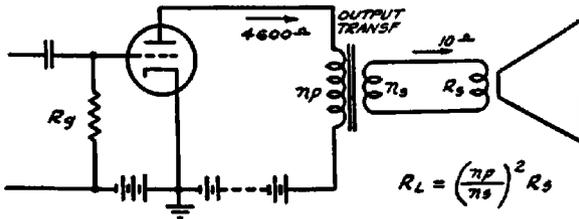


FIG. 2-40. Because the load impedance of the average power tube is much higher than the impedance of speaker voice coils, an output transformer is required to match the two impedances.

to match the impedance of the voice coil, and the method which is universally used employs a speaker matching transformer. Essentially this output transformer, as it is generally called, changes the impedance of the voice coil so as to make it appear to the plate of the tube as a much higher impedance than the

actual value of the voice coil impedance. A typical output circuit is shown in Fig. 2-40.

The turn ratio of the transformer is the important factor which determines the manner in which the voice coil impedance is changed. If, for example, the ratio of the primary to the secondary turns is equal to 30, then a 10-ohm voice coil would appear to the plate of the output tube as a resistance of $10 \times (30)^2$ or 9000 ohms. In general, the load which the output tube sees as it looks into the primary winding of the output transformer is equal to the actual resistance of the voice coil multiplied by the square of the turn ratio. Mathematically, the load resistance which the

transformer presents is thus equal to $R_s \times \left(\frac{n_p}{n_s}\right)^2$ Other factors

besides the turn ratio affect the operation of the transformer as an impedance changing device, but these are primarily design considerations and therefore will not be considered here.

Signal Levels

We are now in a position to examine the various signal levels which normally exist in a power amplifier stage. In the case of triode output tubes, the gain which can be expected is about 2/3 that of the amplification factor of the tube. This is so because the load resistance generally used is approximately twice the plate resistance of the tube. For the type 45 tube, the amplification factor is 3.5 and the gain from grid to plate is about 2.7; for the type 2A3, the amplification factor is 4.2 and the gain from grid to plate is about 3.2, similarly; for the type 6F6G used as a triode with the screen grid and plate tied together, the amplification factor is 6.8 and the gain from grid to plate is about 4.1. Although the rule for triodes that the gain from grid to plate is about 2/3 the amplification factor is not always accurately true, it holds approximately and is always close enough so that it provides information on how much step-up in signal can be expected from grid to plate.

In the case of tetrode and pentode tubes, as has previously been mentioned, the voltage gain from grid to plate is higher than for triodes. The actual values vary from about 10 to 20 depending upon the tube type, and a good average value when in doubt

is that the gain should be about 15. For a type 6F6 pentode, the gain is 17; for a type 6K6G pentode, the gain is 15; for a type 6L6 beam power tetrode, the gain is about 13. In all of these cases, the actual gain from grid to plate is considerably less than the amplification factors which are of the order of 200.

For a stage using a type 6F6 pentode, working into a 10-ohm voice coil, the step-down from plate to voice coil is about 26. Thus with a 10-volt signal at the grid of a 6F6, the signal at the plate is about 160 volts, and the signal at the voice coil is about 6 volts. It is interesting to note that because of the higher load resistance required for pentode type tubes, the step-down between the plate and voice coil is greater for pentodes than it is for triodes. The greater power sensitivity of the pentode type is apparent since it produces about 5 times the voltage, or 25 times the power, across the same voice-coil resistance for the same value of input signal.

The voltage step-down from the plate of the output tube to the voice coil depends upon (1) the rated load resistance of the output tube and (2) the voice-coil resistance. We shall first give some typical values and then show how the expected step-down can always be computed from a knowledge of the load resistance of the output tube and the voice-coil resistance. For a type 45 triode with a 4600-ohm load, the step-down from plate to a 10-ohm voice coil is about 21. Thus with a 10-volt signal at the grid of a type 45 output tube, the signal at the plate should be about 27 volts and the signal at the voice coil should be about 1.3 volts.

In the general case, the step-down which is normal between the plate and the voice coil can be computed from the value of the load resistance and the voice-coil resistance. If the load resistance is equal to R_L and the voice-coil resistance is equal to R_s , then the voltage step-down from plate to voice coil is equal to the square root of the ratio between the load resistance and the voice coil resistance. In symbols, the voltage step down = $\sqrt{R_L/R_s}$. The step-down ratio expressed by this formula is of course also equal to the turn ratio of the output transformer. It will be noted that the greater the load resistance and the smaller the voice-coil resistance, the greater will be the step-down in the signal voltage between the plate and the voice coil.

Push-Pull Operation

To obtain greater power output than is possible with a single tube, two similar tubes are very often used in push-pull. This type of output circuit is shown in Fig. 2-41 for the case where a self-bias resistor is used to supply the necessary grid bias. In operation, a signal is applied to the grid of $V1$ and at the same time an equal signal is applied to the grid of $V2$. Although equal signals are applied to both grids in order to obtain push-pull action, the signals applied to $G1$ and $G2$ must be opposite in phase. Thus, at the instant when the grid of $V1$ is least negative on the

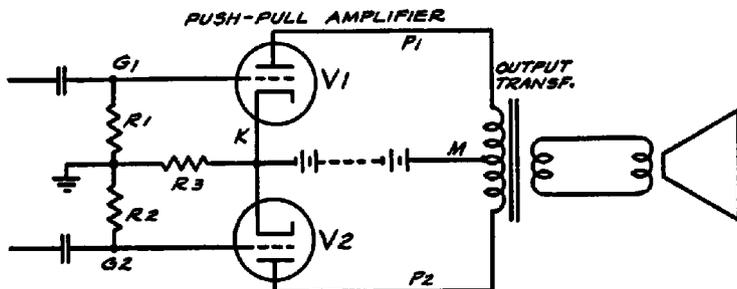


FIG. 2-41. A basic push-pull amplifier circuit. Because of the balanced circuit, no signal voltages are present at either K or M.

positive peak of the cycle, the grid of $V2$ will be more negative by a like amount on the negative peak of the cycle. As a result, the current through the primary winding of the power transformer receives two contributions which add to each other: one of these is the increase in the plate current of $V1$ due to the positive grid voltage, and the other is the decrease in plate current of $V2$ due to the negative grid voltage.

On the second half of the cycle, $G1$ becomes more negative and $G2$ less positive by an equal amount. For this half cycle, the plate current of $V1$ decreases, and the plate current of $V2$ increases by approximately the same amount. Again these two changes in plate current are combined in the primary winding and produce a resultant change in flux which is equal approximately to twice that produced by either one of the two tubes.

The advantage of the push-pull circuit results from the fact that each half cycle of the voltage induced in the secondary winding of the transformer receives a contribution from both tubes—a contribution from the negative part of the characteristic of one tube and a contribution from the positive part of the characteristic of the other tube. In other words, each half cycle is made up of a “push” from one tube and a “pull” from the other tube. An important consequence of this is that if, for example, the positive and negative halves of the input signal are similar, then the positive and negative halves of the output signal must also be similar. In other words, whatever distortion may be introduced by a push-pull amplifier stage will affect both halves of the cycle to the same extent. Although the output waveform may not necessarily be exactly the same as the input waveform, it will always be true in a push-pull amplifier that the output waveform will have identical positive and negative half cycles. This is merely another way of saying that the output wave of a push-pull amplifier possesses mirror symmetry and therefore a push-pull amplifier cannot introduce even harmonic distortion into the output of the amplifier.

The elimination of even harmonic distortion makes it possible for a push-pull amplifier to deliver more than twice the output which it is possible to obtain from a single tube of the same type. Where a single tube is used, the curvature of the grid voltage-plate current characteristic introduces even harmonic distortion which limits the useful output of the stage. In the push-pull circuit, however, the signal is divided between the two tubes and even harmonic distortion which arises from the curvature of the characteristic cancels out. Thus it is possible to use a greater grid swing and to obtain a correspondingly greater power output without excessive distortion.

The signal distribution at the various points in a push-pull amplifier is of interest. At the grids, we have seen that the signal voltages are equal but opposite in phase. At the two plates, the amplified signals appear, and again they are equal in value and 180 degrees out of phase just as at the grids. The output transformer, as we have seen, combines the contributions from the two tubes and produces the final signal voltage across the voice coil of the speaker.

It is important to note that during operation of a push-pull stage there is no signal voltage at the cathode return point *K* or at the plate return point *M*, in Fig. 2-41. This can be seen from the fact that the total plate current drawn from the power supply is constant throughout every point in the cycle. Thus when the plate current of the one tube increases from its no-signal value, the plate current of the other tube decreases by the same amount; as a result the total current drain of the two tubes remains the same and is always equal to the sum of the no-signal plate currents of the two tubes.

An important consequence of the fact that the combined plate currents of two tubes in push-pull remain constant is the fact that no filtering is required at the cathode or at the center-tap of the output transformer. In some receivers a by-pass condenser is used across the cathode resistor but the primary function of this condenser is to remove any signal voltages which may be developed because of differences in the characteristics of the two tubes. The filtering in the B-supply voltage for a push-pull output stage does not have to be as perfect as for a single-ended output stage. This can be seen from the fact that any hum voltage which may be present at point *M* will cause hum currents to flow through the primary winding of the output transformer, but these hum currents will cancel each other so that no hum voltage will be induced in the secondary winding. This makes it possible to feed push-pull output tubes directly from the input to the filter and in some receivers it will be found that as much as 30 volts of 120-cycle hum voltage may exist at point *M* without introducing any noticeable hum into the output.

In circuits where the center-tap of the output transformer is connected directly to the filter input, care must be exercised in measuring the signal voltages at *P1* and *P2* because of the high value of hum voltage which is present at these points. If a small value of signal input is used for testing, this large hum voltage may obscure the signal voltage measurements, and in any event will cause an error in the measurement of the signal voltage. In cases of this kind, errors due to the presence of the hum voltage can be eliminated from the signal-voltage measurement by measuring the signal voltage present across *P1-M* and across *P2-M*. This means that the low side of the instrument being used for the

measurement must be connected to *M*. Care should be taken to avoid coming in contact with the instrument ground while this measurement is made since the instrument ground is some 250 volts above ground. When the measurement is completed, the instrument ground should be returned to its normal position.

In push-pull circuits, the step-up in the signal from the grid to the plate is approximately the same as for a single-ended amplifier. However, because the voice coil receives contributions from two tubes, the power delivered to the voice coil is approximately twice as great as for a single-ended amplifier. As a result, the signal voltage produced across the voice coil is equal to approximately 1.4 times the value which holds for a single-ended amplifier. There is thus a smaller step-down of voltage between the plate of either one of the push-pull output tubes than is the case for a single-ended amplifier.

Classes of Amplifiers

In discussing power amplifiers, it is customary to divide them into different classes depending upon the fraction of the signal cycle during which plate current flows under rated conditions. In the Class A amplifier, which has been taken up under voltage amplifiers, it was shown that the grid bias and other operating conditions are so adjusted that plate current flows throughout the complete cycle. When producing its full rated output, the peak value of the signal is always less than the grid bias so that a stage operating Class A never draws grid current. Other characteristics of a Class A stage are the low percentage of distortion, and the high power amplification resulting from the fact that practically no power is required in the input circuit.

When greater power is required from two tubes than can be obtained from Class A operation, the tubes are used in push-pull in Class AB. A distinguishing feature of Class AB operation is that a higher value of grid bias is used, so that the plate current is reduced to a value lower than for Class A operation. The use of a higher value of bias makes it possible to raise the supply voltages without exceeding the allowable dissipation of the tube, and these higher supply voltages in turn make possible higher output.

For small values of input signal, a Class AB amplifier operates

as a Class A amplifier since plate current flows throughout the cycle and since operation is essentially over the linear portion of the tube characteristic. For higher values of input signal and power output, the operation is no longer Class A since plate current cut-off is reached on the negative half of the cycle. Depending upon whether or not the tubes draw grid current on the positive halves of the cycle, the operation of the stage is said to be Class AB₁ or Class AB₂. The subscript 1 indicates that no grid current is drawn, while the subscript 2 indicates that grid current is drawn during the positive peaks of the cycle.

Class B Amplifier

When the maximum power output is desired from tubes of a given size, Class B operation is generally used. In a Class B stage, two tubes are used in push-pull and the bias and operating conditions are such that plate current flows in each tube only on one half of the cycle. In other words, with no signal input, the bias is adjusted so that the plate current is approximately zero. Clearly, Class B operation is an extension of Class AB in that the bias is made more negative so that the plate current is essentially zero when no signal is applied. Actually, special tubes have been developed for Class B operation. These tubes have a high amplification factor as a result of which the plate current corresponding to zero bias is very small. This makes it possible to operate these tubes with the cathodes grounded and with the grids returned directly to ground.

The method of operation of a Class B amplifier resembles that of a Class A amplifier with this important exception: the contribution which the voice coil signal receives from each half cycle of the input signal is made up only of a push from that tube which has a positive signal voltage on its grid. The other tube, unlike in Class A and Class AB operation, has a negative part of the signal on its grid and is therefore driven beyond cut-off. Because the output signal receives only a "push" from one tube and no simultaneous "pull" from the other tube, the Class B amplifier is sometimes called a "Push-Push" amplifier. However, the circuit connections are of course identical with those of a push-pull Class A amplifier.

Because the current drain on the power supply varies with the input signal, power supplies which are designed for Class AB and Class B amplifiers have better regulation than those for Class A amplifiers. The variation in output voltage of the power supply is usually kept to a low value by using power transformers and chokes having low d-c resistance, and by using rectifier tubes which have a low internal voltage drop. In some receivers mercury vapor rectifier tubes have been used because of their low and constant internal voltage drop. A choke-input filter is often used to improve the regulation. Although a choke-input filter produces a lower output voltage for a given input from the rectifier, it is often used because of the improved regulation which it makes possible.

Unlike the Class A amplifier, the grids of amplifier tubes used in a Class B circuit are driven positive so that current flows in the grid circuit. This in turn means that a certain amount of power is consumed in the grid circuit and this power must be supplied by the preceding stage. To supply this grid-circuit power, the preceding tube is arranged as a power amplifier and is transformer-coupled to match the grid-circuit impedance of the Class B output tubes. This tube is generally called the *driver* tube, because of the fact that it "drives" the Class B tubes by supplying the necessary grid voltage and grid current.

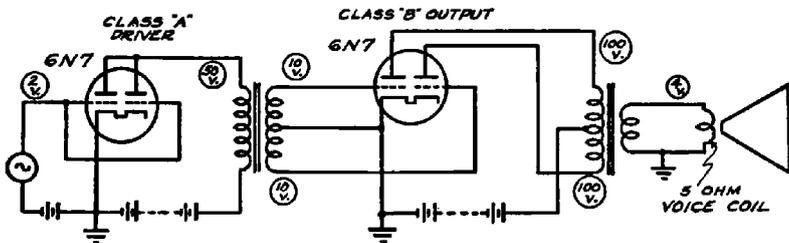


FIG. 2-42. A typical Class B amplifier. The numbers within the small circles represent the signal voltages at the various points in the driver and output stages.

The transformer used to couple the driver stage to the Class B output tubes is generally a step-down transformer in order to match the comparatively high plate resistance of the driver,

which is operated Class A, to the comparatively low input resistance of the Class B tubes. The voltage ratio of this transformer—the ratio between the signal voltage across the primary to that across half the secondary—may vary from about 2:1 to about 5:1. There are numerous other considerations which enter into the design of the driver transformer, but these are design considerations and are beyond the scope of this book.

The signal voltage levels which can be expected in Class B amplifiers are shown with the aid of Fig. 2-42 which represents a typical Class B amplifier design using type 6N7 tubes. The driver stage employs the two sections of the 6N7 in parallel as a Class A amplifier and provides a voltage gain of 25. Assuming a 2-volt input signal to the grid of the driver, this brings the signal level at the driver plate up to 50 volts. The step-down transformer which couples the driver to the Class B output stage has a step-down ratio of primary to one-half secondary equal to 5:1. As a result, the signal voltage of the Class B grids is equal to one-fifth the signal at the plate, or 10 volts. The voltage amplification from grid to plate is about ten and this brings the signal level at each of the plates up to 100 volts. Assuming that the voice coil resistance is 5 ohms, the signal voltage developed across the voice coil is equal to about 4 volts. The latter can be computed by referring to the recommended plate-to-plate resistance of the Class B stage shown in the tube handbooks, and using the formula previously given.

Chapter III

DETECTION

JUST as the amplifier stages of a receiver are invariably followed by a detector, so our discussion of amplification is followed by a consideration of detection. Detectors play an important part in radio receiving systems because they are required in order to reproduce the message which is transmitted by means of the radio-frequency carrier. Thus, it is the function of the detector to interpret the variations in the carrier amplitude in terms of the original message, whether it be code, music, speech, or a video signal. If the detector does its job perfectly, then its output is exactly similar to the original wave which was used to modulate the carrier. It is appropriate to mention here that this function of detection is also sometimes referred to as demodulation or rectification, and that the detector stage in a receiver is often called the demodulator stage.

The Diode Detector

One of the simplest and most effective types of detectors is the widely used diode. Since we have already considered the operation of the triode and other multi-element tubes in some detail, understanding the operation of the diode, which contains only a cathode and plate, is rather easy. Fig. 3-1(a) shows a simple diode circuit connected so as to bring out the essential properties of this two-element tube. As the characteristic in (b) of this figure shows, the electrons given off by the cathode are attracted to the plate when a positive voltage is applied. However, when a negative voltage is applied, the electrons are repelled and no current flows through the tube. Thus the diode has the fundamental property that it will conduct current in one direction only,

and this only when the plate is positive with respect to the cathode. It is for this reason, of course, that the diode is called a rectifier tube.

Although we generally look upon the diode as a linear rectifier in which the current is proportional to the applied voltage, actually the diode current is not strictly proportional to the voltage as Fig. 3-1 shows. However, the characteristic can be

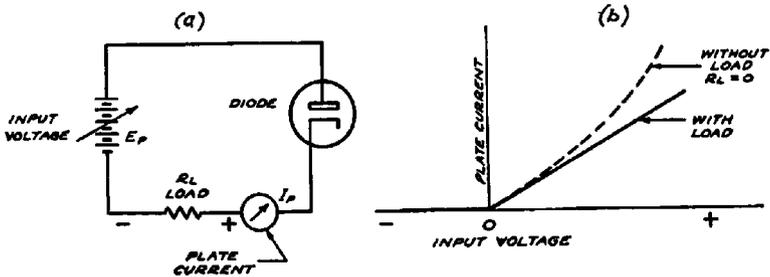


FIG. 3-1. A basic diode circuit is shown at (a). The use of a large value of load resistance has a straightening effect on the plate current variation as shown at (b).

straightened out by using a large value of load resistance. As shown by the full line characteristic in Fig. 3-1(b), the plate current variation becomes more and more closely proportional to the input voltage as the value of load resistance is increased. In all practical circuits which are used with the diode, especially in diode detectors, the load resistance is sufficiently high so that the plate current variation follows the input voltage exactly. In this way the possible introduction of distortion as the result of non-linearity is avoided.

The input voltage, to which we have been referring and which is designated in the figure, should be carefully distinguished from the actual voltage which is applied between the diode plate and its cathode. Thus the input voltage is actually the voltage which is applied to the diode in series with the load resistance. When a load resistance is used, as is almost invariably the case in practical circuits, part of the input voltage appears across the load resistance and part appears across the diode. As the figure shows, the polarity of the voltage developed across the load re-

sistor is such that the plate side of the resistor becomes *negative* as a result of the applied voltage.

Let us examine how the diode is used as a detector by considering the action which takes place when a modulated signal is applied to a typical diode circuit. Basically the circuit shown in Fig. 3-2(a) is similar to that used in the second detector of

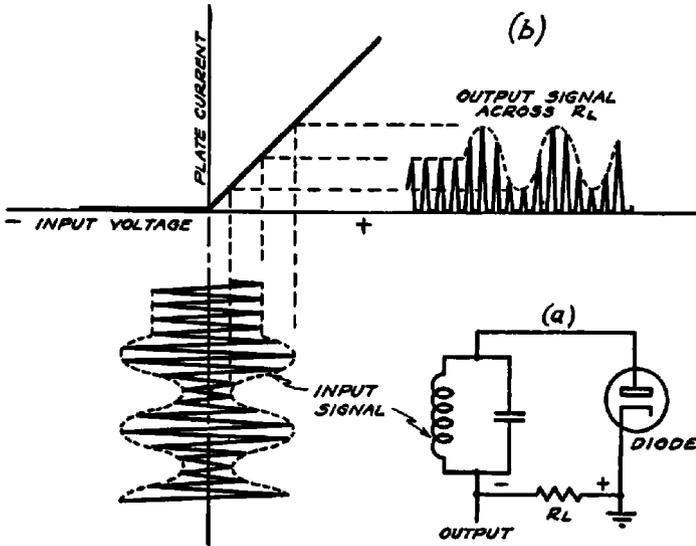


FIG. 3-2. A basic diode circuit is shown at (a). When a modulated signal is applied to the diode input, rectification of the signal takes place as shown at (b).

receivers, but in order to simplify the discussion we have omitted a number of relatively unimportant features. Referring now to this figure, we see that the signal voltage, which for example might be that across the secondary winding of an i-f transformer, is connected in series with the diode plate and with the diode load R_L . Of course, this signal voltage need not be an i-f voltage, it might just as well be at any other frequency, and in fact an action similar to that explained below would be obtained if the input voltage were at 60 cycles and the diode were a power rectifier such as the type 1-V tube.

To illustrate the action which takes place when a signal voltage is applied to the diode, we use the same type of representation which was employed in the preceding chapter in connection with amplifier tubes. Thus in Fig. 3-2(b) we show the diode characteristic which is essentially a straight line because of the high value of load resistance. The input signal, which is a typical modulated wave, is shown below the plate current axis, and the corresponding variations in plate current caused by the application of the signal are clearly shown at the right. The manner in which the rectifying property of the diode is brought into play is clearly apparent. On the negative part of the signal cycle, the electrons are repelled from the plate and no current flows through the circuit. On the other hand, each positive part of the cycle causes a corresponding pulse of current to flow through the circuit and through R_L . Thus the negative halves of the signal are removed and only the positive halves of the signal voltage are effective in causing current to flow through R_L .

As we pointed out above, the purpose of a detector is to produce an audio signal which follows the envelope of the modulated carrier. From the figure which we have been discussing, it is easy to see that the action explained above produces an output the average value of which varies in accordance with the modulated wave. However, along with this a-f signal accompanying the detection of the wave, we also have the r-f variations in the plate current. These variations are present across R_L because no effort has been made in this simple detector circuit to eliminate them. We shall see later that a number of different methods are used in receivers to remove the r-f or i-f pulsations of current from the diode load and to leave only the audio current. The example we have just shown is helpful in that it illustrates clearly the manner in which a modulated signal is rectified.

Speaking of signals, there are a number of interesting things about the voltage developed across the diode load and shown in Fig. 3-2. In the first place, as a result of the fact that the diode passes current only on the positive peaks of the signal, the voltage developed across R_L contains a d-c component, in other words, there is a d-c voltage developed across R_L . The polarity of this d-c voltage developed across the diode load is an important consideration because this voltage is often used as a con-

trol voltage in a-c circuits. As in the previous illustration Fig. 3-1 where a steady voltage is applied to the diode, the plate side of the load resistor becomes negative with respect to the cathode side. Incidentally, this will always take place in every diode circuit no matter whether a d-c or an a-c voltage is applied to the diode. As a consequence of the fact that the diode will pass current in only one direction, that side of the load resistor which is closest to the plate will become negative and that side of the resistor closest to the cathode will become positive.

In addition to the d-c component of voltage produced across the diode load as a result of rectification, there are additional frequencies present across the load as we can easily see from an examination of Fig. 3-2. In the first place, the positive half cycles of the carrier which are rectified and appear across the diode load represent a strong signal at the intermediate or carrier frequency. Since this signal is distorted as a result of the elimination of the negative peaks, it contains many harmonics. In the case of the second detector in a superheterodyne, these frequencies, which we have just said existed across the diode load, would be the intermediate frequency and harmonics of the intermediate frequency.

Leaving these signals for the moment, we hasten to point out that in addition to (1) the d-c component, and (2) the carrier frequency and harmonics of the carrier frequency, there is also present across the diode load (3) the audio wave or more generally the low-frequency signal which corresponds to the modulation of the envelope. In practically all circuits where the diode is used as a rectifier and especially in the detector circuits used in receivers, the presence of the carrier signal and the harmonics of the carrier across the diode are undesirable. Thus in the second detector of a superheterodyne receiver, the presence of this strong i-f signal across the diode load would result in the i-f signal being fed into the a-f amplifier with resultant distortion, overloading, and the causing of numerous whistles.

To eliminate the carrier frequency and its harmonics from the output of diode detectors, it is common practice in receiver design to by-pass the diode load with a condenser. As we show in Fig. 3-3, this condenser *C* offers a low-reactance path to the intermediate frequency, so that practically no r-f or i-f voltage is

developed across the load. With this shunt condenser across the diode load, the application of a signal voltage results in the production of a direct current through the load R_L . Unlike the previous case where no condenser was used, the current in the diode circuit does not return to zero during each cycle, but instead the condenser C charges up to a value which is slightly less than the peak value of the carrier signal. As the figure shows, when the carrier is unmodulated so that its amplitude does not vary, the plate end of the load resistor is maintained at a constant nega-

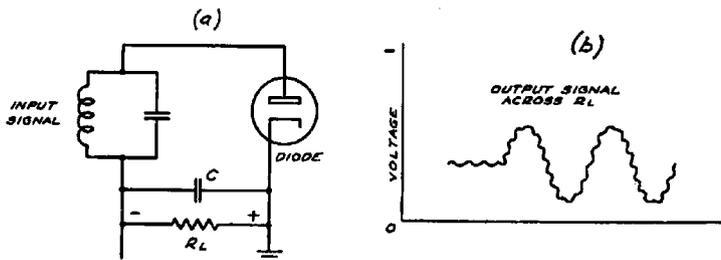


FIG. 3-3. A typical detector circuit using a condenser across the load is shown at (a). The rectified output at (b) shows that this condenser removes practically all of the carrier signal.

tive voltage with respect to ground. When the carrier amplitude varies, as it does when the signal is modulated, the pulsating output follows the modulation in the manner indicated in Fig. 3-3(b). In this way an audio output is produced which has the same waveform as the envelope of the modulated signal.

No doubt you have noticed the ripple in the voltage present across R_L in Fig. 3-3(b). This indicates the fact that the condenser C does not remove all of the i-f signal from the diode load but that a small amount of the carrier is still left across the load. This slight ripple is due to the fact that the diode plate draws a charging current into the condenser only for a very small interval at the positive peak of the cycle. During the remaining parts of the cycle, the steady negative voltage across R_L makes the diode plate negative with respect to the cathode and thus prevents the diode plate from drawing current. Later in this chapter, in examining the application of signal tracing to diode circuits used

in receivers, we shall examine several widely used filter circuits to further reduce the extent of the carrier ripple across the diode load. We might point out, however, that even without additional filtering, the amount of carrier signal which is left across the diode load is not usually sufficient to interfere with the operation of the receiver. This is especially true because the i-f signal will not be amplified by the a-f amplifier since the latter does not amplify at frequencies well above the audio range.

It may have occurred to you that a large condenser might be used across the diode load in order to remove the i-f signal completely from the diode load. Actually, however, the value which is used for this condenser is a sort of compromise value which is arrived at by taking into account the following facts. On the one hand the value of this condenser should be high so that the carrier frequency will be removed from the output of the diode. On the other hand, though, if this condenser is made too large it will by-pass the higher audio frequencies, and decrease the high-frequency response of the receiver by acting in a manner similar to a tone control. Thus the final value of this condenser is the result of taking into account these two factors. An additional factor which is considered by design engineers is the fact that a large value of condenser decreases the ability of the detector to handle high values of percentage of modulation without distortion.

Typical Diode Detector

We are now in a position to examine a typical diode detector circuit and to look into the distribution of signals throughout the circuit. The circuit shown in Fig. 3-4 is in general similar to the preceding circuit, but appears more complicated because of several additional components. However, basically the action taking place in the two circuits is the same. Let us examine these additions which we have just mentioned. You will note that the volume control is the d-c diode load and that the amount of audio signal which is picked off and fed to the a-f amplifier is controlled by the setting of R_2 . At all times regardless of the setting of the volume control, the full value of a-f signal voltage is developed across R_2 . An additional filter has been added in series with the diode load. This consists of the resistor R_1 and the condensers C_1 and C_2 . The purpose of this filter is to remove the i-f

component of the signal more effectively so that only a comparatively small i-f signal will be present across the audio volume control. In addition to improving the filtering of the i-f signal, this filter combination also helps to improve the fidelity of the detector for signals having a high percentage of modulation.

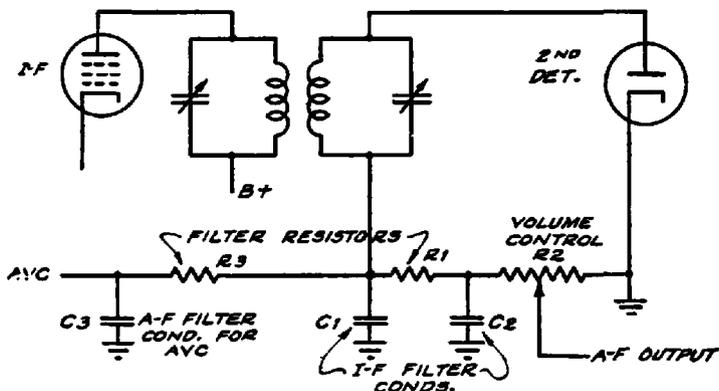


FIG. 3-4. A typical diode detector showing the a-f and avc output circuits.

One of the reasons for the wide popularity of the diode in modern receivers is that its use simplifies the production of a control voltage for use in avc and other control circuits. These will be discussed in detail in the chapter on control circuits. For the present it will suffice to say that the negative voltage produced by the direct current flowing through R_1 and R_2 is suitable for avc purposes since its value is proportional to the carrier amplitude. Since, as we have seen, both d-c, a-f, and i-f signals are present across the diode load, the filter R_3 - C_3 is used to remove the a-f and i-f components from the avc voltage and to leave only the d-c control voltage.

Contact Potential

In connection with the d-c voltage developed across the diode load by the presence of an input signal, we should mention that there will always be a small negative voltage present at the diode

plate and of course at the plate side of the diode load. This voltage which is often called the "contact potential" is produced by the electrons which leave the cathode with sufficiently high speed to reach the plate. For the average diode tube, such as that contained in the 6H6 and similar tubes including dual-diode triode types, this contact potential has a value of about minus one volt under typical circuit conditions. An interesting characteristic of this contact potential is that its value depends upon the diode load resistance and the higher the value of load resistance the higher is the value of the contact potential. Thus, when the diode is open circuited and the voltage at the plate is measured with a high-resistance voltmeter, the contact potential will measure about -1 volt. For a load resistance of about 100,000 ohms, the diode potential will drop to a few tenths of a volt. Finally the voltage at the plate will drop rapidly to zero as the load resistance is decreased further. When troubleshooting, you should remember that this negative voltage normally exists across the diode load and that it does not indicate the presence of a signal.

Full-Wave Detector Circuit

The detector circuits described up to this point have all been half-wave rectifier circuits since only one half of the carrier wave

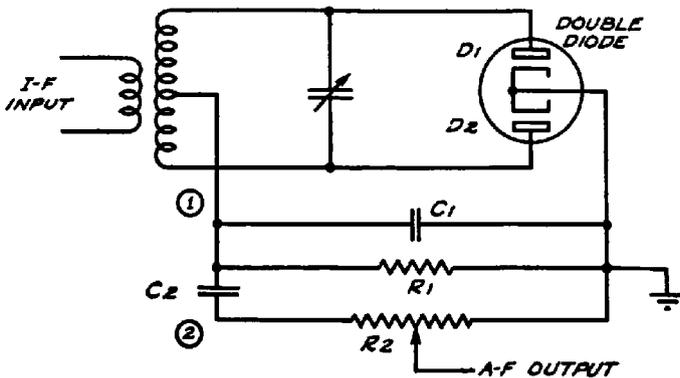


FIG. 3-5. A full-wave detector circuit using a double diode such as a 6H6. The distribution of signal voltages is described in the text.

is rectified. In contrast to these half-wave detector circuits, we show in Fig. 3-5 a full-wave rectifier or detector circuit which has been used rather widely in receiver circuits. If you examine this circuit closely, you will observe that it is similar to the type of full-wave rectifier circuit used in practically all receiver power supplies, with the filter choke omitted and *R1* serving as the load circuit.

From the viewpoint of signal tracing, the full-wave detector circuit has several interesting characteristics. First of all, we note that both halves of the input signal are rectified since each of the diodes draws current on alternate halves of the cycle. Thus on that half of the cycle where *D1* is positive, this diode draws current and contributes a pulse of current through the diode circuit. During this interval *D2* is of course not drawing current because the other half of the center-tapped input winding is negative. During the next half of the cycle, the plate of *D2* is positive with respect to its cathode; thus it contributes a pulse of current through the load in the same direction as the current passed by the first diode on the preceding half cycle. In this way both halves of the input signal are rectified, each of the diodes functioning exactly as in the case of the preceding half-wave detectors. The resultant output is thus similar to the wave shown in Fig. 3-3(b), with the exception that the frequency of the carrier ripple is twice as great because of the full-wave action.

Because of the balanced nature of this circuit there is no i-f signal voltage at the centertap of the secondary winding of the input circuit. However, harmonics of the i-f or carrier frequency are present across the diode load. These, however, are not important and their presence is ordinarily of no consequence. Actually, it is not possible to achieve perfect balance so that in commercial receiver circuits a small by-pass condenser will generally be found across the diode load. Even where the circuits are perfectly balanced, this condenser is useful because it serves the purpose of by-passing the harmonics of the carrier frequency which are always present across the diode load.

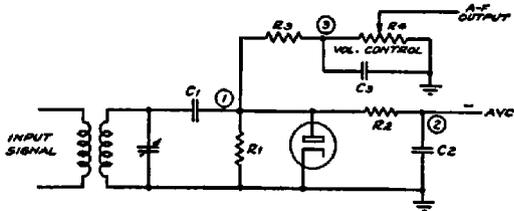
The full-wave circuit shown in Fig. 3-5 shows an interesting variation in that the volume control is located so that the d-c component of the diode current is blocked from the volume con-

trol by means of the condenser $C2$. In practice, $C2$ is large enough so that the audio frequencies developed at point 1 will be fed to point 2 and develop essentially the same value of audio voltage at point 2. A tendency toward longer volume control life and greater freedom from noise has been found to be characteristic of this type of circuit in which the d-c component of the diode current does not flow through the audio volume control.

Capacity-Coupled Diode

The diode circuit shown in Fig. 3-6 is often used as a detector but more especially as a rectifier for supplying control voltages. The essential feature of this circuit is that the signal voltage is

FIG. 3-6. A capacity-coupled diode detector circuit. The operation and signal distribution are discussed in the text.



coupled into the diode circuit by means of a condenser. As a result, the rectified d-c component of the diode current cannot flow through the tuned circuit which generally supplies the signal voltage. This of course is a consequence of the general principle that no direct current can flow through a condenser.

When a signal is applied to the tuned input circuit, this signal voltage is impressed on the plate of the diode. Thus the signal voltage at the plate of the diode is essentially the same as that across the tuned circuit. On the positive peaks of the signal-voltage cycle, electrons are attracted to the diode plate and this rectified current flows through the diode load resistor $R1$. You can look upon the action taking place as one in which a circulating rectified current flows through the closed circuit consisting of the diode and the load resistor $R1$. As in the previous diode rectifier circuits, this current causes the plate side of the load resistor to become negative with respect to ground, and also causes the demodulated or a-f signal voltage to appear across $R1$.

No doubt by this time you have noticed that no by-pass condenser is used across the diode load $R1$ as in the previous cir-

cuits. It is not difficult to see why this is so. In the other circuits, for example that of Fig. 3-3, the action of the circuit did not depend upon the existence of the i-f or carrier signal voltage across the resistor and thus it was both possible and desirable to by-pass this voltage. However, in the present circuit the signal voltage must be impressed across the diode by means of the signal voltage drop across $R1$ so that this signal voltage cannot be by-passed. If a condenser were used across $R1$, on the other hand, then this would have the effect of by-passing the signal voltage, and thus make the circuit inoperative.

An important point in understanding the action of this circuit and one that is often misunderstood is that the diode does not act as a partial short circuit across the input during the interval that the diode is conducting current. Although the diode does have a low internal resistance of approximately 2000 ohms while it is passing current, still this 2000 ohms does not load the input circuit because whatever current is drawn by the diode passes through $R1$ and is limited by this high value of load resistance. Thus the loading is determined not by the low internal resistance of the diode, but rather by the value of $R1$.

As is indicated in Fig. 3-6, the capacity-coupled diode can be used to supply avc voltage and it is often used for this purpose as well as to supply other types of control voltages. To obtain the control voltage produced by the d-c component of the diode current, it is general practice to use a filter similar to $R2$ and $C2$. Since $R2$ effectively shunts the input circuit, its value is generally of the order of a megohm in order to minimize loading. The value of $C2$ is sufficiently large to remove the audio pulsations from the output circuit and its value will generally be of the order of 0.05 mf.

When the capacity-coupled diode circuit is used to supply audio voltage, the load resistor across which the audio voltage is developed is generally coupled to $R1$ by means of a filter $R3$ - $C3$. The values of $R3$ and $C3$ are sufficiently large so that the carrier frequency is kept out of the volume-control circuit and so that the capacity of the volume control does not detune the circuit. Note that with this circuit it is not possible to obtain the full audio voltage across the volume control since part of the audio signal is lost across the filter resistor $R3$. For example, in the

particular case where R_3 and R_4 are equal, then one half the full audio output is available at the volume control.

With reference to the signal distribution in this circuit, at point 1 will be found both the i-f signal and its harmonics, as well as the audio signal, and the negative control voltage. At point 2, however, both the i-f signal and the audio signal are filtered, and only the negative control voltage is present. At point 3, across the volume control, both the negative voltage and the audio signal are present, but of course the full output voltages which were present at 1 are not obtained because of the voltage divider action produced by R_3 and R_4 . Only a small fraction of the carrier signal is present at point 3 because of the filtering action of R_3 - C_3 .

We might point out here that triodes are sometimes used as diodes in receiver circuits by connecting two of the elements together to form a two-element tube. In some cases the triode plate is connected to the cathode and the grid forms the other element of the diode. In other cases, the grid and plate are tied together to form the diode plate, while the other element is formed by the cathode. Where triodes are used in this way as diodes, everything which we have previously said about diodes may be taken as applying to these tubes. Thus, for example, any one of the circuits which has been discussed, or in fact any circuit in which a diode can be used will also function with a triode connected as a diode.

The application of various types of diode circuits to perform different functions, and employing circuit arrangements somewhat different from those considered, is reserved for later discussion in the chapters devoted to the types of radio circuits. We are here referring to double diodes used in automatic-frequency-control systems, discriminator circuits, amplified delayed AVC circuits, noise suppression circuits, limiting circuits, etc.

TRIODE AND MULTI-ELEMENT DETECTORS

While the diode detector is the most widely used detector in modern receivers, there are a number of other detector circuits using *multi-element* tubes which should be discussed in this book. For the most part these detectors were used in early receivers, but

since many of these receivers are still in use, it is worthwhile considering multi-element detectors in some detail. We do not want to create the impression that none of the detector circuits to be described is used in current receivers; in many cases we find that triode and screen-grid detectors are still being used where they are better adapted than the diode to the requirements of particular receivers.

If we examine the various types of detector circuits, we find that they all have this in common: they depend for their operation upon the curvature or bend in the tube characteristic. Without exception we find that the operation of all types of detectors is predicated upon the operation of the tube so that it conducts current better in one direction than in the other. In the case of the diode, we saw that this simple tube is ideally suited for detection because complete rectification is obtained, i.e., on one half of the cycle current was passed and on the reverse half of the cycle no current whatsoever was passed. In the case of the triode and other multi-element detectors, we find as a general rule that the rectification is not so simple as in the case of the diode but that some current is generally passed by the tube on the negative half of the cycle. However, in every case, the current passed on the positive half of the cycle exceeds that passed on the negative half of the cycle so that detection is obtained.

As you read this section, you will note the great similarity between diode and multi-element detectors. True, the triode and screen-grid detectors are somewhat more complicated because the process of amplification is combined with that of detection. Nevertheless these detectors have much in common with the diode detector, especially from the viewpoint of signal tracing. Thus we shall see, for example, that the manner in which the carrier signal is removed from the detector load, and the distribution of signals, is much the same for multi-element detectors as for diodes.

The Linear or Plate Detector

Perhaps the most widely used of the multi-element detectors is the circuit shown in Fig. 3-7 which uses a triode tube. This type of circuit is known by a great many names among which are *linear* detector, *plate* detector, *grid-bias* detector, *anode* detector,

and *power* detector. However, regardless of the name which is used to describe this basic detector circuit, it is important to be able to recognize the circuit when you meet it. As you can see from Fig. 3-7, the circuit shown is very similar to that of an amplifier stage and in fact with the exception of C_2 , which is identified as the plate by-pass condenser, it is identical with that of a resistance-coupled amplifier stage. Because of this similarity we should expect that the operation of this circuit would have much in common with the operation of an amplifier stage, and actually such is the case.

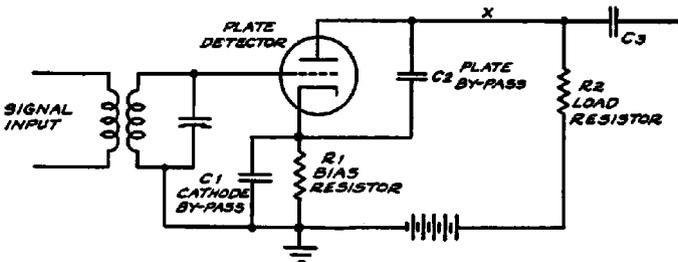


FIG. 3-7. A basic circuit for plate detection showing the function of the various parts.

Although the plate detector circuit shown in Fig. 3-7 shows this marked similarity to a resistance-coupled amplifier stage, actually the action which takes place when a signal is applied to the stage is different. This is because the detector stage, which we are discussing, is biased almost to plate-current cut-off or to zero plate current. On the other hand, in an amplifier stage the bias is set so that the signal will cause the plate current to vary by an equal amount on each side of the steady plate current. An examination of Fig. 3-8 will show you the contrast between the two types of operation. When the triode is used as an amplifier, as in Fig. 3-8(b), the bias and operating conditions are set so that the operating point is in the middle of the straight part of the plate-current characteristic. On the other hand, when operation as a detector is desired, the grid bias and other conditions are adjusted so that the plate current is reduced almost to zero; this is shown in Fig. 3-8(a).

We need not go into a lengthy description of the circuit in Fig. 3-7 because we have already discussed diode detectors and triode amplifiers. Referring to this figure, we note that just as in the triode amplifier, the input signal is applied between the grid and ground so that this constitutes the input circuit. In the cathode circuit the resistor $R1$ supplies the proper bias so that the plate current is practically cut off when no signal is applied. In actual practice, the no-signal plate current for biased triode detectors is usually of the order of 0.2 milliampere. We note that the cathode resistor is by-passed by the condenser $C1$. Because both the carrier signal and the demodulated or audio signal developed as the result of rectification is present at the cathode, $C1$ is generally of the order of a microfarad so that it will by-pass not only the carrier frequency but also the lower audio frequencies.

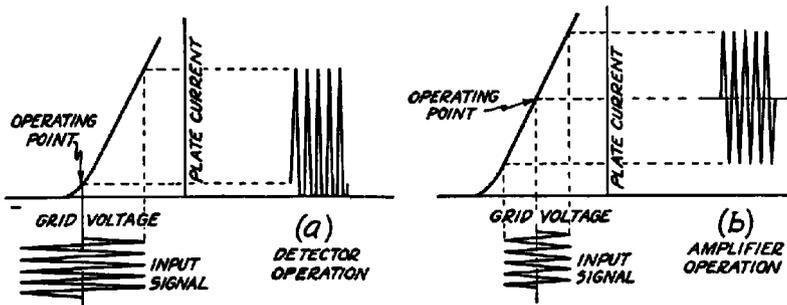


FIG. 3-8. A tube operated as a detector has its operating point near cut-off, whereas in amplifiers the operating point is in the middle of the straight part of the characteristic.

In the plate circuit, we encounter a somewhat different situation. Here the audio voltage is developed across the load resistor $R2$. However, the by-pass condenser $C2$ must be sufficiently *small* so that it will not by-pass the audio frequencies back to the cathode and in this way prevent the development of the audio signal across the load $R2$. On the other hand, $C2$ must be sufficiently *large* so that it will by-pass the r-f or carrier component of the plate current and prevent this carrier signal from being developed across the load. The presence of a carrier signal across the load would of course be undesirable because it would result in r-f voltage being fed into the a-f amplifier. In addition to this

factor, it is necessary to have $C2$ by-pass the carrier signal in order to prevent amplification of the carrier signal from interfering with the action of the tube as a detector.

We can describe the action which takes place in the circuit when a signal is applied by the same method which we used in analyzing the action of the triode amplifier. In Fig. 3-9 we show

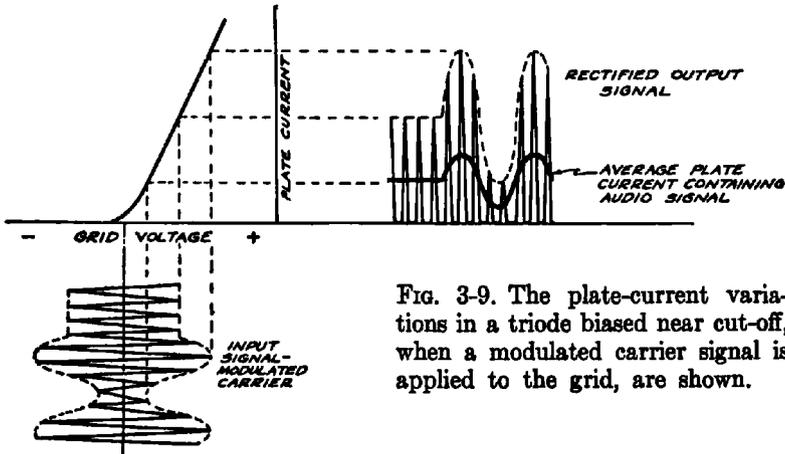


FIG. 3-9. The plate-current variations in a triode biased near cut-off, when a modulated carrier signal is applied to the grid, are shown.

the plate current-grid voltage characteristic of the triode and the resultant variation in the plate current which takes place when a modulated signal is applied to the grid. On the positive half of the input cycle we note that a very large increase in the plate current of the triode takes place. On the other hand, because the tube is biased very near cut-off, only a slight decrease in plate current can take place during the negative half of the cycle. Thus we have detection taking place just as in the case of the diode, and we find that the plate current through $R2$ of Fig. 3-7 varies in accordance with the amplitude of the modulated input signal. In this way, the average plate current causes an audio signal voltage to be developed across $R2$.

Generally speaking the rectifying action which we have just described is very similar to that which takes place in the diode. However in this case the rectifying action is accompanied by amplification so that a considerably greater output is obtained from a triode detector than from a diode, for the same value of

input signal. This accounts for the wide use of the triode detector in the early receivers since at that time r-f amplification was difficult and expensive to obtain. Thus the additional sensitivity which could be obtained by using a triode detector was very helpful.

The distribution of signal voltages in triode circuits is very similar to that in diode circuits, bearing in mind of course that with the diode no amplification is obtained, whereas with a triode both detection and amplification of the output are obtained at the same time. At the control grid of the tube we find that only the input signal is present; this may be either the r-f signal in the case of a tuned r-f receiver or the i-f signal in the case of a superheterodyne receiver. Naturally there is no a-f signal present at this point since rectification does not take place in the grid circuit. On the other hand, you will remember that in the case of the diode detector not only the input r-f signal was present at the diode plate, but the d-c output and the a-f output as well.

At the plate of the triode we find that the a-f signal is present. This signal is considerably stronger than would be the case for a diode because of the amplification which is obtained. A relatively weak component at the carrier frequency is also present at the triode plate because of incomplete filtering.

At the cathode we find that normally no signal is present because the cathode by-pass condenser is made large enough so that it will by-pass both the carrier and the a-f components of the plate current. However, it is worthwhile mentioning that the d-c bias voltage across the cathode resistor R_1 increases as the carrier input signal is increased. The rated value of bias voltage which is given in the service notes is ordinarily the value with no input signal.

There are a great many variations from the basic triode detector circuit which we have just described. Fortunately, many of these have already been covered in connection with amplifier operation so that we shall not have to go into detail here. Thus, for example, the circuit shown in Fig. 3-7 uses a cathode resistor to supply the proper bias for the tube. But the other systems used in amplifier stages to obtain bias can also be used with detectors and so we find that a bleeder circuit, or battery bias in

the case of battery-operated receivers, can be used to supply the bias required to reduce the plate current to cut-off.

Although we have shown the triode detector with a resistor for the plate load, this type of detector is often used with transformer coupling as well as with resistance coupling. In this connection, we have already described transformer-coupled amplifier stages so that further discussion of the transformer-coupled detector is unnecessary. However, the transformer used with a detector stage is different from that used with a transformer-coupled a-f stage even where the same tube type and plate voltage is used in both cases. This is because the triode operated as a detector has a higher plate resistance so that the turn ratio and input impedance are generally higher for the detector transformer. Distorted operation will usually result when an interstage a-f transformer is used to replace a detector output transformer.

Several different types of filter arrangements are used to reduce the level of the carrier signal at the plate of the detector tube. In Fig. 3-7 a by-pass condenser is used to by-pass the signal back to the cathode. Sometimes this condenser is returned directly to ground but this does not change the by-passing action because the cathode is by-passed to ground by means of $C1$. Very often where more effective filtering is required, an r-f choke is inserted at X in Fig. 3-7. This r-f choke has the effect of blocking the carrier currents from the load circuit so that only the a-f signal will be developed across the load. Where this r-f choke is used, it is customary to use an additional by-pass condenser on the load-resistor side of the choke in order to increase further the effectiveness of filtering. Of course the value of both of these condensers is small in order to prevent the loss of the higher audio frequencies.

Tetrode and Pentode Detectors

The biased detector circuit which has just been described is used with screen-grid tubes as well as with triode tubes. When the screen-grid tube is used as a detector, it is adjusted so that the plate current is practically cut off and as a result rectification of the modulated input signal and detection is obtained. Thus we can use the same figure that was used in the case of the triode to describe the effect of the input signal on the plate-current varia-

tion through the detector load. The essential point to keep in mind is that in order to obtain detection, the tube must be adjusted so that the increase in plate current on one half of the cycle will be greater than the decrease in current on the other half of the cycle. Whether the tube is a diode, triode, tetrode, or a pentode, makes no difference in this basic requirement for detection.

Because of the greater amplification possible with the screen-grid tube, it is much more sensitive as a detector than the triode. In addition to the greater sensitivity as a result of the higher amplification, the efficiency of detection is greater for the screen-grid type because of the sharper cut-off which it is possible to obtain in tetrode and pentode tubes. This is especially true of the so-called "sharp cut-off" types where the plate current drops very sharply to zero. Tubes similar to the 57, 77, 6C6, and 6J7 types are examples of sharp cut-off tubes which are often used as biased detectors.

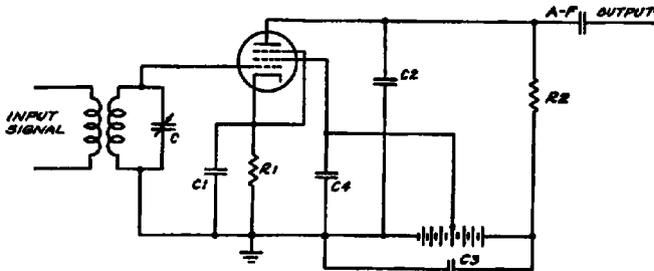


Fig. 3-10. A typical biased detector circuit using a pentode tube.

A typical biased detector circuit using a pentode tube is shown in Fig. 3-10. Again, as in the case of the triode, we need not discuss this circuit at length because of its similarity to the pentode resistance-coupled amplifier. Thus the screen voltage is supplied from the tap on the voltage supply and is by-passed for both r-f and a-f currents by means of the condenser C_4 . Similarly, the cathode resistor R_1 is also by-passed by means of the condenser C_1 . Since a-f as well as r-f currents flow through the cathode resistor, C_1 is generally made large enough so that it will by-pass the lower audio frequencies. The suppressor grid does

not require any special attention since it is usually connected to the cathode of the tube at the socket.

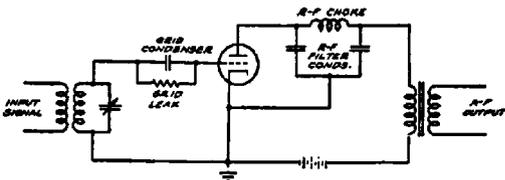
Because of the high value of load resistance required for the proper operation of screen-grid detectors, resistance coupling is almost invariably used. On the other hand, transformer coupling is often used with triode detectors but practically never in receivers with screen-grid detectors. In general the voltages used in screen-grid detector circuits are similar to those used in resistance-coupled screen grid a-f stages. However, because operation at cut-off is desired, the grid-bias used is larger than that used in amplifier stages.

The introduction of the screen grid does not change the signal-tracing procedure appreciably, but it does provide an additional tube element which must be taken into account. Normally, the by-passing action of C_4 will be sufficient to prevent the building up of an a-f signal at the screen grid of the tube so that no signal voltages will be present at this point unless C_4 is open. Signal tracing at the remaining points remains exactly the same as for the triode detector so that no additional comments are required.

The Grid-Leak Detector

Practically all receivers more than twelve years old employ a detector circuit which is somewhat different from any that we have described so far. This is the so-called *grid-leak* detector which was widely used in early receivers because of its high sensitivity on weak signals. In those days it was not possible economically to build amplifiers which provided high gain in the r-f end of the receiver and consequently a detector which was sensitive to weak signals was very desirable.

FIG. 3-11. A typical grid-leak detector. Bias is supplied by the rectified grid current through the grid leak.



The circuit which we show in Fig. 3-11 is typical of grid-leak detectors. These circuits are easy to recognize because practically without exception they were used only in early receivers and

are now no longer in common use. Unlike the grid-bias detector, the grid-leak detector is operated at zero bias and the grid is returned directly to the cathode through the grid-leak and the tuning coil. Since the coil resistance is only several ohms, whereas the resistance of the grid leak is of the order of megohms, the coil resistance is not of importance. As a matter of fact, in some cases the grid leak is returned from the grid directly to the cathode, but this does not alter the operation of the circuit.

To understand the operation of the grid-leak detector, it is convenient to consider that the grid-cathode sections of the tube form a diode and that the grid leak and grid condenser constitute the load for this diode. Thus, when a signal is applied to the input circuit, this signal voltage is fed to the grid through the grid condenser which has a low reactance to the carrier frequency. Exactly as in the case of the diode, a rectified voltage is developed across the grid leak and this negative voltage is applied directly at the grid of the tube. An essential feature of the circuit is the operation of the tube at zero bias, and also the operation of the plate at a low d-c voltage. Both of these factors combine to make the grid-cathode circuits of the tube act as a rectifier, in which the grid acts in a manner similar to the plate of a diode. Once the audio voltage is developed at the grid by the signal, it is amplified by the triode action of the tube and the resultant audio output appears across the primary winding of the transformer.

It is interesting to contrast this action with that in the biased triode detector. For the biased detector, we saw that the application of a signal caused rectification to take place in the plate circuit, and as a result the average plate current *increased* when a signal was being received. In the case of the grid-leak detector, however, the application of a signal causes a *negative* voltage to be developed at the grid, and thus rectification in the grid circuit causes the average plate current to *decrease*. The amount by which the average value of the plate current decreases of course depends upon the carrier level, and for this reason the current flowing through the primary winding of the output transformer follows the envelope of the modulated signal.

The signal distribution in the grid-leak detector is different from that in the biased detector because of the presence of the a-f signal at the grid of the tube. In this connection, the grid con-

denser is made sufficiently small so that it will not short circuit the higher audio frequencies and prevent the audio voltage from being built up at the grid. No discussion of the signals present in the plate circuit is required since this has already been described for the biased detector and is the same for the grid-leak detector.

The grid-leak detector has the disadvantage that it will easily overload even on medium signals and also that the percentage of distortion in the output is higher than for the other types of detectors which we have discussed. In addition, the loading on the input tuned circuit is considerably higher because current is drawn in the grid circuit, whereas in the other circuits (with the exception of the diode) rectification takes place in the plate and not in the grid circuit.

Infinite-Impedance Detector

A few years ago a new detector circuit was introduced to enable obtaining many of the advantages of the diode circuit without the loading effect characteristic of the diode. This circuit is known as the "infinite-impedance detector" and we show it in schematic form in Fig. 3-12. The most striking thing about this

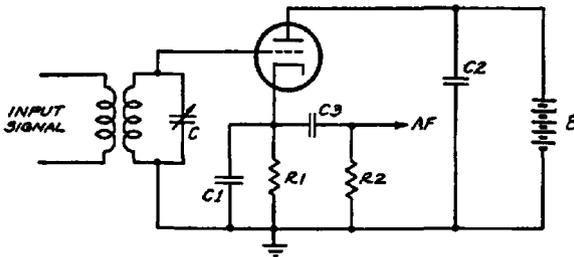


FIG. 3-12. A typical infinite impedance detector circuit. The audio output is taken off between the cathode and ground.

circuit is that the demodulated output is taken off between the cathode and ground, although the input circuit is between the grid and ground. In this respect the circuit is not unlike a widely-used phase-inverter circuit which is arranged similarly.

With respect to the circuit, we note from the figure that the plate of the triode is by-passed to ground by means of $C2$. The

value of $C2$ is sufficiently large so that both r-f and a-f currents are returned to ground and consequently there is no signal voltage of any kind at the plate of the tube. On the other hand, these signal currents must flow through the cathode resistor $R1$ in order to get back to the cathode so that a signal voltage is built up across $R1$. As in the case of the diode detector, the value of $C1$ is chosen so that only the r-f currents will be by-passed and consequently there will be practically no signal voltage at the carrier frequency between cathode and ground. However, the demodulated or audio voltage will of course be available between the cathode and ground because $C1$ is sufficiently small so that it will not by-pass the a-f signal.

In operation, the bias developed at the cathode is sufficiently high so that no grid current will flow when a signal is applied to the grid. This is true even for large values of input signal of the order of 30 volts and as a matter of fact the infinite-impedance detector is ordinarily designed for use in receiver circuits where a high value of signal voltage is available at the detector. In addition to this advantage that no grid current is drawn and that there is no loading on the input tuned circuit, the infinite-impedance detector has the additional advantage that the distortion in the output is lower than it is for the diode. This is especially true for signals which have a high percentage of modulation. Of course, the infinite-impedance detector has the disadvantage that it cannot be used to supply a-v-c voltage in the simple and direct way that the diode can.

Diode and Multi-Element Detectors

Now that we have described the various types of detectors, it is interesting to investigate just why the diode detector is so widely used in present-day receivers while the multi-element detectors find very little application. Among the principal factors which account for the widespread use of the diode is the fact that improved tubes and circuits have made possible high gain in the r-f and i-f sections of receivers, so that high sensitivity in the detector circuit is no longer required. In addition the output of the diode detector has a very low percentage of distortion and it will function satisfactorily over a wide range of input voltages. Multi-element detectors, on the other hand, have higher distortion

and require that the input signal be held within fairly close limits. The development of effective avc circuits, however, has minimized the importance of this last factor since most receivers are designed so that the signal at the detector will have a fairly constant level regardless of the strength of the received signal. Last, but by no means the least important reason for the use of diode detectors is the widespread use of automatic volume control and the fact that the diode is so well adapted to supply control voltage for avc circuits.

Chapter IV

COUPLING DEVICES

WHEN electrical energy is transferred from one circuit to another, these circuits are said to be coupled to each other. Since practically every component in a radio receiver plays some part in coupling circuits, in this chapter we limit our discussion to coupling devices which are used in radio-frequency, intermediate-frequency, and audio-frequency systems to transfer the signal from one stage to a following stage.

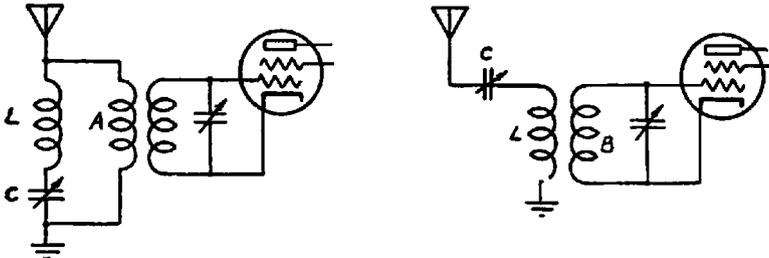
Fundamentally, circuits may be coupled in three ways: capacitively, inductively, or conductively. Circuits are *capacitively coupled* when the signal is transferred from one circuit to another by means of a condenser; this form of coupling is also referred to as *electrostatic coupling*. Circuits are *inductively coupled* when inductances in each circuit are so arranged that there is a linkage or joining of their electromagnetic fields; this form of coupling is also referred to as *electromagnetic coupling*. A combination of these two forms of coupling may exist simultaneously. For instance, in some r-f and i-f transformers, the primary and secondary coils are so arranged that inductive coupling occurs and also, because of the proximity of the primary and secondary coils to each other, a certain amount of capacity exists between the two coils. Therefore, a signal present in the primary coil will be transferred to the secondary coil by both inductive and capacitive coupling. *Conductive coupling* occurs when two circuits are directly joined; this form of coupling is exemplified in direct-coupled amplifiers.

Circuits may be either *resonant* or *non-resonant*. In a receiver, a resonant circuit is one which functions at maximum efficiency at one frequency. If this frequency is selected by tuning so that

resonance occurs at a desired frequency, it is then known as a tuned circuit. A non-resonant circuit is one which is designed to function without tuning over a wide range of frequencies. Let us first consider the characteristics of resonant circuits.

Series Resonant Circuits

Resonance in tuned circuits is obtained either by series tuning or parallel tuning. The former type of circuit is known as a series resonant circuit and it is characteristic of series resonant circuits that maximum current flows during the state of resonance and, since the impedance of the circuit is then a minimum, it is possible to accomplish two things; one of these is to utilize the low impedance as a short-circuiting path at the resonant frequency, or as a trap circuit, and the other is to employ the device so that the maximum current is allowed to flow through the desired circuit at resonance. These two applications, though identical in basic design, differ in circuit arrangement, and are shown



FIGS. 4-1(a) (left), 4-1(b) (right). The wave trap, L and C in the circuit at the left, by-passes the signal at the resonant frequency and thus rejects it. In the circuit at the right the signal at the resonant frequency is passed on to the secondary.

in Figs. 4-1(a) and 4-1(b). In Fig. 4-1(a), the wave trap LC is the series circuit used as a short-circuiting impedance at resonance. It is shunted across the antenna coil A and its purpose is to by-pass the current at the resonant frequency. If we assume that the function of this circuit is to by-pass an interfering signal of, say, 465 kc, tuning this circuit to 465 kc will prevent the development of a signal at this frequency across the antenna coil; consequently, there will be no signal voltage at this frequency applied to the r-f amplifier tube. The impedance of the circuit

being limited solely by the circuit resistance, is consequently very low; much lower than that of the antenna coil *A*. The lower the resistance of the circuit, the less its impedance at resonance and the greater its selectivity. The greater the selectivity of this circuit, the less its effect upon signals higher or lower than the resonant frequency. In other words, its trap action becomes sharper as the selectivity is increased.

Another application of the same principle, but employed differently, is shown in Fig. 4-1(b). *L* and *C* now constitute the tuned circuit in the antenna system. The impedance is a minimum at resonance, consequently the maximum amount of current flows through the system. Coil *B*, being coupled to *L*, receives the maximum amount of energy. In Fig. 4-1(a), the resonant circuit is used to trap out or reject a certain signal, whereas in Fig. 4-1(b) the same principle is employed to accept the desired signal.

Still another practical application of series circuits is the scratch filter used in connection with phonograph pickups and audio amplifiers. The series-resonant circuit, tuned to the approximate frequency of the scratch, is connected across the pickup and its purpose is to by-pass or short-circuit the balance of the system at this noise frequency by offering a low impedance path.

The Parallel-Resonant Circuit

The parallel-resonant circuit finds far more extensive application in radio receivers than the series-resonant circuit. This condition is not due to any difference in the operating efficiency of the two circuits, but rather to the fact that the arrangement of the elements of the parallel circuit is such that the coil presents a ready path for the application of operating voltages to the elements of the respective tubes. Perhaps the most important reason for the greater use of the parallel tuned circuit is that it offers a high impedance at resonance, while the impedance of series tuned circuits is very low at resonance. Since it is necessary to provide a high-impedance load in order to obtain any degree of amplification from a vacuum tube, the reason for the more frequent occurrence of the parallel-resonant circuit is at once apparent.

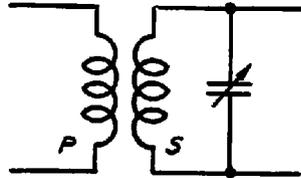
Series and parallel tuned circuits find a number of different applications. In this chapter, we are primarily concerned with

their applications at frequencies within the r-f and i-f bands wherein they serve to select desired signals and to exclude interfering signals. While the parallel-resonant circuit is occasionally employed as the sole coupling medium between r-f and i-f amplifying tubes, by far its widest application is in single-tuned and double-tuned transformers in which the primary and secondary circuits are inductively coupled.

The Simple Tuned Transformer

The simple tuned transformer shown in Fig. 4-2, consisting of a single tuned secondary circuit coupled to an untuned primary circuit, is productive of a resonance curve which has but a single

FIG. 4-2. A simple two-winding transformer. The primary is untuned, while the secondary is tuned by means of the shunt condenser.



peak at resonance. With respect to the width of the curve, the resonance curve for a complete transformer is somewhat wider than for the transformer secondary alone—taken with the primary absent. The presence of the primary—untuned though it may be—has the effect of introducing some resistance into the secondary winding. Maximum signal transfer from the primary to the secondary winding occurs when *optimum coupling* exists. Increasing the coupling beyond this point will reduce the signal transfer somewhat and will tend to broaden the resonance curve. Reducing the coupling below the optimum point will likewise reduce the signal transfer and make the curve narrower.

As far as coupling is concerned, what is said about the simple tuned circuit transformer is true about all other types—that is, with respect to optimum coupling. The shape of the resonance curve may change with other types of transformers, but for each there is an optimum adjustment of coupling, sometimes expressed in terms of the coefficient of coupling which provides maximum transfer of energy. At this time we wish to add that, with the exception of those transformers which are provided with

means for changing the coupling, you who may have occasion to service finished receivers should not change the coupling in the transformers. The desired condition will be obtained by correct alignment. Of far greater importance is that you should know the type of resonance curve to be attained, in accordance with the type of transformer involved. Let us now consider the most popular type of transformer used in modern radio receivers: the double-tuned transformer.

The Double-Tuned Transformer

The double-tuned, inductively-coupled transformer is illustrated in Fig. 4-3. The basic description of such a transformer is one in which two separate circuits, coupled to each other, are

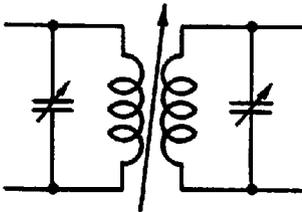


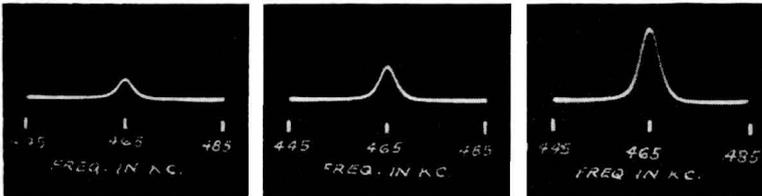
FIG. 4-3. A conventional i-f transformer with both primary and secondary windings tuned. The arrow between the windings indicates that the coupling between the windings can be varied.

tuned to the same frequency. Some variations of this condition will be found in practice as outlined later, but the basic condition is as has been stated. In this transformer both the primary and secondary are parallel resonant circuits. This is common practice as far as receiver application is concerned, but what will be said applies equally to transformers in which either or both circuits are of the series-resonant type, and whose inductances are inductively coupled. What happens in this type of unit under two conditions—first, the effect of coupling and second, the effect of incorrect tuning?

What can we expect when the coupling is varied? In accordance with the function of coupling and from what has been said in connection with the simple single-tuned transformer, it is more or less obvious that the overall resonance curve is going to depend on the coupling. In order that the effect of coupling be illustrated in the most practical manner, a conventional i-f transformer of the commercial variety used in a modern superheterodyne receiver was arranged to simulate working conditions and in such manner

that the coupling could be changed at will. The unit was connected into an oscillograph circuit so that oscillograms of the overall resonance curve could be taken. The constant-voltage input to the transformer was obtained from a frequency-modulated oscillator. The two windings were tuned accurately to the same frequency, with minimum coupling between the windings, so that there would be no reaction between the windings and accurate tuning would be possible (For a complete description of how such curves are made with the cathode-ray oscillograph, see Rider's "The Cathode-Ray Tube At Work.")

The amplitude of the response curve for each condition of coupling is representative of the actual performance of the unit under the conditions named. The results are shown in the series of nine oscillograms given in Fig. 4-4 and are for increasing values of coupling, beginning with minimum coupling, which would result in the transfer of just sufficient energy so that a resonance curve could be obtained.

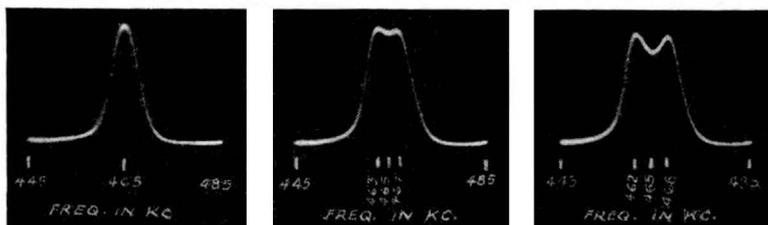


Figs. 4-4(a), 4-4(b), 4-4(c), left to right. As the coupling between the two windings is increased, more and more signal is passed, as can be seen from the increasing height of the signal across the secondary.

The effect of increasing coupling is evident in Figs. 4-4(a), 4-4(b), 4-4(c) and 4-4(d). As you can see, increasing the coupling from the minimum point results in an increase in signal transfer until a critical point is reached where there is no further increase in the amplitude of the response curve, but there is a slight broadening of the peak. Fig. 4-4(d) illustrates the curve with the slightly broadened peak. During this time, there has been no change in the tuning or in the magnitude of the signal voltage fed into the test circuit. The frequency-modulated oscillator supplies a signal voltage which varies from about 445 kc to 485 kc twenty-five times per second and is constant in voltage

over this range. The resonant frequency of the transformer is 465 kc.

Up to this time the effect of an increase in coupling is to increase the energy transfer. Neglecting the very slight amount of interaction between the primary and secondary, as indicated by the slightly broadened peak, we can say that critical coupling exists. A slight increase in coupling, with everything else unchanged, develops the curve shown in Fig. 4-4(e). Note that the amplitude of the curve does not change, but the shape of the



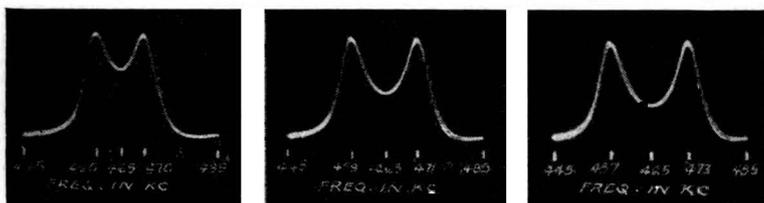
Figs. 4-4(d), 4-4(e), 4-4(f), left to right. As the coupling is increased further, an optimum value is reached in Fig. 4-4(e). A further increase in coupling results in the development of a peak on each side of the resonant frequency.

curve is changed in that two distinct peaks have been produced with a slight dip in the center. Also that the band width has increased at the top of the curve, as well as at the base. Note that the dip occurs at the point which was originally the peak and that one peak now occurs below the resonant frequency and another peak above the resonant frequency. A still further increase in coupling develops the curve shown in Fig. 4-4(f), which illustrates an accentuation of the condition shown in Fig. 4-4(e). The dip is more pronounced and there is a slight decrease in the overall amplitude of the resonance curve. Also, the frequency band pass is increased as indicated by the increased separation between the two peaks.

The interaction between the primary and secondary windings, as a result of the higher degree of coupling, is manifesting itself. Coupling which produces a double-peaked, or doubled-humped, resonance curve is known as *close* coupling. Naturally, there are various degrees of close coupling, as is evident in Figs. 4-4(e) and

4-4(f) and more to follow. The following is a brief explanation of why the resonance curve appears as shown.

For coupling in excess of the critical or optimum amount, the presence of the secondary winding reduces the current through the primary at the resonant frequency. Since the current in the secondary circuit conforms, to a major extent, to the primary current variations, a dip at the resonant frequency occurs. The greater this current, the greater is the dip. At frequencies above and below resonance, the effect of the secondary is to increase



Figs. 4-4(g), 4-4(h), 4-4(i), left to right. As the coupling is increased still further, the frequency at which the peaks occur departs further from the resonant frequency and the dip between peaks increases.

the primary current to values greater than those when the secondary is absent. The closer the coupling, the further apart the two peaks and the greater the dip at the resonant frequency—simultaneous with a gradual reduction of the amplitude of the curve. This is shown in Figs. 4-4(g), 4-4(h) and 4-4(i), where Fig. 4-4(i) is the maximum coupling possible with the i-f transformer used in the test.

When external influences such as regeneration are absent, the resonance curve is quite symmetrical. By this is meant that the variations in the curve are essentially the same both sides of the resonant frequency and the amplitude of the two peaks is the same.

Let us now analyze the curves of Figs. 4-4(a) to 4-4(i) and see what can be learned concerning the resonance curves of such double-tuned transformers. First, it is evident that such a transformer is capable of providing a single-peaked or a double-peaked resonance curve. Whichever is developed depends upon the de-

gree of coupling. Second, that unless external and undesired influences are present, the curve should be symmetrical. This is of value when the resonance curve is established by any one of the numerous means available, as will be stated later. Third, because of the range of resonance curves possible with such a unit, it is possible to increase the band of frequencies passed by the device—*provided that the coupling is variable*. However, in the event that the coupling is fixed, then the optimum setting is that which can be secured solely by correct tuning. If the design of the transformer is such that the curve of Fig. 4-4(d) is the correct figure, then the correct tuning and correct conditions will develop such a curve.

Correct tuning can be stated as being that which provides the maximum amplitude for the resonance curve, consistent with the proper frequency band pass. Information concerning the frequency band pass is given under the heading "Selectivity Requirements," later in the chapter.

What happens if the two windings are not resonated to the same frequency? The major effect is that the two curves are not

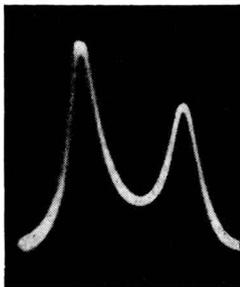


FIG. 4-5. Two peaks of different height are obtained in a closely coupled transformer when the primary and secondary windings are not tuned to the same frequency.

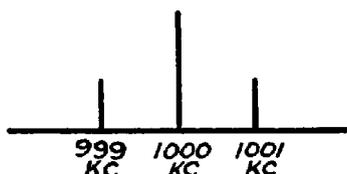
of like amplitude. If the frequency of resonance in the primary circuit does not differ very greatly from the resonant frequency of the secondary circuit, then the two peaks will not be far apart; but if these two resonant frequencies differ widely, then the two peaks will be far apart and of unequal amplitude. Another effect is that the dip does not take place at either resonant frequency, but some place between—at least not midway between the peaks, as is the case when both primary and secondary circuits are tuned to the same frequency. Furthermore, the two peaks do not

occur at the two resonant frequencies of the primary and secondary respectively. An example of an asymmetrical curve, or one with unequal amplitudes for the peaks, due to incorrect tuning, is shown in Fig. 4-5.

Selectivity Requirements

An understanding of the selectivity requirements and how these are related to fidelity of reception is highly desirable, because it establishes the type of resonance curve which should be developed and the advantage of one type of curve over another. Suppose we consider the frequency composition of a 1000-kc carrier, which is modulated with a 1000-cycle tone. Such a modulated wave consists of three frequencies—the 1000-kc carrier, the 1001-kc upper side band and the 999-kc lower sideband. This is

FIG. 4-6. When a 1000-kc carrier is modulated by a 1000-cycle note, then the frequencies of the two sidebands will be 999 kc and 1001 kc.

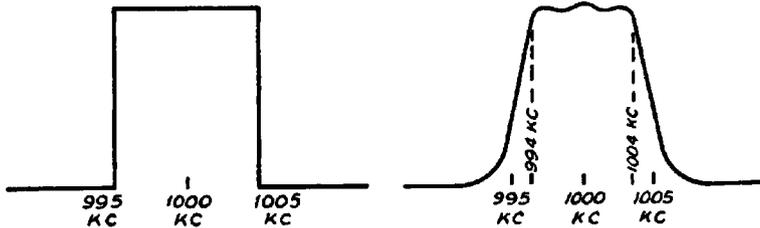


shown graphically in Fig. 4-6. If this same carrier is modulated by a 30-cycle tone, the frequencies in the wave are the carrier of 1000 kc, the upper sideband of $1000 \text{ kc} + 30 \text{ cycles}$ and the lower sideband of $1000 \text{ kc} - 30 \text{ cycles}$. If the modulating frequency is 10,000 cycles, then the three frequencies are 1000 kc, 1010 kc and 990 kc. In actual voice transmission, the highest frequency used for modulation by the majority of broadcast stations is 5000 cycles, though a few high-fidelity transmitters use about 7500 cycles, or slightly higher.

In these examples we assume a constant tone for modulation. If complex tones are used so that 30 to 5000 cycles is the band of modulating frequencies, then the upper and lower sidebands are limited by the highest modulating frequency. The carrier frequency remains as before, 1000 kc.

Now, an essential characteristic of a receiver is to pass the modulated carrier without suppression of the modulating frequencies. This means that those parts of the receiver which are re-

quired to pass the modulated carrier should be equally responsive to the sidebands as well as to the carrier. In order for this to be realized, the ideal response curve required for the various tuned circuits should be a square-topped curve with vertical sides. The width of the top should be the full width of what is classified as the normal sidebands for normal broadcast transmission. . . . With 5000-cycle modulation this is 10 kc, or 5 kc each side of the carrier frequency. This is illustrated in Fig. 4-7. If the modu-



FIGS. 4-7 (left), 4-8 (right). The ideal square-topped response for receiving signals which contain frequencies extending 5 kc on either side of the carrier. In practice, the response shown at the right approaches the ideal characteristic.

lating frequency limit is 10,000 cycles, then each sideband is 10 kc wide and the total band width must be 20 kc.

Up to the present time, square-top resonance curves have been impossible to attain, but an approach to this ideal has been reached. For example, the curves of Figs. 4-4(e) and 4-4(f) show a fairly flat top. If you compare Figs. 4-4(d) and 4-4(e), you will note that while the amplitude or the response of both is substantially the same at the carrier frequency, which in this case is assumed to be the resonant frequency, the response 3 kc each side of the carrier is greater with the adjustment indicated by Fig. 4-4(e) than with the adjustment indicated in Fig. 4-4(d). In turn, the adjustment indicated in Fig. 4-4(f) shows greater response at about 5 kc each side of the carrier than either Figs. 4-4(d) or 4-4(e). At the same time, Fig. 4-4(f) shows less response at the carrier frequency than either of the other two oscillograms.

In the modern high-fidelity receiver, even a closer approach to the ideal is attained by developing a curve, such as that shown

in Figs. 4-4(f) or 4-4(g), in the i-f system and depending upon r-f selectivity, which is most responsive to the carrier, as shown in Fig. 4-4(d), to fill in the dip between the two outside peaks. The curve developed as a result of the combination of the response characteristics of the i-f amplifier, with a resonance curve such as that shown in Figs. 4-4(g) and 4-4(d), is shown in Fig. 4-8. The variation in amplitude between the peaks is not sufficient to cause any complications. At the same time, the proper band pass is obtained and the sides of the curve are a close approach to the straight lines of Fig. 4-7. The flat top of Fig. 4-7 is simulated by the top of the curve of Fig. 4-8.

Variable Selectivity Circuits

The effect of a very sharply tuned amplifier, which has a characteristic similar to that of Fig. 4-4(d), is to attenuate the outer sidebands and hence to attenuate the higher audio frequencies, which are contained in these sidebands. Thus, excessive selectivity results in reduced high-frequency (audio) response. It is for this reason that the intermediate-frequency amplifiers of almost all the high-fidelity receivers on the market incorporate some arrangement for broadening the response of the amplifiers so that the higher audio frequencies will not be lost. If you examine the modern receiver you will find that many systems are in use for accomplishing this result and also that they all depend upon the fact that the frequency response of a transformer becomes broader as the coupling is increased.

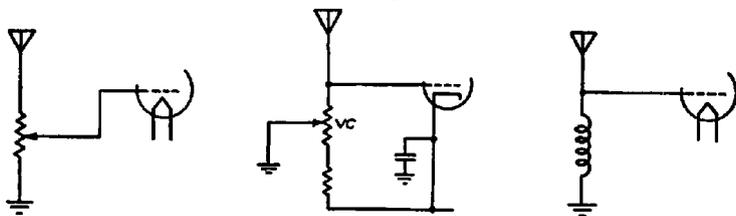
In the foregoing discussion we have considered the characteristics of coupling devices in which tuned circuits are involved and their general applications in r-f, mixer and i-f stages. Now let us see how these and other coupling devices are employed in specific receivers.

Antenna Coupling Circuits

In commercial radio receivers, a large variety of devices have been employed to couple the antenna circuit to the input grid of the first tube. Fig. 4-9 shows one of the earlier coupling devices used for this purpose. The signal voltage from the antenna is applied across a simple potentiometer which serves as a volume

control by enabling the signal voltage applied to the first r-f tube grid to be varied.

In Fig. 4-10, the antenna coupling device is also a volume control which serves to vary the cathode bias on the first r-f tube and, at maximum bias setting, to ground the antenna so that the



FIGS. 4-9, 4-10, 4-11, left to right. Three methods for feeding the signal from the antenna to the grid of the first r-f tube are shown in the figures. No provision for tuning to the frequency of the signal is made in any of these circuits.

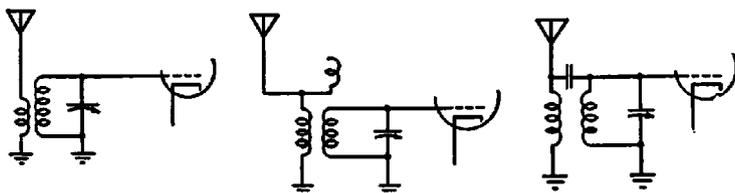
signal voltage applied to the r-f tube grid is a minimum when the cathode bias is maximum. This affords a wider range of control than is possible with the simpler system shown in Fig. 4-9. This type of control has been used in a very large number of small receivers which do not employ automatic volume control.

In Fig. 4-11, the coupling device from the antenna to the r-f tube is an r-f choke, which is designed so as to have a substantially uniform impedance over the broadcast band. In the three coupling circuits just described, there is no step-up in signal voltage from the input terminals of the receiver to the first r-f grid and also, since the input circuit is untuned, these coupling circuits have no ability to discriminate between signals of different frequencies and are consequently not selective.

Most present-day receivers employ single-tuned transformers to couple the antenna circuit to the first tube. In Fig. 4-12, this type of input circuit is shown in its simplest form. The primary coil is usually designed to resonate at a frequency below that of the band over which it is to operate, so that its impedance is high at the low-frequency end of the band and low at the high-frequency end of the band. The secondary circuit is tuned to resonance with the signal frequency. When this is done, the signal voltage developed across the primary coil is amplified and applied to the grid of the first tube. The signal amplification, due

to the transformer, varies in different receivers, ranging from about 2 to 10 in home broadcast receivers and from 10 to 50 in automobile receivers.

With the simple design shown in Fig. 4-12, the antenna



FIGS. 4-12, left, 4-13, and 4-14. Three methods for coupling the signal from the antenna to the grid of the first r-f tube. Each of these circuits is tuned to the frequency of the desired signal by means of a variable condenser.

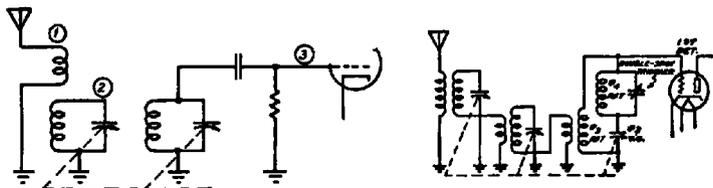
transformer may provide less signal amplification at the high-frequency end of the band than it does at the low-frequency end. This is usually due to the design of the primary coil, the impedance of which is higher at the low-frequency end of the band. To increase the gain at high frequencies, a small amount of capacity coupling from the antenna coil to the secondary coil is often added, as shown in Fig. 4-13. Note that this is capacitive coupling and not inductive coupling, even though a few turns in the form of a coil is used, its inductance is practically zero. In Fig. 4-14, a small condenser is shown, joining the primary and secondary windings. This condenser is employed for the same purpose as the small coil shown in Fig. 4-13.

Image Suppression Circuits

In superheterodyne receivers, a high degree of selectivity is desirable in the circuits preceding the mixer tube. In the formation of the intermediate frequency, the local oscillator in such receivers beats with all signals which are present in the mixer input circuit. If undesired signals of certain frequencies are present, it is possible that they, too, may appear in the mixer plate circuit and be amplified by the i-f amplifier along with the desired signal. This causes interference, chirps and other troubles which cause objectionable reception.

One of the principal causes of such troubles is image-frequency interference. In receivers which employ an oscillator frequency

higher than the signal frequency, the image frequency is equal to the signal frequency *plus* twice the intermediate frequency. In receivers which employ an oscillator frequency *lower* than the signal frequency, the image frequency is equal to the signal frequency *minus* twice the intermediate frequency. In the first case, if the receiver is tuned to 1000 kc and the intermediate frequency is 180 kc, the oscillator frequency is 1180 kc. This 1180-kc oscillator frequency will beat with any 1360-kc signal present in the mixer input circuit to produce an intermediate frequency of 180 kc in the same manner as the 180-kc i-f signal is produced from a 1000-kc signal to which the receiver is tuned. If the signal voltage of the 1360-kc signal at the mixer input were the same as that of the desired 1000-kc signal, they would be of equal strength and frequency at the input to the i-f amplifier. The same situation



FIGS. 4-15 (left), 4-16 (right). Two circuits for obtaining r-f selectivity and minimizing image response. Their operation is described in the text.

exists in receivers in which the oscillator frequency is lower than that of the signal, but in this case, the interfering image frequency, under the conditions previously specified, would result from the presence in the mixer input circuit of a 640-kc signal when the receiver is tuned to 1000 kc.

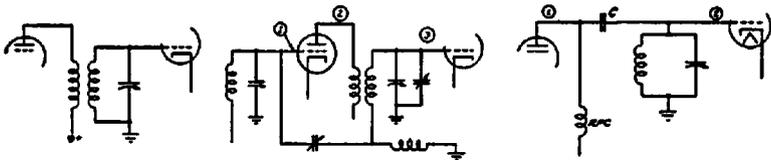
To render this type of interference negligible, additional tuned circuits between the antenna and the mixer input grid are sometimes used. Often one or more tuned r-f stages are employed, but in modern receivers which are not so equipped, a high intermediate frequency is employed. If the intermediate frequency, for instance, is 465 kc instead of 180 kc, the image frequency will differ by 930 kc from the signal frequency. This wide frequency separation is often sufficient to render special image suppression circuits unnecessary in most localities, even when only a single tuned circuit precedes the mixer.

Examples of image suppression circuits are shown in Figs. 4-15 and 4-16. As you will note in Fig. 4-15, the antenna coil is inductively coupled to an intermediate tuned circuit which, in turn, is similarly coupled to the mixer input tuned circuit. If a signal is fed to the antenna coil, the signal amplification due to transformer action is maximum at point 2 when the intermediate circuit is turned to resonance with the incoming signal. Since there is some loss in coupling, the signal strength at point 3 will not be as great as at point 2. However, the selectivity will be improved, since the intermediate tuned circuit acts as a filter.

In Fig. 4-16, a special circuit is shown which is used for image rejection in many early Atwater Kent superheterodynes, such as the 72, 74 and 76 series. This is called the *double spot* system. Since the intermediate frequency employed is 130 kc, the image frequency occurs at 260 kc above the signal frequency. The image-suppression circuit is adjusted to resonate at a frequency 260 kc higher than that of the r-f tuning system. The double-spot trimmer is adjusted by feeding a 1500-kc signal to the input terminals of the receiver and tuning the receiver to 1240 kc. The double-spot trimmer is then adjusted for *minimum* receiver output. It is assumed that the r-f system has previously been aligned in the usual manner at 1500 kc.

Radio-Frequency Coupling Devices

Typical r-f coupling systems used in radio receivers are shown in Fig. 4-17. The r-f transformer illustrated in Fig. 4-17(a) represents a type which is in general use in modern radio receivers.



FIGS. 4-17(a), 4-17(b), 4-17(c), left to right. Typical r-f coupling systems used to transfer the signal from the plate of an r-f tube to the grid of the succeeding tube.

Such a transformer is used to couple the plate of an r-f amplifying tube to the grid of the following tube. For efficient operation,

the design of any coupling transformer depends upon the type of tubes which are being coupled. In modern receivers, r-f amplifying tubes are of the pentode type which have a high plate resistance and require a high-impedance plate load for maximum signal amplification. Consequently, the primary of such r-f transformers, which forms the plate load, is designed to have a high impedance to frequencies over its operating range. In this way, the amplifying properties of the tube are most efficiently utilized.

In such r-f transformers, little or no gain is obtained from the transformer action itself, since both the secondary and the primary circuits have a high impedance to the signal frequencies. We can obtain amplification from transformers only when the impedance of the secondary and its load is higher than that of the primary circuit. With triodes, which formerly were widely used in r-f amplifiers, the plate load, or transformer primary, is of low impedance since the plate resistance of triodes is much lower than that of pentodes. The tuned secondary, however, has a much higher impedance than that of the primary and consequently the signal is amplified by such coupling transformers. The signal amplification obtained in this manner by the transformer is often greater than that obtained from the triode, though the combined gain from both sources is less than is obtained from pentodes.

In a typical receiver employing triodes in the r-f section, such as the Majestic 90 shown in Fig. 4-17(b), the measured gain of each r-f stage was found to be 10. The gain from point 1, the control grid, to point 2, the plate of the r-f triode, was only 2, while from point 2 to point 3 the measured gain was found to be 5. Since the stage gain is the product of the transformer gain and the tube gain, the total gain for the single stage at one frequency is 10. In modern pentode r-f amplifiers, there is usually no gain in the r-f transformer but the gain due to the tube ranges from 10 to 40. A complete table of gain-per-stage values is shown in Chapter 9.

Fig. 4-17(c) shows the form of coupling used in an r-f stage of the Midwest Model 9-31 receiver. As shown, the plate load for the r-f tube is an r-f choke and the coupling to the grid of the following tube is effected by means of the coupling condenser *C*. There is no signal amplification in this form of coupling, the signal level at the plate of the r-f tube point 1, being the same as

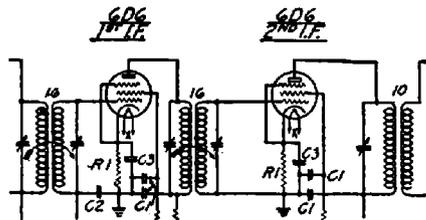
that at the control grid of the following tube, point 2. The signal gain is obtained entirely by the r-f tube and its plate load.

I-F Systems

We have already discussed the characteristics of coupled circuits used in i-f systems and the effect of various degrees of coupling upon the performance of the coupling unit. From the signal-tracing standpoint, we are also interested in the gain or loss which results from the use of various types of i-f coupling methods. In practically all commercial radio receivers, transformers are used for coupling in i-f stages. Also, we find that the primary and secondary windings are tuned to the intermediate frequency. This means that both windings normally present a high impedance to the signal frequency and consequently, as pointed out in the discussion of r-f transformers, we can expect little or no gain in the i-f transformer itself. A decrease in stage gain will result from any factors which lower the impedance of primary and secondary circuits of such transformers. Such a condition may result not only from misalignment, since the impedance is greatest at resonance, but also may occur due to moisture absorption, decrease in coupling due to shifting of the position of one coil with respect to the other, as well as from troubles arising in other components of the i-f stage.

A direct application of the principles previously discussed is found in the Zenith Stratosphere. That part of the receiver which concerns us is shown schematically in Fig. 4-18. As indi-

FIG. 4-18. The selectivity of the i-f amplifier is controlled by varying the coupling between the primary and secondary windings in the first two i-f transformers.



Courtesy Zenith Radio Corp.

cated by the conventional arrow, the coupling in the first and second i-f transformers is continuously variable. This receiver is representative of that type which uses a mechanical variation

of the coupling in a two-winding transformer to accomplish a continuous variation of the selectivity. It is interesting to note that only the first two i-f transformers are so controlled, the response of the third i-f transformer being sufficiently broad so that the sidebands are not appreciably attenuated.

The Wells-Gardner Model ODM is typical of the class of receivers which uses a switching arrangement to obtain various degrees of coupling in the i-f amplifier. Referring to the partial schematic shown in Fig. 4-19, you can see that a third winding

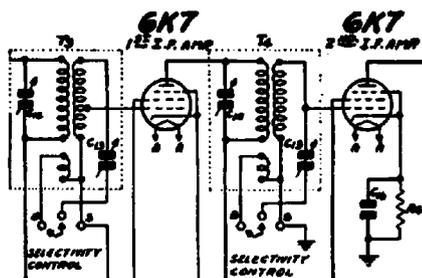


FIG. 4-19. A variable selectivity circuit employing an auxiliary winding to control the coupling.

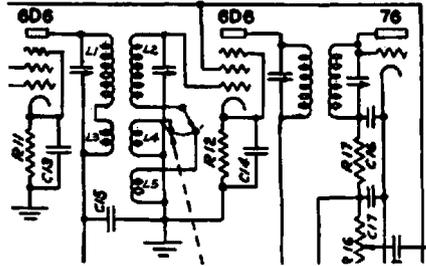
Courtesy Wells-Gardner & Co.

is included in the first and second i-f transformers. The primary and secondary are loosely coupled, while the auxiliary winding is closely coupled to the primary winding. The required close degree of coupling is obtained by winding the third coil underneath the primary. By means of the selectivity control switch, this third winding can be put into or out of the circuits. Two values of coupling are provided. With the switch in the "broad" position, the third winding is part of the secondary tuned circuit and the effect is to produce a large value of coupling between primary and secondary. With the switch in the "sharp" position, the third winding is out of the circuit and the resultant coupling is loose. The result is a sharp selectivity characteristic. The coupling in the second i-f transformer is controlled in the same way and the two selectivity control switches are ganged to form the overall selectivity control. A general idea of what represents a "sharp" selectivity characteristic is shown in Fig. 4-4 (d) and Fig. 4-4 (f) illustrates in a general way, a "broad" characteristic.

A slightly different variation of the same principle is used in the Fairbanks-Morse 100. Reference to Fig. 4-20 shows that the

secondary is composed of three sections— L_2 , L_4 , and L_5 . The primary is composed of L_1 and L_3 L_1 and L_2 are loosely coupled to each other and constitute the major portion of the primary and secondary inductances respectively. L_3 and L_4 are tightly coupled, while the coupling between L_5 and the primary is loose. With the switch in the broad position, L_5 is out of the circuit and the secondary winding consists of L_2 and L_4 . Since L_4 is closely coupled to L_3 , the coupling between the secondary

FIG. 4-20. A variable selectivity circuit employing a transformer with two auxiliary windings. Coupling is controlled by switching either L_4 or L_5 into the circuit.

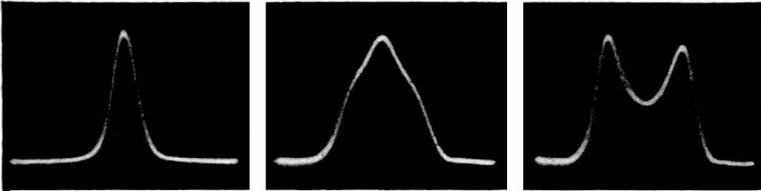


Courtesy of Fairbanks-Morse Home Appliances, Inc.

and primary windings is sufficiently great so that a broad response is obtained. With the switch in the "sharp" position, the closely coupled L_4 is replaced by L_5 , which has the same inductance but is loosely coupled. Thus, in this position the overall coupling between primary and secondary is low and hence the frequency response is sharp. The alignment is not disturbed when changing from the sharp to the broad selectivity position.

Up to the present point we have limited our discussion to i-f transformers wherein selectivity is a function of the coupling between two tuned circuits. A variable-selectivity type of three-winding transformer in common use is shown in Fig. 4-21; this is a partial schematic of the Stromberg-Carlson Model 70. Note that the first and second i-f transformers consist of three tuned circuits. Transformers of this type operate in the following manner: The primary and secondary windings are loosely coupled, while the third or tertiary winding is closely coupled to the secondary winding. When the resistance in series with the tertiary winding is greatest, the tertiary tuned circuit draws practically no current and consequently there is practically no reaction between it and the other windings. Thus the transformer operates

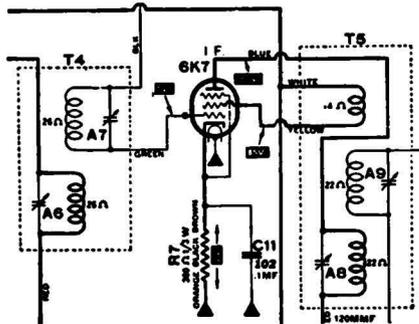
an intermediate value of resistance in the tertiary circuits. Note how the selectivity is broadened as against the sharp response of Fig. 4-22(a). With no resistance in the tertiary circuits, the absorption of energy at the peak frequency results in the familiar dip and greatly increased band-width, as is shown in Fig. 4-22(c). An intermediate setting between Figs. 4-22(b) and 4-22(c) results in a flat top.



FIGS. 4-22(a), 4-22(b), 4-22(c), left to right. The overall response of a three-winding transformer is shown for three different values of resistance in series with the tertiary circuit. Note the broadened response obtained as the resistance is decreased.

While on the subject of three-winding transformers, the function of the transformer used in the Atwater Kent Model 856, Fig. 4-23, is not to provide a control over the selectivity, but to make

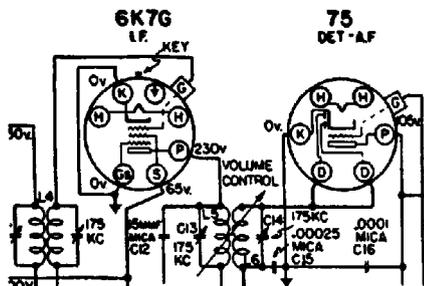
FIG. 4-23. The third winding feeds back a portion of the voltage from the plate to the screen circuit in the correct phase to prevent oscillation.



Courtesy Atwater Kent Mfg. Co.

possible increased gain in the i-f stage by stabilizing the amplifier. This, as can be seen from the schematic, is accomplished by using the third winding to feed back a portion of the voltage from the plate to the screen circuit in the correct phase to prevent any tendency toward oscillation.

In the oscillograms shown in Fig. 4-4, we showed how the gain as well as the selectivity was dependent upon the degree of coupling. A practical example of such gain control is shown in Fig. 4-24. The volume control in this receiver is effected by varying



Courtesy Sears Roebuck & Co.

FIG. 4-24. The volume is controlled by varying the coupling between the primary and secondary windings.

mechanically the coupling between the primary and secondary of the last i-f transformer. It should be noted that there is no appreciable change in selectivity with this arrangement, since the coupling is at all times sufficiently loose so that there is negligible reaction between primary and secondary. This arrangement is used in several receivers made by Sears-Roebuck.

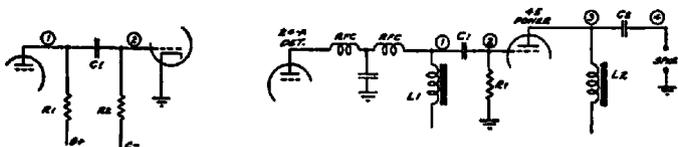
AUDIO-FREQUENCY COUPLING CIRCUITS

Types of coupling circuits used in a-f amplifiers may be divided into the following classes: (1) Resistance coupling; (2) Transformer coupling; (3) Choke coupling; (4) Direct coupling. Practically every commercial radio receiver employs one or more of these types of coupling in the a-f amplifier section of the receiver, resistance and transformer coupling being used almost exclusively in all modern receivers. Choke coupling was rather widely used in earlier receivers, before the introduction of the tetrode and pentode, because the triodes then available required high plate current for efficient operation and this could not be obtained without using excessively high power-supply voltages to make up for the voltage drop which would necessarily occur when high resistance was placed in the plate circuit. The high plate resistance and low plate current of pentodes, tetrodes and high-mu triodes enable the use of high-resistance plate loads with

satisfactory operation at normal power-supply voltages. Furthermore, the latter types of tubes are capable of providing far more signal amplification than is possible with earlier triodes.

In power output stages, transformer coupling is essential for efficient operation in modern receivers because this is the most satisfactory method of coupling the relatively high-impedance power tube plate circuit to the very low-impedance voice coil of the modern dynamic speaker.

In Fig. 4-25, a partial schematic of a typical resistance-capacity coupled amplifier stage is shown. The amplified audio signal voltage is developed across R_1 and is measured at point 1, the amplifier tube plate. The coupling condenser, C_1 , serves to trans-



FIGS. 4-25 (left), 4-26 (right). Two circuits for coupling the signal from plate to grid. The circuits are described in the text.

fer the a-f signal to the grid of the following tube and, at the same time, prevents the high d-c voltage present at the plate from being impressed on the control grid of the following tube. Except at very low audio frequencies, the reactance of the coupling condenser is sufficiently low so that the signal voltage appearing at point 2 is substantially the same as that at point 1.

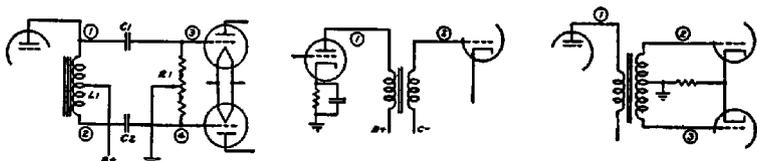
Choke Coupling

In Fig. 26, the a-f system of the Radiola 44 is shown. The plate load of the type 24-A detector is a high-impedance a-f choke L_1 , the inductance of which is approximately 300 henries. A choke of such high impedance is necessary because the type 24-A tube has a high plate resistance and the plate load must always be much higher in impedance than the plate resistance of the tube with which it is used, if distortion is to be kept low.

In the output circuit, the plate load is actually the magnetic speaker, with which this set was designed to be used. The choke L_2 , acts merely as a path for the plate current of the type 45

tube. This is done because the high d-c plate current required by this tube might affect the operation of the speaker. The impedance of the $L2$ is high with respect to that of the speaker so that very little power is lost in the choke.

The signal level at point 2 will be substantially the same as that at point 1, since the impedance of the coupling condenser $C1$ is very low with respect to $R1$, over most of the a-f range. In the output circuit, when a speaker is connected, the signal voltage at low audio frequencies will be somewhat lower at point 4 than at point 3. If $C2$ is open, there will be no signal at point 4 though the signal will be normal at point 3. If $C2$ is shorted, connecting the speaker will short-circuit the plate voltage. With the speaker disconnected, the signal level will be the same at points 3 and 4, but of course the d-c plate voltage will be present at point 4 as well as point 3.



Figs. 4-27, 4-28, 4-29, left to right. Three methods for obtaining interstage coupling. The operation and signal distribution are described in the text.

Push-pull operation is sometimes obtained by means of a tapped choke, as shown in Fig. 4-27, which represents the a-f system employed in the Stromberg 29 receiver. The plate voltage is fed to the a-f tube by means of a center-tapped choke $L1$. The a-f voltage is developed across the entire choke, so the signal voltage at point 1 is normally the same as that at point 2, but these signal voltages are opposite in phase. The signal voltages at points 3 and 4 should likewise be equal.

Interstage Transformer Coupling

In the partial schematic diagram Fig. 4-28, the a-f transformer is used to couple the relatively low-impedance plate circuit of the amplifying triode to the high-impedance grid circuit of the following tube. In Class A amplifiers, a signal voltage step-up

from point 1 to point 2 of two or three-to-one is normal; therefore the signal level will be appreciably higher at point 2 than at point 1.

In push-pull input stages, such as that shown in Fig. 4-29, only one-half the total signal voltage across the a-f transformer secondary is applied to each grid. Consequently, the signal voltages at points 2 and 3 will normally be very little higher than at point 1.

In Class B input stages, a step-down ratio is required from the primary to the secondary winding so the signal voltage will normally be less at points 2 and 3 than at point 1. The signal distribution in Class A, driver, and Class B stages is discussed in Chapter 2 in the section on power amplifiers.

DIRECT COUPLING

As the name implies, a direct-coupled amplifier is one in which each stage is directly coupled to the preceding one, so that coupling condensers and transformers are eliminated. In practice, the grid of each stage is connected directly to the plate of the preceding tube. Because this places the grid at the same positive voltage as the plate, direct-coupled amplifiers employ various methods for providing each tube with the proper bias voltage.

The primary purpose of direct-coupled amplifiers is to enable the amplification of d-c voltage and signals of very low frequencies. This is not possible with the conventional amplifier which employs either coupling condensers or transformers, for at very low frequencies the coupling condenser blocks the passage of the signal. In a similar way, the action of the transformer depends upon the production by the signal of a rapidly varying flux. At low frequencies this rapid variation does not exist and hence the signal is not transferred efficiently from the plate to the grid of the succeeding stage.

In a direct-coupled amplifier, a direct link or coupling is used and this provides the same voltage amplification of the signal regardless of the frequency. In fact, the amplifier functions just as efficiently for the amplification of direct currents and voltages as it does for alternating voltages. The gain of a direct-coupled amplifier is independent of frequency from the lowest value up to

fairly high frequencies. The upper-frequency limit, as in the case of a resistance-capacitance coupled amplifier, is reached when the shunting effect of the tube capacitances becomes sufficiently great so that the signal is by-passed around the load resistances.

A simple direct-coupled amplifier circuit employing two stages is shown in Fig. 4-30. Note that the customary blocking condenser or coupling transformer is not used and instead the plate

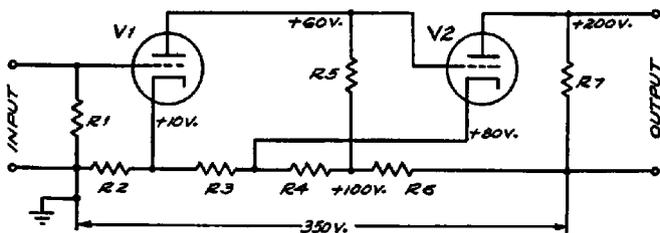


FIG. 4-30. A two-stage direct-coupled amplifier. The voltage distribution is indicated on the figure.

of $V1$ is connected directly to the grid of $V2$. The necessity for a special biasing arrangement can now be seen. In the circuit shown, the voltage at the plate of $V1$ with no signal applied is equal to 60 volts. To obtain the correct bias voltage for $V2$, the cathode of $V2$ is returned to a point on the voltage divider which is 80 volts positive with respect to ground. As a result of this connection, the bias on the second tube—which is equal to the difference between the voltage at the grid and that at the cathode—is equal to -20 volts. The voltage supply to the plate of $V1$ is equal to 100 volts $- 10$ volts, or 90 volts. In the same way the plate voltage supply for the second tube is equal to 350 volts $- 80$ volts, or 270 volts.

To examine the method of signal amplification and transfer in a direct-coupled amplifier, let us assume that a positive voltage (or pulse) is applied to the input grid of $V1$. As a result of this positive voltage (or pulse), the plate current of $V1$ increases so that the voltage drop across $R5$ also increases. Since the voltage of points along the voltage divider remains essentially constant, it follows that the voltage at the plate of $V1$ decreases and the voltage at the grid of $V2$ become more negative. This negative voltage at

the grid of V_2 causes the plate current of V_2 to decrease. As a result, the voltage drop across R_7 also decreases, so that the voltage at the plate of V_2 increases above its normal value of +200 volts. In this way the original positive pulse of voltage applied to the input produces an amplified positive pulse of voltage across the output of the amplifier. Similarly, if a negative pulse of voltage were applied to the input of the amplifier, this same negative pulse would appear at the output but would of course be greatly amplified.

Insofar as the transfer of the signal is concerned, it is clear that the action which takes place is similar to that occurring in a conventional amplifier which employs coupling condensers. For this reason everything that has been said in connection with these amplifiers is applicable here so that a detailed discussion of signal tracing is not required.

Voltage Measurements

The importance of proper voltage measurements in a direct-coupled amplifier cannot be over-emphasized. To avoid errors it is of the utmost importance that a high-resistance voltmeter be used, preferably one in which the resistance of the voltmeter is always at least twenty times as high in resistance as the resistance of that portion of the circuit being measured. If measurements are made with a voltmeter of low or even medium resistance, the operating conditions in the amplifier will be disturbed so greatly as to destroy the value of the measurements. Suppose, for instance, that the voltage at the plate of V_1 is being measured with a low-resistance voltmeter. This will change the voltage at the grid of V_2 because of the loading effect of the voltmeter and the direct coupling to the grid. In turn, the plate current of V_2 will be changed and this will cause a change in the current flowing through R_2 and R_3 . As a result, the normal division of voltages along the divider is completely changed. It should be noted that a somewhat similar effect occurs when a low-resistance voltmeter is used in a conventional amplifier. However, in the case of a direct-coupled amplifier, the error introduced by the voltmeter is amplified and reflected back so that the error is considerably greater than just the direct error produced by the voltmeter.

Chapter V

SIGNAL TRACING IN OSCILLATOR CIRCUITS

TESTING superheterodyne oscillator circuits by the signal-tracing procedure provides definite and complete information regarding the functioning of such systems. Through signal tracing, obscure faults in oscillator circuits can now be located in a small fraction of the time required when other methods are used.

Signal tracing in oscillator circuits differs from that in other parts of the receiver in that the signal to be checked is generated by the set oscillator and not supplied by an external signal generator. In some sets, the heterodyning oscillator signal is developed by a separate tube and circuit which is coupled to the mixer circuit; in other sets, the functions of the mixer and oscillator are combined within a single tube. No matter which system is used, the purpose of the oscillator is to provide a signal of the proper frequency to combine with the incoming r-f signal in order to enable the mixer to produce the intermediate frequency at which the i-f amplifier is designed to operate.

This is illustrated in the block diagram, Fig. 5-1. In this diagram the r-f signal in the antenna circuit has a frequency of 1000 kc. The intermediate-frequency amplifier is designed for a 450-kc signal. We can produce an i-f signal of this frequency by tuning the oscillator to 1450 kc. Then, when both the 1000-kc r-f signal and the 1450-kc oscillator output are fed to the mixer, a signal representing the difference between 1450 and 1000, 450 kc, is developed in the mixer. Other combinations are possible and the 450-kc signal likewise would result if the oscillator were tuned to a frequency of 550 kc, which is 450 kc lower than the r-f signal; this is true since the difference between 1000 and 550

would also be 450. In actual practice, though, you will find that most receiver oscillator circuits are designed to operate at a frequency which is higher than that of the incoming r-f signal.

Any amplifier tube may be used as a superheterodyne oscillator and we find in commercial practice that triodes, tetrodes, and

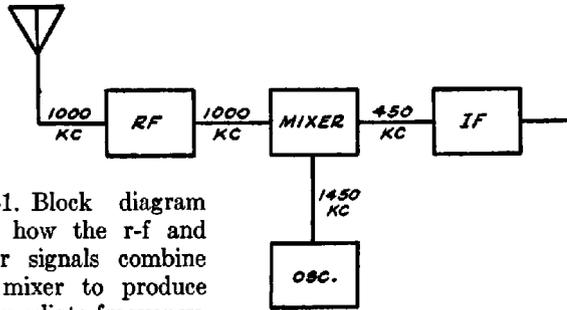


FIG. 5-1. Block diagram showing how the r-f and oscillator signals combine in the mixer to produce the intermediate frequency.

pentodes are employed. When the oscillator is combined with the mixer, a pentagrid converter tube is generally used though this same action can likewise be performed, but less efficiently, by any of the simpler amplifier tubes.

Fundamental Oscillator Circuits

A wide variety of oscillator circuits is to be found in broadcast receivers, but actually these are simply minor variations of a few fundamental circuits which are shown in Fig. 5-2. Of these cir-

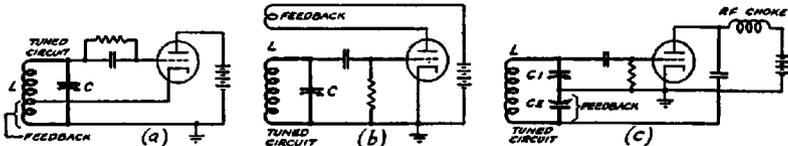


FIG. 5-2. Three basic oscillator circuits. In each case, the feedback winding is indicated and the tuned circuit which determines the frequency of oscillation is shown in heavy outline.

cuits, most sets use either the Hartley shown in Fig. 5-2(a) or the tickler-feedback circuit of Fig. 5-2(b). In the Hartley circuit, the signal voltage developed between cathode and ground

(which is equivalent to the signal voltage between plate and cathode since the plate is by-passed to ground) is coupled back into the grid circuit to produce oscillation. The number of turns above ground at the point to which the cathode is connected determines the amount of feedback in the circuit and consequently governs the oscillator voltage developed. This tap likewise is chosen to produce relatively uniform oscillation over the tuning range of the oscillator. It is important to remember the influence of the tap position with regard to oscillator performance. Sometimes the wire becomes loose on the coil form so that the amount of feedback is less than it should be. Then the oscillator performance will be affected, causing "dead spots," wide variation in oscillator voltage over the tuning range, poor tracking and misalignment. These faults may occur in all the circuits shown and are readily revealed in the signal-tracing process.

One of the most widely used circuits is that shown in Fig. 5-2(b). This is the familiar tickler-feedback circuit, in which a coil in the plate circuit is coupled inductively to the grid coil in proper phase relationship to produce oscillation. The number of turns in this plate coil and the degree of coupling to the tuned circuit determines the amount of feedback. The Colpitts circuit shown in Fig. 5-2(c) is seldom used in receivers, though frequently in transmitters. Feedback is obtained by coupling the plate to $C2$ and the amount of feedback is determined by the ratio of the capacities of $C1$ and $C2$. The r-f choke prevents the plate-supply from shorting out the signal across $C2$.

The proper oscillator signal voltage required depends on the type of mixer used and the method of coupling to the mixer circuit. If a pentode mixer is employed, the peak oscillator signal voltage applied to the pentode grid should not be greater than 9 volts when the d-c bias of the pentode mixer is -10 volts. For any other bias, the peak oscillator signal voltage should be one volt less than the pentode grid bias. In pentagrid mixers, such as the 6L7, the peak oscillator signal voltage should not be less than 12 to 18 volts, depending upon the operating voltages of the 6L7. Any normally obtained value in excess of this minimum voltage is satisfactory.

It is seldom necessary to measure the oscillator peak voltage directly since d-c voltage measurements will give us all the in-

formation we need. Let us consider the oscillator and mixer circuit of the Colonial 47, 48, shown in Fig. 5-3. As a result of oscillation, grid current flows through the resistor $R1$ causing a negative voltage at point 2 with respect to the cathode. This is a pulsating d-c voltage which is caused by rectification of the oscillator signal voltage in the grid circuit of the oscillator tube. We should expect this voltage to be of the order -10 to -30 volts.

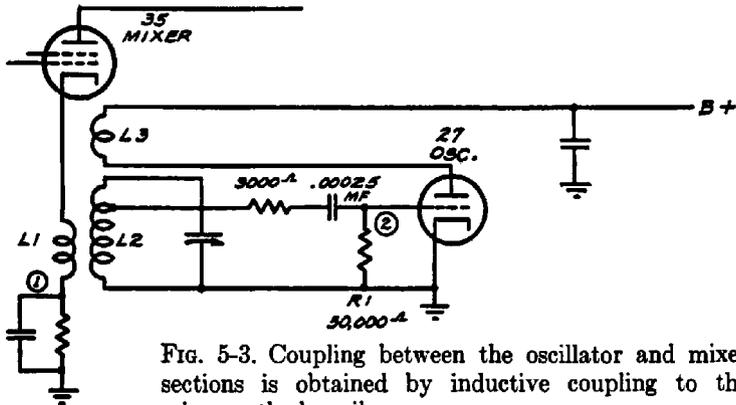


FIG. 5-3. Coupling between the oscillator and mixer sections is obtained by inductive coupling to the mixer cathode coil.

It is unlikely in any event that the voltage will become too high, since the oscillator circuit is ordinarily so designed that the maximum signal voltage can be developed only when all components of the circuit, including the tube, are new and functioning properly. Any effects which cause trouble in this circuit normally tend to lower the signal voltage, rather than raise it. The oscillator voltage is coupled into the cathode circuit of the type 35 mixer in this receiver by means of the inductive coupling between coils $L1$ and $L2$, the former being in series with the cathode bias resistor for the mixer tube.

Measurements of the d-c voltage across the oscillator grid leak preferably should be made with a very high-resistance voltmeter and a special probe which prevents detuning and loading of the circuit. This probe is described in the chapter on signal-tracing instruments. It is also possible to make such measurements by opening the oscillator grid leak connection at the low side and inserting a milliammeter (full scale about 1 ma) in series with

the grid leak. If the grid leak resistance is 50,000 ohms, the current through the resistance should not be less than 100 nor more than 500 microamperes. The uniformity of oscillation over the operating range is tested by simply rotating the receiver gang condenser over its range and, with the test instrument connected, noting the variation in the d-c voltage as the oscillator is tuned. If the tube stops oscillating at any point, the voltage will drop to zero or become positive with respect to the cathode.

Frequency stability is checked by means of a tuned vacuum-tube voltmeter which is calibrated in frequency over the operating range of the oscillator to be tested. The check is made by connecting the test probe to some portion of the oscillator circuit where the signal voltage is indicated. The vacuum-tube voltmeter is then tuned until its indicator gives a maximum reading. If the oscillator frequency should change, the tuned vacuum-tube voltmeter will no longer show a maximum indication, but may be returned to a maximum by adjusting it to the frequency to which the oscillator has drifted. The amount of frequency change which takes place may be determined by comparing the initial frequency setting with that to which the voltmeter must be tuned to restore the original indication. Thus, if the oscillator signal frequency were originally 1500 kc and the frequency to which it had drifted were 1600 kc, the amount of oscillator drift is 1600-1500 or 100 kc.

Proper tracking may be checked by signal tracing, not only at the aligning and padding frequencies, but also at any other frequency over the tuning range. By measuring the operating frequency of the oscillator at any setting of the tuning condenser, you can find out if it is tuned to produce the required intermediate frequency for the incoming r-f signal to which the receiver is tuned.

A tuned vacuum-tube voltmeter is used in making these tests. This instrument is similar to that employed in making tests by signal tracing in other portions of a superheterodyne receiver ahead of the second detector; it is described in the chapter on signal-tracing instruments to which we refer you. Its probe is placed sufficiently close to the oscillating circuit to provide enough oscillator signal pickup to give an indication on the test instrument. The signal frequency is then determined by noting the

frequency on the dial of the instrument at which a maximum indication is secured.

A Typical Oscillator Test

Let us take an oscillator circuit and check it by this method. The circuit of Fig. 5-4 is used in the RCA model C9-4 receiver and will serve as an example for practical application of this test

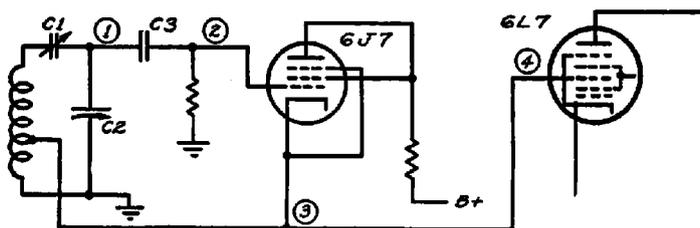


Fig. 5-4. Oscillator circuit used in the RCA Model C9-4.

system. We shall assume that the receiver is inoperative, yet signal tracing of the r-f signal has shown that the r-f signal is present in the mixer circuit. Our first test is to discover if the oscillator is functioning. This is done by using the *isolating* test probe to connect our voltmeter from point 2 (the oscillator control grid) to ground and noting if a negative voltage is present. If so, the tube is oscillating and further tests will be required. If the voltage at point 2 is zero or positive, then the trouble is immediately localized in the oscillator circuit and tests of individual components will determine the exact cause.

If we find that the oscillator circuit is functioning, then we should check the frequency with the tuned vacuum-tube voltmeter. This is done by placing the test probe adjacent to some point in the oscillating circuit where a strong signal is normally present. This point may be the stator of the oscillator tuning condenser (point 1) or the control grid of the oscillator tube (point 2). The signal voltage will cause the test instrument to give a maximum indication when we tune it to the frequency at which the oscillator is operating. We know that this frequency should ordinarily represent the sum of the r-f signal frequency to

which the receiver is tuned and the intermediate frequency employed in the i-f amplifier. If the incoming signal is 600 kc and the i-f 465 kc, then the oscillator should be operating at 600 plus 465 or 1065 kc. If the measured frequency differs greatly from 1065 kc, then we have localized the trouble to some component which affects the tuning of this circuit.

The actual frequency which we measure gives us a good clue to the cause of the trouble. If the padder condenser, $C1$, is shorted, then the operating frequency of the oscillator will be much lower than 1065 kc when the receiver is tuned to 600 kc. In fact, we find the oscillator frequency to be only slightly higher than 600 kc, since a short in $C1$ places all of the capacity of $C2$ across the oscillator tuning coil. A short in the oscillator tuning coil, or loosening of its turns decreases the inductance of the tuning coil and thereby raises the oscillator frequency to a value higher than 1065 kc. An open circuit in $C2$, which might result from a broken connection to a stator lug on this tuning condenser, would also increase the frequency at which the circuit oscillates, since then the only tuning capacitance would be the minimum capacitance of the circuit, i.e., the tube input capacitance, and stray capacitance in the wiring.

Minor changes in the measured operating frequency will be caused by misalignment, slight inaccuracies in the measuring apparatus and slight reaction of the test probe on the circuit under test.

Having checked the oscillator frequency, the next step is to see whether the oscillator signal reaches the mixer circuit. In Fig. 5-4, we note that the injector grid of the 6L7 mixer is directly connected to the oscillator cathode. To make certain that the oscillator signal is being fed to the mixer, we may check first at point 3, noting the oscillator signal level at this point; it will be lower in voltage than at points 1 and 2 since it represents only a portion of the total voltage across the oscillator coil. Now we move our test probe to point 4, the mixer injector grid. Since points 3 and 4 are directly connected, the oscillator signal voltage at each point should be the same. If the circuit connecting these points is broken, then we shall find no oscillator signal at the mixer, other than some small indication caused by stray coupling, and our trouble is localized to a simple continuity test.

A short-circuit to ground at either point 3 or point 4 would likewise short out the feedback winding of the oscillator, stopping oscillation. This would be caught in the initial test for oscillator operation.

Other methods of coupling the oscillator to the mixer are also in general use. In Fig. 5-5, the oscillator signal is capacity-coupled through $C1$ to the mixer cathode. Signal tracing proceeds along

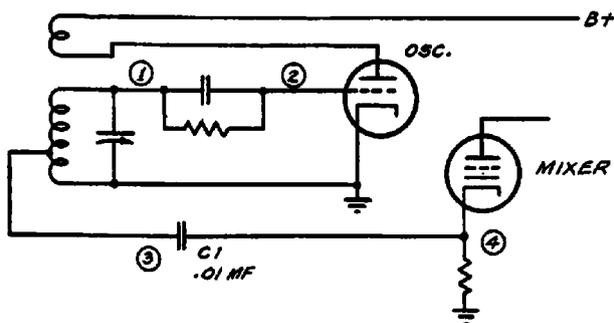


FIG. 5-5. The oscillator signal is coupled into the mixer circuit by means of the condenser $C1$.

the same lines as described above with the following difference that the coupling condenser $C1$ should be checked in case there is no signal transfer between points 3 and 4. A short circuit in $C1$ will shunt the mixer cathode resistor directly across the feedback tap on the oscillator coil. This may not stop oscillation but it will affect the operation of the mixer tube, since the cathode bias will then be shorted out.

In Fig. 5-6, the path of the oscillator signal is a trifle more involved. The signal voltage is taken from the plate, which is not directly a portion of the oscillating circuit. The plate is electronically coupled to the other elements of the tube, but it is possible for the circuit to oscillate normally and yet give very little signal voltage at the plate.

Checking of this circuit (and others utilizing this form of coupling) involves checking the signal at points 3 and 4 in addition to the tests described for simple triode oscillators. The signal volt-

age is normally lower at point 3 than at points 1 or 2, but if there is no signal at 3 then some component connecting to this circuit is at fault. If either $R2$ or $R1$ were shorted, such a defect would

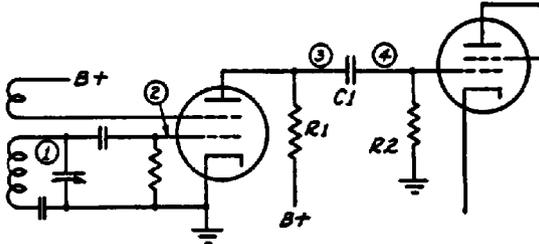


FIG. 5-6. An electron-coupled oscillator circuit.

result. Shorting of the coupling capacitor $C1$ would reduce both the signal voltage and the plate voltage at point 3. If the circuit is performing properly, the same signal voltage will be present at both points 3 and 4.

In Fig. 5-7, the oscillator tuning condenser $C1$ is arranged differently; therefore, the signal voltage will be a maximum at

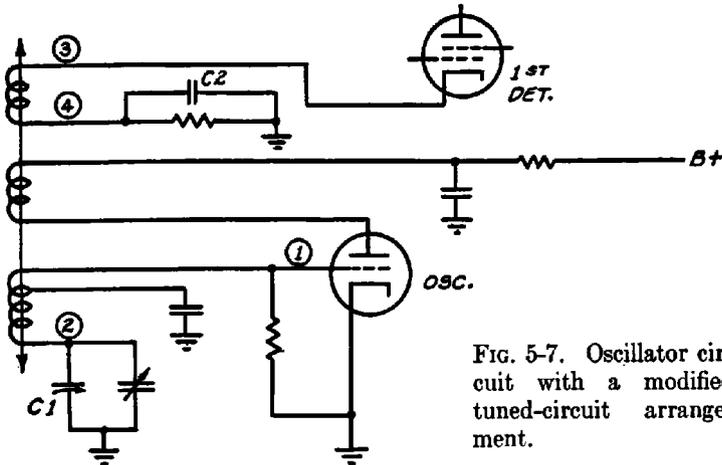


FIG. 5-7. Oscillator circuit with a modified tuned-circuit arrangement.

point 2 rather than at point 1. The oscillator signal is transferred to the mixer by inductive coupling between a coil connected in series with the mixer cathode, and the oscillator tuning coil. The

oscillator signal should be present at point 3, but not at point 4 since point 4 is by-passed to ground by $C2$.

Some receivers are designed so the desired intermediate frequency is secured when the second harmonic of the set oscillator beats with the incoming signal. When this is the case, it is so stated in the service notes for the receiver. Signal tracing, in the manner described above, can be carried out most conveniently at the fundamental frequency (one-half the second harmonic frequency) since the fundamental is always stronger. In most oscillator systems, though, precautions are taken to keep the harmonics weak in order to prevent them from beating with undesired r-f signals to produce interference or "birdies" on the desired signal.

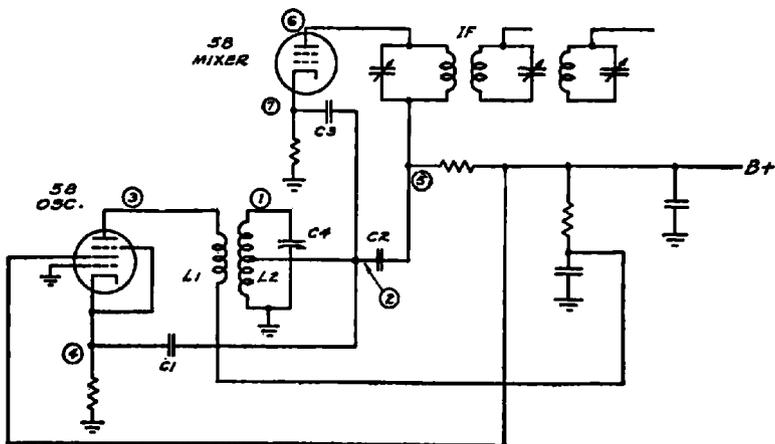


FIG. 5-8. Oscillation is secured by feeding a portion of the signal voltage in the plate circuit to the cathode of the oscillator tube.

This method of signal tracing is applicable to the most complicated oscillator systems, as well as the simpler ones. In the circuit shown in Fig. 5-8, for instance, oscillation is secured by feeding into the cathode circuit of the oscillator tube a portion of the signal voltage in the plate circuit. This is accomplished through inductive coupling between the plate coil, $L1$, and the oscillator tuning coil, $L2$. The close coupling between these coils

enables the oscillation frequency to be governed by the tuning of $L2$, even though the only other point of coupling is to the cathode through $C1$. This oscillator is coupled to the mixer at the mixer plate and cathode through $C2$ and $C3$. Since the control grid is at ground potential, there will be no voltage at this point but the circuit may be checked for oscillation by noting the change in cathode voltage when the tuning condenser, $C4$, is shorted. This may be done by connecting an electronic or other very high impedance voltmeter to point 4 and ground. If there is no voltage change when $C4$ is shorted, then the circuit is not oscillating.

The signal may be checked at point 1 and its frequency determined. Tracing the signal from point 2 to point 7 will show whether the coupling to the mixer cathode is effective. The signal voltage at both points should be the same. Likewise the signal voltage should be the same at points 2, 5 and 6, if the plate coupling circuit is in proper operating condition.

In the foregoing, we have outlined in detail the various steps in signal tracing in simple and complex circuits. The information gathered is sufficient to reveal any fault which may exist in oscillator circuits when the receiver is weak or inoperative.

Other oscillator troubles may be present in which additional information may be required regarding the characteristics of the oscillator signal. It is possible that the oscillator signal may not be a pure, unmodulated wave such as is required for perfect operation. If the filtration of the voltage supply for oscillator operation is inadequate, hum may appear on the oscillator signal. This hum will then modulate any r-f signal present in the mixer, though the hum may not appear in the speaker unless the r-f signal is tuned in. Where there is reason to suspect this condition, the hum level of the d-c voltage supplied to the oscillator should be checked. If this is abnormally high, additional filtering should be introduced and its effect on the output of the receiver noted. If the modulation of hum disappears, then it can be assumed that it was caused by insufficient filtering of the plate supply. In this connection, proper by-passing of the heater is important, especially at the higher frequencies.

It is possible that the oscillator signal may "flutter" due to "motor-boating" in the power supply, or to frequency modulation caused by vibration of some component of the oscillator

system such as a loose trimmer or padder screw, variable-condenser plates, microphonic tube, etc. If such a trouble is present, it will be indicated by a corresponding flutter of the indicator on the tuned vacuum-tube voltmeter when the oscillator signal is picked up. To localize the trouble, the power-supply system may be checked by signal tracing while the set oscillator is rendered inoperative (by removing the oscillator tube or short-circuiting the tuning coil). If the flutter is then indicated on the audio testing device, then the oscillator is not at fault.

If the receiver blocks when tuned to a strong local station or when too high a signal is fed into it from the test oscillator, a variation in power-supply voltage may cause fluctuation of the oscillator voltage and consequently of the oscillator frequency. Occasionally this trouble also results in "motor-boating." The method of test described above will show whether the trouble is tied in with the local oscillator or elsewhere.

Oscillator circuits also can be checked by substituting the test oscillator for the set oscillator and comparing the receiver performance before and after making this substitution. In this method, the test oscillator is tuned to the required oscillator frequency and its signal is fed into the mixer coupling circuit. Thus, if the receiver is inoperative and the oscillator is suspected, an antenna is connected to the receiver and the set is tuned to the proper frequency setting of a strong local station. The test oscillator is then adjusted to a frequency equal to that of the local station plus the i-f for which the receiver is designed. If the local station frequency is 600 kc and the set i-f is 465 kc, the test oscillator should be adjusted to 1065 kc. This 1065-kc signal is then fed into the mixer circuit. If the receiver were inoperative due to a fault in the oscillator circuit, operation should now be restored. This method is somewhat limited in scope since the maximum output of most service test oscillators is far below that required to duplicate the signal voltage of the set oscillator when it is functioning normally and, further, this method is not as convenient and rapid to apply as the procedure originally described.

Chapter VI

SIGNAL TRACING IN MIXER CIRCUITS

THE function of the mixer tube has been mentioned briefly in the discussion of signal tracing in local oscillator circuits of superheterodyne receivers. This tube serves to combine or mix the broadcast signal with the locally generated heterodyning signal. As a result of the mixing process, a frequency-changing action takes place whereby a new frequency is formed, representing the difference between the frequency produced by the local oscillator and that of the incoming broadcast signal.

The mixer tube is also identified by other names. Because of its frequency-changing action, it is sometimes called a *frequency changer*. Since it operates as a detector for the incoming broadcast signal, which is heterodyned by the set oscillator, it is occasionally referred to as a *heterodyne detector*. Other terms applied to it are *first detector*, *converter*, *translator*, *modulator* and even *demodulator*. Each of these terms refers to some phase of mixer operation.

Any tube which can serve as a rectifier or detector of radio-frequency signals can act as a mixer. In fact, even a crystal detector or other rectifying device could be used for the purpose. In actual practice, though, only tubes are used and the tube types are so chosen and operated that amplification is combined with mixing. As there is no known method of obtaining amplification when using diodes or other two-element rectifiers as mixers, and for other reasons, they are not used in broadcast receivers.

Earlier receivers employed triodes or tetrodes as mixers, while more recent sets use pentodes or pentagrid converters. Modern all-wave receivers, when a separate tube is used as the local oscil-

lator, usually employ a hexode such as the 6L7. No matter which type of tube is employed, the mixing action is essentially the same and while it is unnecessary to know precisely what takes place during the mixing process in order to apply signal tracing successfully to such circuits, some knowledge of the manner in which the mixer functions will be of value in analyzing mixer faults.

Mixer Action

When two signals which differ in frequency are fed simultaneously into a detector tube input circuit, both signals will appear in the output circuit. At some instants, these two signal voltages will be in phase and the resulting output signal voltages will add; at other instants they will be out of phase and therefore will oppose each other. This aiding and opposing effect results in beat frequencies which correspond to the sum and difference of the original frequencies introduced into the input circuit of the mixer. Since harmonics are also present, a number of beat frequencies normally are formed in the mixer output circuit. These are usually small in magnitude in comparison with beat frequencies formed from the fundamental frequencies. In most superheterodyne receivers, the beat frequency which is selected for amplification by the i-f amplifier is that which represents the difference in frequency between the two original fundamental frequencies. When the i-f transformer primary in the plate circuit of the mixer tube is tuned to resonance with this difference frequency, the signal voltage across this winding is greatest for this frequency and therefore harmonics and undesired beats are further minimized.

Tubes which are used as mixers usually operate as linear detectors, that is, the rectified output signal is directly proportional to the amplitude of the incoming broadcast signal. This means, if we tune to one broadcast signal and get a given output i-f voltage, another broadcast signal of twice the voltage at the mixer input will give twice the i-f voltage at the mixer output, when AVC action is absent. For minimum distortion when this type of detector is used as a mixer, the heterodyning oscillator signal voltage must be much higher than the broadcast signal voltage at the mixer input grid.

For triodes, tetrodes or pentodes, linear detection action for mixer operation is usually secured by using a high value of cathode bias. Accordingly, the grid is highly negative with respect to the cathode and the plate current is low, near cut-off. This method of operation permits a high oscillator voltage to be introduced in the input cathode or grid circuit without causing the control grid to draw current and thus load the input circuit as well as affect detector action. In more modern mixers, the local oscillator signal is fed to a grid which is electrostatically shielded from the input grid and therefore reaction of the oscillator signal on the mixer input circuit is usually negligible. Hence, for such tubes, a high cathode bias is unnecessary and is not used because it would result in reduced efficiency.

Gain in the Mixer

When a mixer tube is operating efficiently, the i-f signal voltage in the mixer output circuit is greater than the broadcast signal voltage in its input circuit. This gain resulting from the frequency-changing or conversion action in the mixer tube is called the *conversion* gain, or the *translation* gain. More precisely, this may be expressed as the ratio of the i-f voltage across the mixer output load to the r-f signal voltage applied to the mixer input grid. Conversion gain may be accurately measured with a tuned vacuum-tube voltmeter, of uniformly high sensitivity at both the radio and intermediate frequencies, by checking the i-f signal voltage at the mixer plate when an r-f signal is present in the input grid circuit. The r-f signal level is then measured and the ratio of the i-f signal voltage to that of the r-f signal voltage gives the conversion gain. This is greatest when the alignment is exact. It is not necessary to know the absolute value of the signal voltages present at each point to determine the gain, but it is necessary to be able to determine the relative intensity of each signal. For example, let us assume that the i-f signal at the mixer plate gives a reading of 100 on our measuring device while the r-f signal gives a reading of 10. The ratio is 100 to 10 or 10 to 1 and the conversion gain is therefore 10. It does not matter whether the readings are in microvolts or millivolts as long as the measuring device is properly calibrated and equally sensitive at each frequency, and the signal voltage applied is not so great as to overload the mixer.

It is also possible to measure the conversion gain with a signal generator which is equipped with an accurately calibrated attenuator. An i-f signal of the same frequency as that to which the i-f amplifier is tuned is fed to the input grid of the first i-f tube. A modulated signal is used so that an output meter may be connected at some point in the audio system and its reading noted for the signal passing through the i-f and audio systems.

The signal generator is then connected to the mixer input circuit and a modulated r-f signal is fed into the mixer. The receiver oscillator is tuned to the frequency required to mix with this r-f signal and produce a maximum response as indicated by the receiver output-meter reading. If conversion gain is being secured in the mixer, the output-meter reading should be greater than it was for the i-f signal test. Then the signal-generator attenuator should be readjusted until the receiver output meter reads the same as it did when the i-f signal was fed to the i-f tube. The conversion gain is the ratio between the two readings of the signal-generator attenuator. If the setting for the i-f signal is 50 and that for the r-f signal is 5, the ratio is 10.

This method of injecting a signal from grid to grid rather than from grid to plate does not take into account any gain or loss which may take place in the i-f transformer which couples the plate of the mixer tube to the grid of the first i-f tube. Usually there is a slight loss in the transformer so that the actual conversion gain will be a trifle higher than indicated by the above test. The reason that the signal generator is not connected directly to the plate of the mixer when making the i-f measurement is because to do so would load the i-f transformer primary excessively and would therefore give misleading results.

In typical modern broadcast receivers, the conversion gain ranges from about 30 to 60 when no AVC action is present. The AVC action reduces gain to a degree dependent upon its effectiveness in the receiver, but in any event there will usually be some conversion gain.

The Triode Mixer

Now let us consider a simple triode mixer circuit from the signal-tracing standpoint. In Fig. 6-1, let us assume that the schematic represents a portion of a typical receiver which is con-

needed to an antenna and is functioning normally. Assume that the set is tuned to an incoming broadcast signal on 600 kc. The set oscillator is feeding a 775-kc heterodyning signal into the mixer input circuit due to inductive coupling between the oscillator coil L_4 and the coupling coil L_3 which is in series with the mixer tuned circuit, L_2 and C_1 .

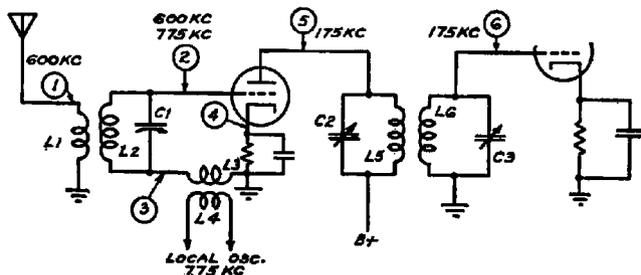


FIG. 6-1. A triode mixer circuit showing the distribution of signals at the various points in the circuit.

Before proceeding farther, let us examine this circuit with regard to the signals present in each portion of the circuit. At point 1, which corresponds to the antenna post on a typical receiver, we find two principal signals in which we are interested. One of these is the broadcast signal of 600 kc which is picked up by the antenna, another is the local oscillator signal of 775 kc which is being introduced into the grid circuit of the mixer by means of the inductive coupling between L_3 and L_4 . While the antenna coil is not directly coupled either to L_3 or L_4 , some of the 775-kc signal will appear in the antenna circuit due to the coupling between L_1 and L_2 . While L_2 is tuned to resonance with the incoming broadcast signal at 600 kc, the tuning is not sufficiently sharp to reduce its impedance to zero at the frequency of the 775-kc signal which is in series with it. Therefore there is a 775-kc signal voltage drop across L_2 , and because of its coupling to L_1 , this 775-kc signal appears in the antenna circuit and is radiated in the same manner as any broadcast carrier. Consequently, this type of coupling causes interference with the operation of other receivers and has been used but little.

The signal voltages in the mixer input circuits are shown at points 2 and 3 in the diagram. At point 2, the 600-kc signal and 775-kc signal will be found; likewise at point 3. However, the 600-kc signal will be much stronger at point 2 than at point 3 because $L2$ is tuned to resonance with this frequency and consequently offers a high impedance to it. Due to this high impedance, there is a large voltage drop across $L2$ and the 600-kc signal voltage is a maximum at point 2. On the other hand, the oscillator coupling coil $L3$ offers a low impedance both to the oscillator voltage and to that of the incoming signal. The 600-kc signal will therefore be much lower in voltage at point 3 than at point 2. The oscillator signal voltage will be greatest at point 3, and since the oscillator signal voltage is normally much higher than that of any broadcast signal at this point, it will be difficult to check the presence of the 600-kc signal at this point due to the blanketing effect of the strong oscillator signal. At point 2, though, both signals can be checked.

We have mentioned that several frequencies are present in the mixer plate circuit. In the circuit of Fig. 6-1, we find that the principal frequencies which are present at point 5, the mixer plate, are the 775-kc heterodyning oscillator signal, the 600-kc broadcast signal, and the 175-kc i-f signal, which represents the frequency difference between the 775-kc local oscillator signal and that of the 600-kc broadcast signal. We also find a weak 1375-kc signal, which represents the *sum* of the 775-kc and the 600-kc signals. Since the i-f amplifier is designed to operate at 175 kc, the i-f transformers are tuned to this frequency and therefore the primary circuit of the first i-f transformer, shown as $L5$ and $C2$, present a maximum impedance to this frequency. Thus the i-f signal voltage at 175-kc should be far higher than any of the other signal voltages present at this point. At point 6, the grid of the first i-f tube, undesired frequencies will be further filtered out so that little but the 175-kc i-f signal will be applied to the grid of the first i-f amplifier tube.

In Fig. 6-2, the mixer action and circuit are similar to that shown in Fig. 6-1, but the heterodyning oscillator voltage is in series with the cathode and ground rather than with the grid and ground. This is a more commonly used type of oscillator frequency coupling when the older types of tubes are used as mixers.

In this circuit, the mixer grid voltage with respect to ground varies only at the incoming broadcast signal frequency and not at oscillator frequency as was the case shown in the circuit, Fig. 6-1. Accordingly, there will be no 1065-kc signal present at point 2, except that introduced by coupling within the tube and stray coupling in the circuit. Both these effects may combine to produce a slight 1065-kc signal at this point, but it will be negligible in comparison with that which will be found at the corresponding point in the circuit of Fig. 6-1. At point 3, the mixer cathode, the oscillator signal will predominate to a greater degree over the r-f signal for the same reason. We find then, in this circuit, that the

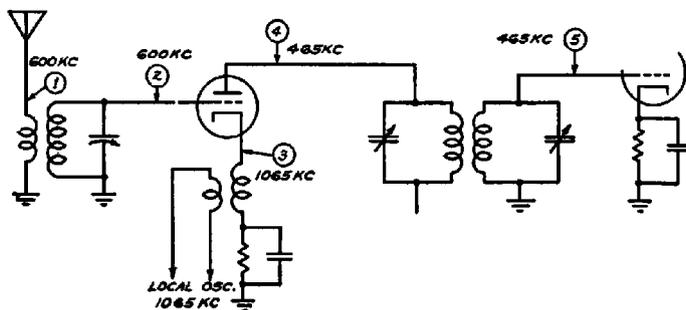


Fig. 6-2. A triode mixer circuit in which the oscillator signal is fed into the cathode circuit.

cathode potential is varied at the heterodyning oscillator frequency while the grid potential is varied at the broadcast signal frequency, both with respect to ground. However, the operation of any amplifier tube is based on the variation of the grid potential with respect to cathode and not to ground. With this in mind, we can see that the grid voltage is varied at both frequencies and consequently the plate voltage is varied in the same manner. Since the tube is biased as a plate detector, rectification occurs and the intermediate frequency is formed.

In Fig. 6-2, the radiation of the oscillator signal into the antenna system will be reduced for the reasons given in the preceding paragraph, and also because the wider difference between the

frequency of the oscillator and that of the tuned input circuit will tend to reduce the small oscillator voltage which appears across the tuned input circuits. In the plate circuit, the original frequencies as well as the sum and difference components will be found, but again the undesired frequencies will be much lower in voltage than the desired 465-kc signal when the i-f transformer is tuned to that frequency.

The Tetrode Mixer

In Fig. 6-3, another method of coupling the oscillator signal to the mixer is shown. This is used in the Franklin Model 94 receiver. As shown, the screen grid of the mixer is directly coupled

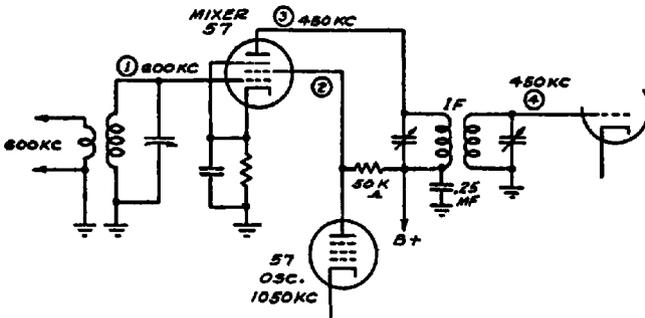


FIG. 6-3. A pentode is used in the mixer stage and the oscillator signal is fed into the mixer circuit by connecting the screen to the plate of the oscillator tube.

to the plate of the local oscillator tube. The oscillator signal voltage developed across the 50,000-ohm load resistor in the oscillator plate circuit varies the screen potential at the oscillator frequency. That is, on the positive half of the oscillator signal wave, the screen voltage of the mixer is increased while on the negative half the the voltage decreases. This increase and decrease of voltage causes a corresponding increase and decrease of plate current, hence modulation of the plate current at the oscillator frequency results. This is one form of electronic coupling. Any other tube element whose potential affects electron flow could be used for the same purpose. At the mixer grid, point 1, we

distribution throughout this circuit is indicated on the schematic. At point 1, we find only the incoming broadcast signal, assumed to be 600 kc, which is being fed directly into the circuit. Any oscillator signal voltage which may appear will be due to stray pickup by the test probe and incidental coupling due to imperfect shielding of the oscillator coil itself. Such effects are negligible compared with those which occur in the older types of mixers which we have just described.

At point 2, the r-f signal grid, we shall find the maximum 600-kc signal with the 1065-kc heterodyning oscillator signal reduced to negligible proportions because of the shielding effect of the second and fourth grids which surround the oscillator signal grid at point 3. These extra grids, which are by-passed to ground by *C1*, prevent the formation of excessive oscillator voltage at point 2 and thus eliminate the need for high negative biasing of the control grid to remove the possibility of grid current. Operating the tube at its normal control-grid bias increases its conversion gain and consequently its efficiency as a mixer. The control grid bias in this receiver is furnished by a bias diode which forms a portion of the avc system.

The oscillator signal grid of the 6L7, at point 3, in Fig. 6-4, receives a negative bias due to its coupling to the 6J5 local oscillator control grid. As mentioned in the discussion of signal tracing in oscillator circuits, oscillation causes a negative, pulsating d-c voltage to appear across the oscillator grid leak. The direct connection through resistor *R1* applies a large portion of the negative biasing voltage in the oscillator circuit to the third grid of the 6L7. In mixing circuits in which electronic coupling is employed, the oscillator signal voltage should be sufficiently high to provide complete modulation of the plate current. In most commercial broadcast receivers, our concern is that this peak signal voltage be not less than 12 volts when the 6L7 voltage is 100 and not less than 18 volts when the 6L7 screen voltage is 150. If no vacuum-tube voltmeter, which measures peak r-f signal voltages, is at hand, the voltage may be determined to a degree sufficiently accurate for service purposes by measuring the d-c voltage at point 3. For a 20,000-ohm grid leak *R₂*, the rectification efficiency is of the order of 0.7, which means that a d-c reading at

this point of -8.4 volts will indicate an oscillator peak voltage of 12. For a 50,000-ohm grid leak, the rectification efficiency is somewhat higher, so the resulting d-c reading should also be somewhat greater than -8.4 . In any event, this voltage is normally considerably greater than the minimum value specified. When the maximum oscillator voltage is applied to the mixer, the voltmeter used for such measurements should have an input resistance of at least 10 megohms and some means should be incorporated in its design to make certain that no appreciable amount of oscillator signal voltage at point 3 is by-passed by the voltmeter leads when the instrument is connected to the circuit.

In Fig. 6-5, we have another example of electronic coupling using a 6L7 mixer. This diagram shows the oscillator and mixer

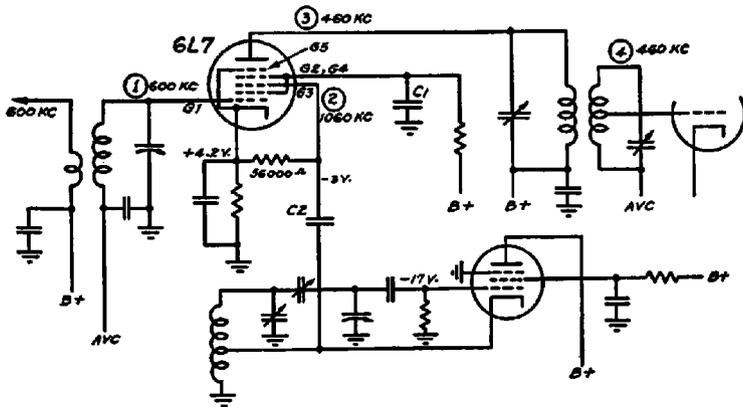


FIG. 6-5. The mixer circuit used in the RCA Model C15-3. The relative signal strengths is discussed in the text.

circuits of the RCA Model C15-3. This receiver was checked with a Rider Chanalyst to determine the relative strength of the various signals in the mixer circuit when the receiver was performing normally.

In making this test, a 600-kc signal was fed to the antenna and the receiver was tuned to resonance with it. The test probe was connected to *G1* (point 1) and the signal level was found to be 7.5 millivolts. The probe was then moved to *G3* (Point 2) and

the 600-kc signal was noted but it was necessary to increase the signal at $G1$ eight times to provide a 7.5-millivolt signal at $G3$. Therefore, the r-f signal appearing at $G3$ is only $\frac{1}{8}$ th that at $G1$. At the mixer plate (point 3), the 600-kc signal was found to 1.2 times the signal voltage at $G1$. . . a 20-percent gain. It is important for us to know this, since this measurement shows that the signal level at the mixer plate is sufficiently high, even though the circuit is tuned to 460 kc instead of 600 kc, so that aligning and padding operations in the r-f circuit may be carried on with the test probe at point 3. In this manner, any slight detuning effects, which might otherwise interfere with aligning operations, may be avoided.

Some of the 600-kc signal voltage also appears when the probe is connected to $G4$, which is already by-passed to ground. Normally this signal is very weak, about $\frac{1}{30}$ th of that at $G1$, and is due more to stray pickup by the probe rather than to the presence of a signal voltage at this point. If the shield grids, $G2$ and $G4$, are not by-passed, however, the signal level increases greatly. By actual measurement, when $C1$ is open-circuited, the 600-kc signal at $G2$ and $G4$ is 5 times that at $G1$. So by signal tracing, we can check condensers for proper functioning in this circuit.

In this receiver, only a portion of the oscillator voltage is fed to the third grid of the 6L7 since the coupling condenser $C2$ connects to a tap well down on the oscillator coil. This is frequently done in all-wave receivers when the range extends to ultra-high frequency bands and assures more uniform oscillator operation on such bands at a slight sacrifice of conversion gain in the mixer tube. The heterodyning oscillator signal is applied to $G3$ which returns to cathode through a 56,000-ohm resistor. If no oscillator voltage were present, $G3$ would have the same potential as the mixer cathode, which is plus 4.2 volts with respect to ground. When the oscillator signal is applied to $G3$, its intensity is sufficiently great to change this positive voltage to -3 volts. This pulsating d-c voltage results from rectification of the oscillator signal voltage by $G3$. Since the potential of $G3$ is thus changed from $+4.2$ volts to -3 volts, the total change is 7.2 volts so the actual d-c voltage of this grid with respect to cathode is -7.2 volts. The peak value of the oscillator voltage applied to this grid is approximately 6.3 volts. The measured conversion gain

under these conditions was found to be 20, which is somewhat less than could be obtained with a higher oscillator voltage, though still high. The advantages derived compensate for the slight drop in conversion gain resulting from the use of less than normal oscillator signal voltage.

The oscillator signal voltage at $G3$ is 600 times as great as the 600-kc signal in the mixer input circuit, thus fulfilling the requirements stated earlier in this chapter that the oscillator voltage should be large in comparison with the incoming signal. While this voltage remains constant as the incoming signal varies, AVC action in the receiver tends to keep the ratio of oscillator voltage to signal voltage high.

This 1060-kc oscillator signal also appears at the plate of the mixer, point 3 in Fig. 6-5, and its intensity at this point is 100 times as great as the 600-kc signal at this point. Therefore the oscillator frequency can be checked at this point, thus avoiding any detuning of the oscillator circuit through the effect of test leads on the oscillator.

The 460-kc signal, representing the frequency difference between the incoming r-f and local oscillator signals, is 20 times as great at the mixer plate as the 600-kc signal at the mixer input grid, $G1$. This ratio represents the conversion gain of the mixer, which is therefore 20. The 460-kc signal is also detectable at $G3$, but its voltage is less than $\frac{1}{10}$ th that of the 600-kc signal at $G1$. This is because the circuit at $G3$ has very low impedance to the 460-kc signal. The 460-kc signal was not detected at $G1$ or $G2$.

The 1660-kc signal, representing the sum of the 600-kc and the 1060-kc signals is present both at $G3$ and at the mixer plate. Its strength at $G3$ is $\frac{1}{25}$ th that of the incoming 600-kc signal at $G1$ and at the mixer plate it is $\frac{1}{7}$ th that of the 600-kc signal at $G1$. This 1660-kc signal is weak at the mixer plate because the i-f transformer is tuned to 460-kc and therefore is far off resonance for 1660-kc.

The foregoing tests apply, of course, only to this particular receiver and to the results secured at a single point in its tuning range, 600 kc. If a 1400-kc signal is applied to $G1$, this signal will be only $\frac{1}{6}$ th as strong at the mixer plate. But this will serve to give an idea of the relative magnitude of various signal frequencies so that conditions which are abnormal may be more readily recognized.

Mixer Circuit Troubles

Any fault which may occur in a mixer circuit will affect its output i-f signal. One of the most common troubles, for instance, is circuit misalignment. If the heterodyning oscillator signal is off frequency when the receiver r-f system is tuned to an incoming signal, then the i-f signal will be off frequency by the same amount. If the i-f transformer is also tuned off frequency to resonate with the incorrect intermediate frequency produced by the local oscillator, then the conversion gain at this frequency will be normal but the oscillator will not track properly. By checking all signal frequencies at the plate of the mixer, any circuit misalignment is promptly revealed and the faulty circuit is definitely identified.

In the circuit of Fig. 6-5, for instance, the required i-f is 460 kc. Our first step is to feed a signal of known frequency to the receiver, and with the probe of our test instrument connected to the mixer plate, to tune in this r-f signal until a maximum indication is secured when the test instrument is tuned to the same frequency. This test should be made with the avc system, if used in the receiver, rendered inoperative either by grounding the oscillator grid or removing the avc tube. If the pointer on the receiver dial does not indicate the proper frequency, or if readjusting the r-f trimmers produces a stronger signal, the r-f system is out of alignment.

If the r-f system is properly aligned, then the oscillator frequency may be checked in the same manner, without readjusting the gang tuning condenser. The oscillator frequency should be 460 kc higher in frequency than the incoming r-f signal. If not, then the i-f signal will be higher or lower in frequency by the same amount, and the oscillator frequency will have to be re-adjusted.

The i-f signal now may be checked. If it is found to be weak, then the adjustment of the i-f transformer primary trimmer may be checked by moving the test probe to point 4, or to any other point in the i-f system where the connection of the test probe will not affect the first i-f transformer primary tuning circuit, and adjusting this trimmer for maximum i-f signal output. A defective transformer primary will not align sharply.

If all mixer circuits are in proper alignment and there is little or no conversion gain, the tube may be checked independently in a tube checker, or by substituting another in the circuit. If necessary, this may be followed by voltage tests and resistance measurements until the exact component at fault is located.

Distortion in mixer circuits employing triodes, tetrodes, or pentodes may occur as a result of incorrect tube voltages, defective tubes or excessive oscillator signal voltage. Any of these conditions will decrease the conversion gain, thus localizing the trouble. Distortion may be directly examined by checking the signal with phones or an oscillograph connected to the output of the test instrument when the test probe is at the mixer plate.

SIGNAL TRACING IN CONVERTER CIRCUITS

When the functions of the oscillator and mixer are combined within a single tube, such a tube is now generally known as a converter. Occasionally this term is also applied to tubes which are ordinarily used as combination oscillator-mixers, such as the

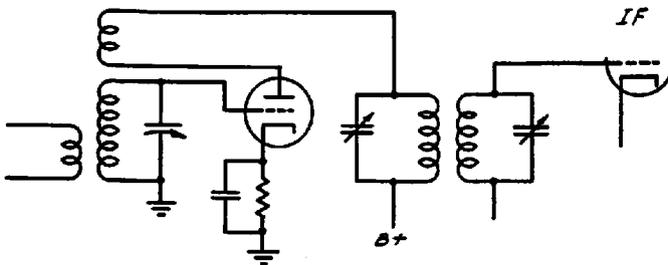


FIG. 6-6. An autodyne mixer circuit. The input circuit is tuned to the oscillator frequency so that it is somewhat detuned for the incoming signal.

6A7, when such tubes are employed as simple mixers. In the converter circuits we are going to discuss, we refer to those in which both operations are performed by the same tube. Any tube which can be made to oscillate can be used as a converter, though all modern receivers have discarded the simple triode for this purpose. In all converter circuits, the incoming signal modulates the oscillator-frequency current produced within the tube and thereby

forms the required intermediate frequency as described in the preceding chapter.

The simplest form of converter is called the autodyne mixer. A typical circuit of this type is shown in Fig. 6-6. The incoming broadcast signal is impressed upon a triode oscillator grid circuit, which is tuned to the oscillator frequency. The intermediate-frequency voltage is developed across the primary of the tuned i-f transformer in the plate circuit. Since the triode is tuned to the oscillator frequency, and only a single tuned mixer input circuit is used, it is detuned for the incoming broadcast signal. Therefore, the maximum signal voltage is not secured with this type of autodyne mixer and inefficient operation results. Variations of this autodyne circuit in which the oscillating circuit is tuned to one-half the desired oscillator frequency, so that the second harmonic produces the required beat, were used in later receivers and this eliminated one of the objections to the simple autodyne, in that the input circuit could be separately tuned to the broadcast signal. More modern circuits using tetrodes or pentodes, accomplish the same results without using the oscillator second harmonic.

A Tetrode Autodyne Converter

An example of a tetrode autodyne converter is shown in Fig. 6-7. Oscillation is maintained by feedback between L_2 and L_3 and the frequency of oscillation is controlled by tuning L_4 . C_2 acts as the oscillator tuning condenser, C_3 as the oscillator padder and C_4 as the oscillator trimmer. The converter input circuit is tuned to the incoming broadcast signal frequency by C_1 .

In tracing the signals in this circuit, we shall find the broadcast signal to be a maximum at point 1 when the converter input circuit L_1 , C_1 is tuned to resonance with it. Since the required intermediate frequency is 262 kc, the oscillator frequency should be 262 kc higher than that of the broadcast signal. Though the converter input circuit is grounded and detuned from the oscillator frequency by 262 kc, the magnitude of the oscillator signal voltage is so much greater than that of the broadcast signal that coupling within the tube and radiation from the oscillator tuning condenser and coil will produce an appreciable oscillator signal voltage on the converter input grid.

At the converter plate, point 2, a strong oscillator signal voltage will be present because in this circuit the plate forms a portion of the oscillating circuit. The oscillator signal will also be strong at points 3, 4 and 5 if testing at these points is required.

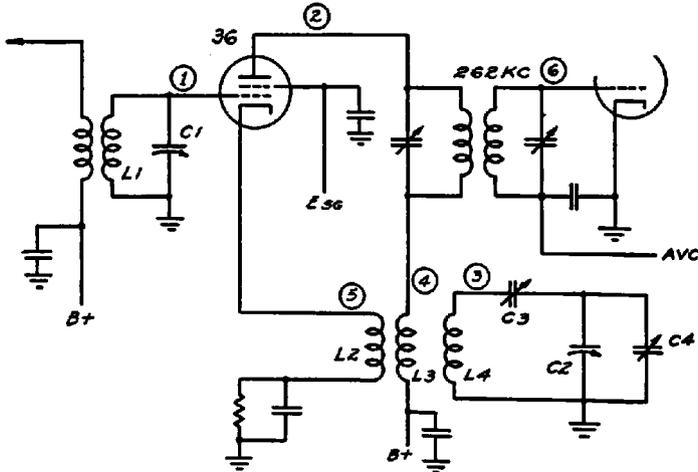


FIG. 6-7. An autodyne converter circuit using a screen grid tube. The local oscillator frequency is controlled by the oscillator section of the tuning condenser C2.

The general procedure in testing any circuits of the converter type follows the same routine as that described for separate oscillator and mixer circuits, but it will be found that circuits of the autodyne type usually will give evidence of reaction of one circuit upon another. When the r-f circuit is precisely aligned, changing the oscillator trimmer and padder adjustments will affect not only the tuning of the oscillator circuit but also that of the converter input circuit. This should be taken into account when aligning by making certain that the output signal voltage is greatest when the adjustments are completed.

An application of a pentode as a converter of the autodyne type is shown in Fig. 6-8. This is the circuit employed in the Majestic 400-A. The oscillator tuning is done by resonating the suppressor circuit to the desired oscillator frequency. The input circuit

to the converter is tuned to the frequency of the broadcast signal. Though this circuit is rather unusual in design, testing by signal tracing is done in the same manner as with any other converter

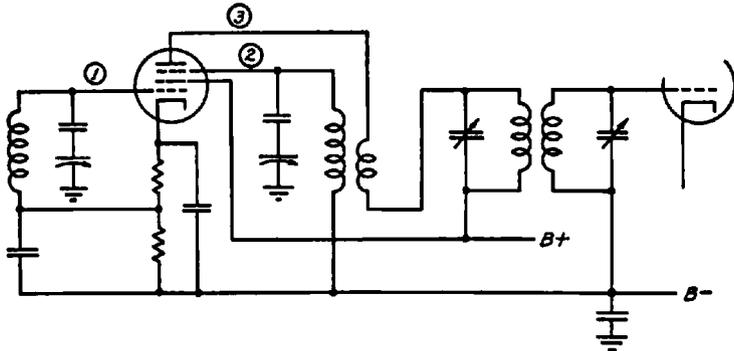


FIG. 6-8. The converter circuit used in the Majestic Model 400-A. The suppressor circuit is tuned to the desired oscillator frequency.

circuit. The r-f signal may be checked at point 1, the oscillator signal at point 2 or point 3 and the i-f signal at point 3.

Pentagrid Converters

Pentagrid converters are the most widely used of all types in most modern receivers. Of these, the 6A7 or its equivalent is most often employed and a typical circuit for this converter is shown in Fig. 6-9. This type of tube has five grids, whence the name pentagrid is derived. The first grid, nearest the cathode, acts as the oscillator grid while the second serves as the oscillator anode. The third grid forms a screen around the fourth, or signal grid to minimize interaction between the oscillator and r-f signal sections the tube. The fifth grid serves as a screen grid and provides a high plate resistance so that a high plate load may be efficiently utilized. The third and fifth grids are connected to each other within the tube.

In operation, oscillation in the section of the tube composed of the cathode and the first two grids causes the electron flow to the plate to vary at the oscillation frequency. Since these electrons must flow through all five grids, they will be affected by

signal voltages which happen to vary any of these grid voltages. The incoming r-f signal is applied to the fourth grid, and the varying potentials resulting from the r-f signal voltages on this grid modulate the electron flow which is already varying at the oscillator frequency. This causes the plate current to vary, not only at the oscillator and signal frequencies, but also at the difference

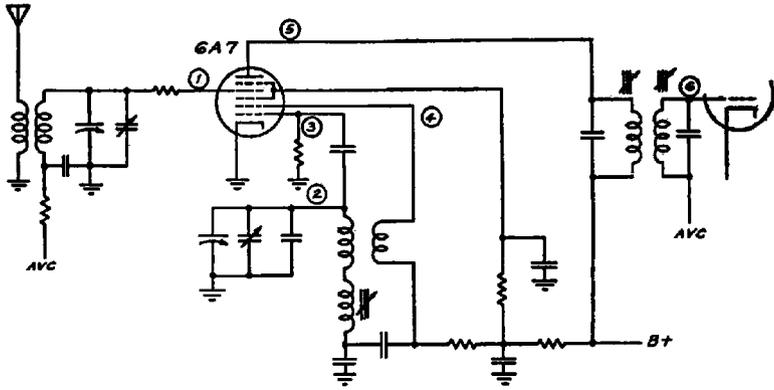


FIG. 6-9. A typical pentagrid converter circuit. The incoming signal is applied to the fourth grid and the oscillator frequency is controlled by tuning the circuit connected to the second grid.

frequency which is the required intermediate frequency when the circuits are properly adjusted.

Signal tracing in pentagrid circuits follows the same general procedure as that described for separate oscillators and mixers. We check the conversion gain by measuring the i-f signal voltage at the pentagrid plate and the r-f signal voltage at the input grid, the fourth grid from the cathode. The ratio of these two voltages is the conversion gain, which varies from about 10 to 40 in broadcast receivers when the avc system is inoperative. When avc action is present, the conversion gain is reduced to about $\frac{1}{5}$ th of these figures. Exact gain measurements are seldom necessary in servicing procedure; usually the mere fact that there is a conversion gain, rather than a loss, in the converter tube is sufficient to eliminate this portion of the receiver as a cause of poor operation.

The pentagrid converter circuit shown in Fig. 6-9 is that used in the RCA Models 85E and U102E; it is representative of a large number of designs. The r-f signal is checked at point 1, the oscillator signal at point 2, 3, 4 or 5, the i-f signal at points 5 and 6. At point 3, the rectified oscillator voltage across the oscillator grid leak can be measured. This voltage varies widely in different receivers, usually ranging from -3 to -20 volts with respect to ground. If the oscillator section is inoperative, this voltage will be zero or some positive value, depending upon the circuit used. However, regardless of the circuit used, a measurement of the voltage which is made with the test leads connected to each terminal of the oscillator grid leak, rather than to grid and ground, will tell the story. Then the grid always will be negative when the oscillator is functioning.

In using a test oscillator for signal tracing in pentagrid circuits, the converter may be separately checked by feeding a modulated signal at the intermediate frequency to point 1 in Fig. 6-9. The 6A7 will then act as an i-f amplifier and the output signal level in some portion of the a-f system may be checked with an output meter. The test oscillator then may be connected to point 6, the first i-f control grid, and the test oscillator attenuator readjusted to give the same output-meter reading. The ratio of the test oscillator voltage outputs at the two settings of the attenuator show the gain of the converter tube at the intermediate frequency, less any loss or gain in the i-f transformer. This is not the same as the conversion gain, which is obtained in the same manner except that an r-f signal is fed to the mixer instead of an i-f signal.

The oscillator section of the pentagrid converter is checked by feeding the test oscillator signal to point 3 in Fig. 6-9. The receiver should be tuned to a broadcast signal or any other signal the frequency of which is definitely known. The test oscillator should be adjusted to produce a frequency equal to that of the incoming r-f signal plus that of the intermediate frequency. Thus, if the receiver is tuned to a 600-kc signal, and the i.f. is 460 kc, the test oscillator should be set at 1060 kc. The attenuator should be adjusted for maximum output; even so, the maximum voltage delivered by the test oscillator will be far less than that supplied by the pentagrid converter oscillator section when it is

working properly. However, this substitution method may be used to localize faults in the pentagrid converter when no other suitable equipment is on hand.

Summary

The general remarks regarding trouble-shooting in oscillators and mixers are equally applicable to pentagrid converters. In some receivers, AVC action causes the frequency of the oscillator section of the converter to change. This is particularly troublesome at the high-frequency end of the tuning range. When a strong signal is being tuned in, especially on short-wave bands, the point of resonance is not the same when the receiver is tuned from a higher-frequency point on the dial as it is when the tuning is approached from a lower-frequency point. Often it is necessary to tune back and forth around the normal point of resonance before the station can be tuned in for maximum response. Then when the receiver is tuned a little beyond this point, the signal may drop out completely and retuning in the same manner may have to be repeated. This annoying condition occurs because a strong signal creates a high AVC voltage and the high AVC voltage increases the bias on the converter input grid, thereby decreasing the mutual conductance of the converter tube. This changes the tube load on the oscillator tuning circuit and causes a frequency shift which is particularly large when the shunt capacity of the tuning system is a minimum, as it is at the high-frequency end of the tuning range.

The correction of this trouble requires some modification of the AVC so that less control voltage is applied to the converter grid or reduction of the signal strength of the offending station by changing the antenna location or otherwise decreasing the signal pickup. Triode-hexode converters, such as the 6K8, are substantially free from this trouble due to modifications in the design of the tube, but triode-heptodes, such as the 6J8, will be subject to this trouble unless precautions were taken in the design of the receiver to minimize such effects. Signal tracing in the two latter types of converter tubes follows along the same lines as for pentagrid types.

Chapter VII

SIGNAL TRACING IN CONTROL CIRCUITS

AUTOMATIC volume control, generally called "avc," has become an integral part of practically all commercial radio receivers. The few modern receivers which are not so equipped are mainly small tuned r-f sets, employing not more than three or four tubes.

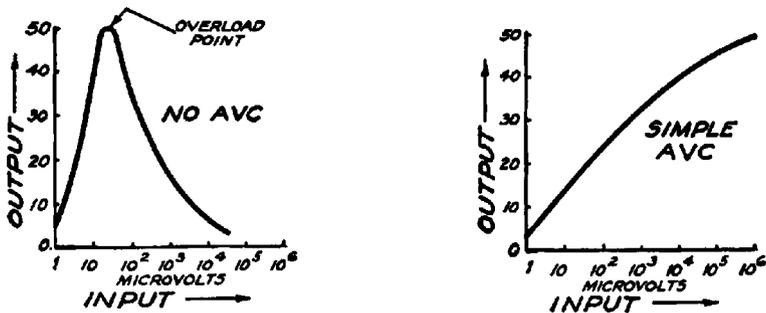
It is easy to see why automatic volume control has been so universally adopted. The signal strength of broadcast programs in any one radio receiver installation may vary over an extremely wide range as great as one million to one. A nearby powerful station may provide a signal as strong as one volt across the antenna while another station, weaker and remote from the receiver, may supply a signal of only two or three microvolts. Even strong signals sometimes fade, due to changes in the transmitting medium between the transmitter and the receiver, so that the received signal fluctuates. These various influences, up to the time automatic volume control was introduced, represented some of the objectionable characteristics of broadcast reception.

Automatic volume control controls sensitivity by making the gain of the receiver lower for strong signals than for weak ones. This is done automatically and in a perfect avc system only as much reduction in gain takes place as is required to provide a uniformly strong signal to the detector in the receiver.

If we tune the receiver from one station to another which is ten times as strong, the sensitivity of the receiver is automatically reduced to about one-tenth of what it was for the first station. Therefore the signal which reaches the detector is of substantially the same strength for both stations. If there were no avc in the receiver, the stronger signal would produce a much louder sound

from the speaker, or, if the speaker were already working at full volume, one or more of the tubes in the receiver would become overloaded and reception would be weak and distorted. Through the use of avc, such troubles are avoided. One can tune from one station to another which is weaker or stronger without bothering to readjust the volume control to give the desired sound volume. And the possibility of "blasting" when passing from a weak station to a stronger one is eliminated.

Automatic volume control also increases the sensitivity of the receiver when the set is tuned from a strong signal to a weaker one. Thus it is possible to rotate the tuning dial over its range without continually readjusting the volume control to avoid passing a desired weak station which otherwise might not be heard.



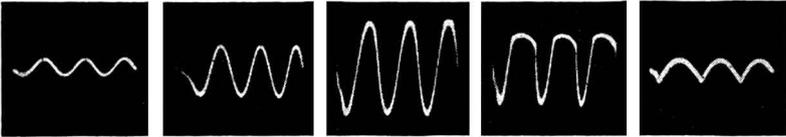
FIGS. 7-1 (left), 7-2 (right). The variation in output of a receiver without avc for different values of input signal is shown at the left. When avc is used, no overloading takes place on strong signals.

This increase in sensitivity, under these conditions, does not mean that additional amplification is put into the receiver; it means that more of the amplification of which the receiver is capable is being utilized. Receivers employing automatic volume control usually operate at the maximum possible sensitivity of which they are capable when no signal at all is being received. Then, as soon as any signal which the receiver is able to detect is received, the avc starts to function.

No avc system is perfect. If it were, then every signal within the sensitivity range of the receiver would be of precisely the same strength at the detector. However, a very substantial

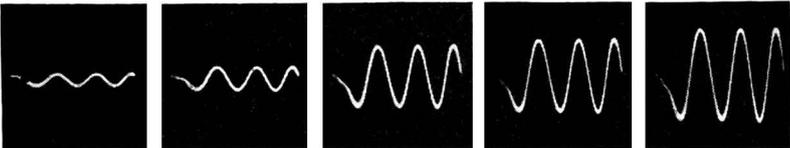
degree of uniformity of signal strength is realized through its use. With even a simple avc system, a change in input signal from 10 microvolts to one volt changes the receiver output from 10 units to 50 units. In other words, a change of 100,000 to one in the input signal level changes the output signal level in the ratio of only 5 to 1.

The action of a simple avc system is shown graphically in Fig. 7-2. Note that the curve climbs uniformly and gradually tapers off. Comparing Fig. 7-2 with Fig. 7-1, it is significant to note



Figs. 7-3 to 7-7, left to right. These oscillograms show how the output of a receiver without avc changes as the input signal is increased.

that Fig. 7-2 shows no overload point. While the receiver without avc, shown in Fig. 7-1, overloads considerably with an input signal of less than 100 microvolts, the receiver equipped with simple avc does not overload even when the input signal is as



Figs. 7-8 to 7-12, left to right. These oscillograms show how the avc action prevents overloading as the input signal is increased.

much as 1 volt. This is also demonstrated by comparing the waveforms of the output signals in Figs. 7-3 to 7-7 inclusive with those shown in Figs. 7-8 to 7-12 inclusive. The excellent waveform of the latter, even at high signal levels, shows that no distortion results at any signal level while in Fig. 7-6, without avc, the output is already badly distorted when the input signal is 200 microvolts. These figures do not represent the performance of

any one specific receiver, but rather are simple illustrations of the action of a receiver without avc.

Delayed AVC

A close examination of Figs. 7-1 and 7-2 shows that a receiver which is equipped with simple avc has lower sensitivity for very small input signals than one without avc. The reason for this is that simple avc acts to cut down the sensitivity of a receiver as soon as a signal is received and this happens no matter how weak the signal may be. This is a disadvantage, since the maximum sensitivity of the receiver is required when weak signals are tuned in. This makes very weak signals difficult to receive properly because, during the time when the maximum sensitivity is needed, the action of the avc lowers the sensitivity.

To enable better reception of very weak signals, the type of circuit known as "delayed avc" was introduced. The improved performance made possible with this type of circuit is due to the fact that the application of avc action is delayed until the signal strength reaches a certain predetermined value. Practically, this means that for very weak signals there is no avc action.

A performance curve of a receiver equipped with delayed avc is shown in Fig. 7-13. You will note that for small values of

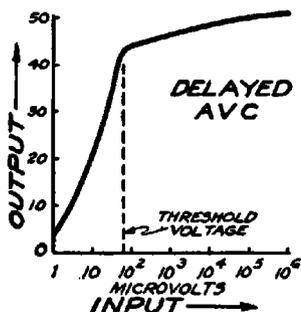


FIG. 7-13. In delayed avc circuits, the application of the control voltage is delayed until a minimum value of input signal is reached. Beyond this threshold voltage, the avc action keeps the output almost constant.

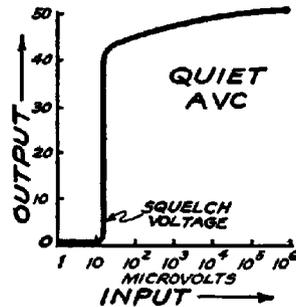
input signal, up to about 60 microvolts, the operation of the receiver is similar to that of the one shown in Fig. 7-1. That is, the output is proportional to the input for signal inputs up to this level. In other words, the receiver performs for weak signals just as if it were not equipped with avc. Yet, when the signal level exceeds 60 microvolts the avc action begins to "take hold" and the

control effect for strong signals, where it is most needed, is present.

Quiet AVC

We mentioned previously that receiver sensitivity is greatest when no signal is being received, because the avc action cannot take place until a signal reaches the detector or avc tube. Now, in actual operation of a receiver, as we rotate the dial over the tuning range, there are some points where signals are present and others where signals are not received. At these points where no signal is being received, the sensitivity of the receiver is greatest. Yet a certain amount of electrical noise is always present in the antenna system and consequently we find that the maximum sensitivity of the receiver again is available when it is undesirable,

FIG. 7-14. In quiet avc or noise suppression circuits the output is zero for small values of input signal. Above the squelch voltage point, the normal avc action keeps the output essentially constant.



i. e., when only noise is present. This is naturally very annoying so a means for overcoming this fault also has been devised. This means is known as *quiet avc* or "qavc."

Quiet avc functions to reduce the sensitivity of the receiver until the signal reaches a certain predetermined level. Since the noise level in any given location varies from day to day and often from hour to hour, provision is made to adjust the level at which the signal will be received. In other words, by this method we can adjust the receiver so as to receive a weak signal with noise, if desired, or to reduce the sensitivity so that the signal must be stronger than the noise before it will be heard.

The relation between the output signal and the received signal is shown in Fig. 7-14. In contrast to Figs. 7-1 and 7-2, Fig. 7-14 shows the relation between the receiver output signal and the

received signal rather than the second detector output and the received signal, as in Figs. 7-1 and 7-2. The reason for this is that in qavc systems, which are also known as *noise-suppression* and *squelch* circuits, the action of the avc system is to block one of the audio tubes during the time that the received signal is below a predetermined level and to open the system when the received signal is of sufficient intensity. This is one method; others will be discussed later.

If you will examine Fig. 7-14, you will note that there is no output from the receiver over a certain range of input signal levels—from zero input up to a certain predetermined value. It is during this time that the audio system is blocked by the control circuit. Then, if the receiver is tuned to some station which is received with an intensity equal to or greater than the critical value, generally known as the squelch voltage, the audio system is unlocked and normal avc operation is restored. It is because of this steep rise in the output that receivers equipped with qavc are silent during tuning and then, when the proper signal is tuned in, the output signal suddenly appears.

These are the fundamental properties of the three principal types of avc systems. What we have tried to do up to this point is to develop a general acquaintance with the main features of these systems and to show how each works toward the ultimate goal of avc. The various circuits utilized to accomplish the results described are basically the same but contain extensive modifications which we will discuss from the signal-tracing standpoint, because automatic volume control, like many other forms of automatic control of receivers, is operated *by and for the signal*.

We stated that automatic volume control, as the term is generally understood, is really the control of the sensitivity of the receiver ahead of the second detector tube—and that this control of sensitivity depends upon the intensity of the received signal. Now in order to control the sensitivity of the receiver automatically, it is necessary to control the amount of gain or amplification available in the r-f and i-f amplifiers. But in order to understand how the amplification of these stages is controlled, it is essential to comprehend the manner in which the amplifying properties of tubes can be varied.

Controlling Gain

In avc systems, varying the control-grid bias is used as a means of varying the mutual conductance and consequently the amplifying properties of tubes in the r-f and i-f amplifiers. Since the sensitivity of the receiver is dependent upon the amount of gain or amplification in the r-f and i-f amplifying stages, by varying the mutual conductance of the tubes in these stages, avc controls the sensitivity of a receiver.

The manner in which the control-grid voltage changes the plate current and gain in any tube depends upon a number of different factors, primarily the design of the tube. However, irrespective of design, one condition exists in general—an increase of the negative bias applied to the control grid reduces the plate current and likewise reduces the gain or amplification available with the stage. If we express this condition in relation to the sensitivity of the receiver, rather than in terms of gain or amplification, it means that an increase in the negative control-grid bias applied to the r-f and i-f tubes in a receiver reduces the sensitivity of the complete system.

Not all tubes are equally suitable for use in amplifiers which are controlled by avc. With some tubes, the reduction of sensitivity which occurs as a result of increasing negative bias on the control grid is so abrupt that the controlled tubes cease to function as amplifiers and act as rectifiers. Then distortion results. In Fig. 7-15, for instance, curve *A* represents the variation in mutual conductance which takes place with a "sharp-cut-off" tube, such as the 24, 57, 6C6, 6J7, etc. Note that the mutual conductance drops to zero for a very small value of grid voltage, approximately 7 volts. The amount of signal voltage permissible in these tubes is definitely limited by the very low bias voltage. Consequently strong signals overload the tube. Then when the bias voltage is applied as a control voltage, it is very critical and its range of operation is extremely limited. To reduce the sensitivity of a very strong signal to the required level a fairly high bias is needed. This results in operation near cut-off and rectification occurs. The result is distortion and cross-modulation, which is the "riding through" of an undesired station on the carrier of a desired station. In r-f amplifiers, increase of the

control-grid bias causes distortion of the modulated wave envelope and this, in turn, causes a distorted audio output.

Curve *B* in Fig. 7-15 represents the characteristics of a remote cut-off tube, such as the 35, 58, 6D6, 6K7, etc. Note that the change in gain as a result of increasing control-grid bias is very gradual and extends over a very wide range, cut-off not appear-

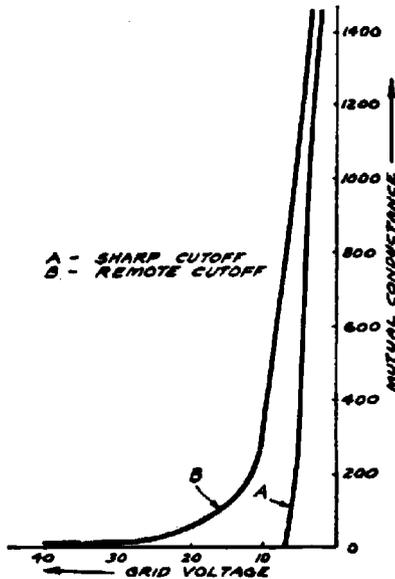


FIG. 7-15. The variation in the mutual conductance of sharp cut-off and remote cut-off tubes. The gradual cut-off shown in curve *B* makes the remote cut-off pentode suitable for use in receivers equipped with avc.

ing until approximately -40 volts bias has been applied. Operation without rectification due to overload is therefore possible even with very strong input signals. Such is the type of tube used in the r-f and i-f amplifiers of receivers equipped with avc.

Let us now consider the characteristics of the control voltage which is utilized to reduce the gain depending upon the strength of the signal being received. It stands to reason that since it is to act as a bias voltage it must have d-c characteristics, yet since it is to vary as the incoming signal varies in strength, it must be produced as the result of an applied signal. Since the signal is an alternating current, some form of rectification is therefore necessary.

As a high control voltage is often necessary when the incoming signal is very strong, the rectifier for the avc voltage is usually placed at a point in the circuit where the signal voltage is strongest. This point is in the output circuit of the last i-f stage of a superheterodyne receiver, since the signal must pass through all the amplifying stages before it reaches this point. Since rectification is also necessary for detection, both these functions are frequently combined.

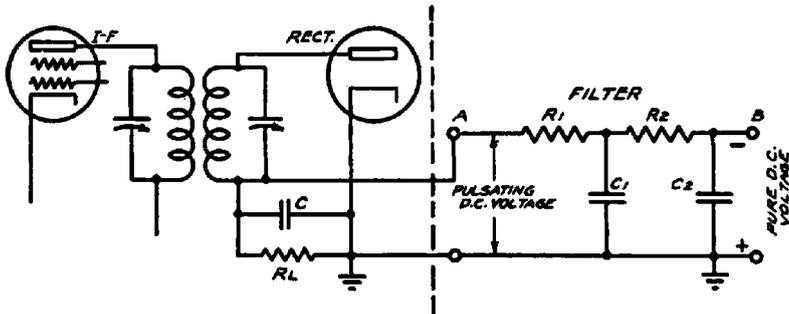


FIG. 7-16. A typical diode rectifier and filter. The filter circuit shown at the right removes the audio component from the avc voltage.

In the chapter on detectors we saw that the diode provides a convenient means for obtaining a d-c voltage which is proportional to the strength of the signal. Since the action which takes place in a rectifier for avc purposes is essentially the same as in a detector, we need not repeat the discussion of diode rectifiers in this chapter. Referring to Fig. 7-16, which shows a typical diode rectifier and filter which are used to operate an avc system, we note that this circuit is in many respects similar to Fig. 3-4. Thus the modulated input produces a d-c voltage at point A which is proportional to the strength of the carrier and an audio voltage which is dependent upon both the strength of the carrier and the percentage of modulation. In the chapter on detection, we were primarily interested in the audio part of the voltage across the diode load, whereas in the present chapter we are interested in the d-c voltage across the diode load.

We know that the purpose of this d-c voltage is to function as a control-grid bias. This means that the circuits to which this voltage is applied consume no direct current. Consequently, no

direct current flows through resistors $R1$ and $R2$; this means that there is no d-c voltage drop across $R1$ and $R2$. Therefore, the d-c voltage at point B is the same as that at point A . The fact that no d-c flows in this circuit accounts for the use of high resistance instead of chokes, which are needed to reduce the d-c resistance in power supply circuits where d-c also flows in the filter circuit.

In the case of the audio or a-c component, the action is somewhat more complex. The capacities of $C1$ and $C2$ are so chosen that they offer a low impedance to the flow of alternating currents of low frequency. This means that only a very small part of the total a-c voltage will be developed across the first filter condenser, $C1$, because of its relatively low impedance with respect to the first filter resistance, $R1$. The a-c voltage is further reduced in the same way by the $R2$ - $C2$ combination, which forms the second section of the filter, so that the output of the filter is essentially a pure d-c voltage.

The reduction in a-c voltage by means of this filter depends upon the frequency of the audio signal. For higher frequencies, the filter action will be more effective; for lower frequencies, it will be proportionately less. Since, in broadcasting, frequencies below 100 cycles are often present, it is important that the a-c filter be effective even at such low frequencies. Since increasing the values of $C1$ and $C2$ would improve the filter action, why not do so?

The answer is that it takes a certain amount of time for a condenser to charge and discharge when there is resistance in the circuit. This is described by the "time constant" which is the actual time in seconds required for a given condenser to receive 63 percent of its final charge; its value is equal to the product of the total capacity in the circuit times the total resistance in series with the capacity. In a circuit composed of a 1-megohm resistor in series with a 1-mf condenser, the time constant is one second. Once the condenser has received a charge, it takes an equal amount of time for its voltage to drop to 37 percent of its original value.

What effect does this time constant of the a-c circuit have on the operation of the circuit? Simply this—when we tune from a strong signal to a weak one, it is important that the a-c voltage

change as rapidly as one rotates the tuning dial, otherwise the high avc voltage which is developed for the strong signal will "hang on" and temporarily reduce the sensitivity of the receiver when the tuning point for the weak signal is reached. Then the signal may not be heard. Also, in tuning from a weak signal to a much stronger one, if the avc voltage takes too long to reach its proper value, the strong signal will blast and then gradually fade as the avc voltage approaches its maximum and therefore reduces the sensitivity of the receiver. The final result is that the choice of values for the resistors and condensers in an avc circuit is a compromise, and the values chosen are those which will give satisfactory filter action and yet keep the time constant low enough. These values, in commercial broadcast receivers, are generally chosen so that the time constant is about $\frac{1}{10}$ th second. In making replacements of defective condensers in avc circuits, it is important to realize this limitation regarding the size of the replacement condenser. Don't use a larger value of capacitance than is called for on the schematic on the theory that too much capacity is always better. Replace with the identical value specified by the manufacturer.

Basic Control Circuit

While there are a great many types of avc circuits, all operate upon the same basic principle—the incoming signal is used to actuate a device which develops a d-c voltage to be used for control purposes. The manner in which this is done has been discussed in detail so that, no matter how complex the circuit may be, its fundamental operation may be readily understood.

Since all such automatic control circuits are actuated by the signal, it follows that tracing this signal is necessary in any complete check of the performance of such circuits. Let us first consider a simple avc circuit and trace the signal from point to point in the circuit.

The diagram, Fig. 7-17, can be considered to represent an i-f stage and avc rectifier of a superheterodyne receiver. Let us assume that a modulated signal is being applied to the input terminals of this receiver and has been traced, stage by stage, to the avc rectifier. If the intermediate frequency employed in the i-f amplifier is 465 kc, then a strong, modulated 465-kc signal

should be present at point 1, the avc diode plate. At point 2, if the by-pass condenser C is functioning, this 465-kc signal should be reduced to a very low value. But since the signal is modulated, a strong audio voltage should be present at point 2.

We know from our previous study of avc filter circuits that the purpose of $R1-C1$ and $R2-C2$ is to filter out the audio signal voltage which is normally present at point 2. So we trace this audio signal to point 3 and compare the value of the audio signal voltage found at this point with that at point 2. It should be very much lower at point 3 and in fact for ordinary modulating frequencies its value will be negligibly small. At point 4, only a bare trace of audio signal will be left so that the control voltage which is applied to the grid of the i-f amplifier tube (point 5) is essentially pure d.c. We need not check the audio signal at point 5 since no additional filtering of the control voltage is contributed by the i-f transformer tuned circuit.

So far we have discussed signal tracing in this avc circuit on the assumption that the circuit is performing normally. Also we have confined our discussion to the modulated signal which actuates the avc rectifier. Before considering the resulting d-c control voltage, let us see how faults in the circuit are revealed by the procedure just described.

The 465-kc signal voltage at point 1 is normally about one-half to one-third that present at point 6, the plate of the last i-f tube. If there is a short or open circuit anywhere in the circuit from the plate to the cathode of the avc rectifier, this signal voltage will be greatly reduced. If condenser C should become shorted, or either $R1$ or R_L should become grounded at point 2, the load on the tuned circuit would become extremely heavy; consequently the signal voltage at the diode plate would be greatly reduced. Similarly, shorted turns in $L3$, which might not be revealed in ordinary resistance testing, would reduce the signal voltage at point 1.

An open circuit, whether in R_L , C , $L3$, or its trimmer condenser, would drop the applied signal voltage at the diode plate to a very low value or eliminate it completely, depending upon the component affected. If C were open, for instance, the signal voltage would not be by-passed around R_L ; consequently the signal voltage measured between the plate and cathode of the diode

should be the same at points 1, 2, 3, 4 and 5. Leakage, short circuits or open circuits at points 3, 4 and 5 will affect the voltage readings at these points and consequently the AVC action. Such troubles are localized by comparing the voltage readings at these points with that at point 1 or point 2.

A strong signal voltage should be present at the diode plate when making d-c voltage measurements in AVC circuits. Then the rectified d-c voltage may be checked either at point 1 or point 2. Since there is no appreciable voltage drop across the coil L_3 , the reading at point 1 should be the same as that at point 2, so either of these points can be checked to determine a reference voltage reading for comparison with the readings obtained at other points in the circuit.

Let us suppose that $C1$ is leaky. Then some of the direct current in this filter circuit will pass through this resistance leak to ground and the voltage at point 3 therefore will not be the same as that at point 2. If, for instance, $R1$ is 1 megohm and the resistance of $C1$, due to leakage, is also 1 megohm, the effect is similar to that which would occur if two 1-megohm resistors were joined together and shunted across R_L . They would form a voltage divider, and since both resistors are of equal value, the voltage at the junction of these two resistors would be one-half the total voltage across R_L . In the diagram, this would mean that the d-c voltage at point 3 would be one-half that at point 2.

Suppose that $R1$ is open; then no d-c voltage (except the contact potential at the i-f grid) will be present at point 3, though the voltage will be normal at point 2. A decrease in resistance of $R1$, if of sufficient magnitude to affect appreciably the filter action would be revealed through signal tracing, though it would not affect the d-c voltage at this point. The same applies if a short-circuit exists between points 2 and 3. The second section of the filter can be checked in the same manner at point 4.

We have pointed out that normally no d-c flows in the AVC filter circuit. However, in making voltage measurements some current must flow through the input resistance of the test instrument unless a type of voltmeter is used which consumes no current whatsoever. Since the types of meters generally employed in service work usually place some load on the circuit under test, the readings obtained are not the true voltages present at each

test point. Just how much error is introduced by the loading effect of the voltmeter depends upon its input resistance for the range being used.

To keep this error to a minimum, the input resistance of the voltmeter must be very high in comparison with the resistance of the circuit under test. Since all *avc* filter circuits are of high resistance, the instrument used for measuring d-c voltages in such circuits must have an input resistance of about 10 megohms or higher.

When measurements of d-c voltages are made at points where an r-f signal is present, it is not enough that the input resistance of the voltmeter be high. In addition, care must be taken to prevent detuning of the circuit. This can be done provided the measurements are made with a special isolating probe as described in Chapter 12 and shown in Fig. 12-3. This probe must of course be used with a suitable high resistance voltmeter.

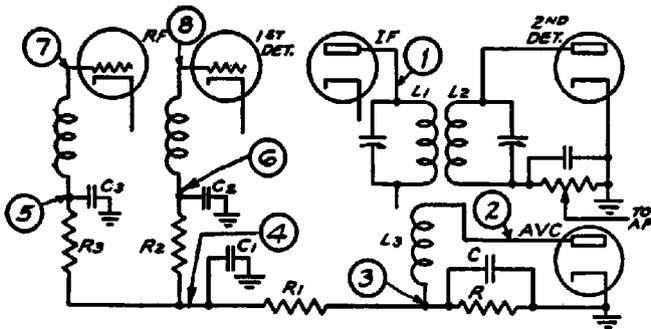


FIG. 7-18. An *avc* system in which a separate rectifier tube is used to produce the control voltage. Both the r-f and 1st-detector stages are controlled.

Fig. 7-18 shows an *avc* circuit in which the *avc* rectifier is inductively coupled to the primary of the last i-f transformer. L_3 is untuned, but due to its close coupling to L_1 a portion of the i-f signal is transferred to the *avc* rectifier and applied to the diode. The *avc* voltage is developed across the load resistor R and is applied to the r-f and first detector tubes through the common filter R_1-C_1 and the individual grid filters R_3-C_3 and R_2-C_2 .

Testing of this circuit follows along the same lines as that described previously. The i-f signal is first checked at point 1 then at point 2, to make certain that the signal is being transferred to the diode circuit. Since the avc rectifier is used only for avc operation and not as a detector, there is no need to keep C small enough in capacity to avoid by-passing audio frequencies. So if C is of the order of .01 to .1 μf , little a-f voltage should be found at point 3. If, however, C is .0005 μf or lower in capacity, the a-f signal will be found and traced for proper filtering through the filter circuits by testing at points 4, 5 and 6. The control voltage may be tested at points 2 or 3 and the resulting voltage reading compared with that secured at any of the numbered points in the balance of the avc circuit.

Another form of simple avc circuit is shown in Fig. 7-19. As shown, a triode instead of a diode is employed as the avc tube.

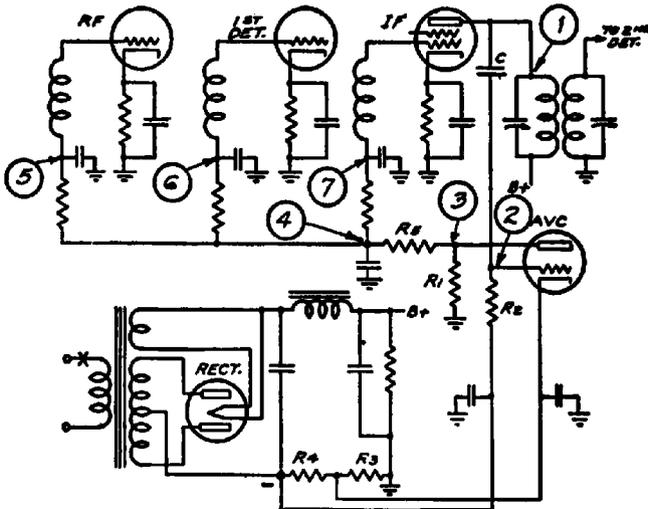


Fig. 7-19. An avc circuit in which a triode is used as the avc rectifier. Note the distribution of the d-c voltages.

The i-f signal voltage is fed from the plate of the last i-f tube by means of the coupling condenser C to the grid of the avc

rectifier. This signal voltage causes a change in the plate current of the avc tube and therefore a change in the voltage drop across $R1$. Though $R1$ returns to ground, the cathode and grid of the avc tube are both negative with respect to ground; the plate of the avc tube is accordingly positive with respect to its cathode.

The grid of the avc tube is connected to a point in the power supply system which is highly negative with respect to the cathode so that no plate current flows when no signal voltage is applied to point 2. Then, since no current flows through $R1$, there is no voltage drop across it and therefore point 3 is at ground potential. When an i-f signal is applied to point 2, the grid of the avc tube swings in a positive direction on the positive half of the signal wave, causing plate current to flow through $R1$ and making point 3 negative with respect to ground.

In signal tracing, the usual procedure of feeding a modulated signal to the receiver input terminals is followed. This signal is checked at point 1 and the signal strength noted. The presence of the i-f signal at point 2 shows that the coupling condenser C is performing its function. Note that the i-f is not by-passed at this point, nor at point 3. The a-f signal may be checked at point 3 and the functioning of the avc filter determined by noting the a-f signal attenuation at point 4. Individual decoupling and avc filtering is provided for each tube under avc control. The action of these filters is checked by testing at points 5, 6, and 7.

In checking the d-c voltages, a negative voltage reading at point 2 will of course be normal even when no signal is applied to the grid of the avc tube; then it should become increasingly negative as the signal voltage is raised; the actual d-c voltages at points 3, 4 and 5 should be the same at point 2. This control voltage can be traced through the numbered points in the avc system in the manner described before.

Delayed AVC Systems

We have discussed earlier in this chapter the limitations of simple avc systems and the reasons why delayed avc systems are sometimes used. We know, then, that by delaying the application of the avc voltage until the signal reaches a certain strength the sensitivity of the receiver to weak signals is increased. Let us

now consider a few representative circuits and see how this is accomplished and how faults in such circuits are revealed by signal tracing.

In all delayed avc systems, a separate tube or a separate section of a double tube is required to obtain the delay action. The reason for this is obvious: if a combination detector and avc tube were used and the avc voltage were taken from the common diode load resistor across which the a-f voltage was being developed, any means which would render the avc action inoperative until a certain signal level were reached would likewise eliminate the desired a-f signal until it reached the same intensity.

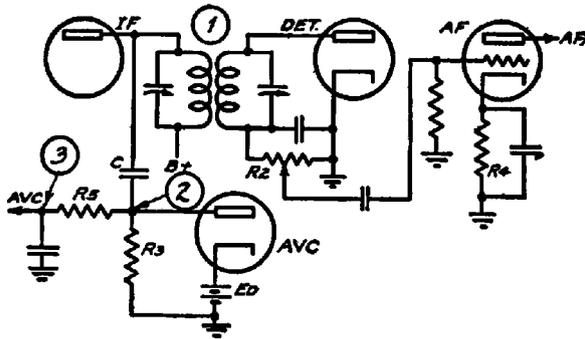


FIG. 7-20. A typical delayed avc circuit. The delay voltage E_D prevents the avc diode from rectifying the signal until the peak signal exceeds the delay voltage.

In delayed avc systems, no current flows in the diode circuit until the signal reaches the desired level. Consequently some means must be incorporated in the circuit to prevent current flowing through the diode load until this point is reached. One method of doing this is to apply a positive bias to the diode cathode. This is equivalent to applying a negative bias to the diode plate, since the cathode is the reference point in all considerations of tube operating voltages.

Fig. 7-20 shows a typical delayed avc circuit. The delay voltage is supplied by the battery E_D which biases the cathode of the avc tube. Since the plate is negative with respect to the cathode, no current flows in the diode circuit and therefore there is no voltage drop across R_3 . However, when an i-f signal reaches

is applied to point 1 to cause a rectified control voltage greater than -3.3 volts, practically no avc voltage can be applied to the controlled tubes. As soon as the signal level exceeds that required to produce -3.3 volts in the avc circuit, the delay diode ceases to draw current and the avc functions.

In signal tracing, the rectified voltage resulting from a signal applied to the detector diode will be present at points 1, 2 and 3, but there should be no d-c voltage reading at point 4 until the signal level is sufficient to raise the d-c voltage above that of the negative bias on the delay diode. This is quite easily checked by connecting the voltmeter from point 4 to ground and increasing the signal fed to the receiver until a voltage reading is noted. When this point is reached, the avc should function and tests follow along the same lines as those discussed previously.

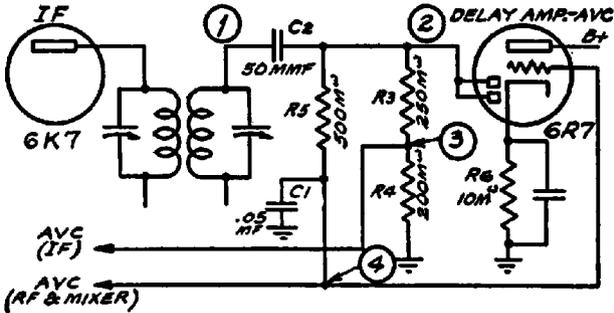


FIG. 7-22. A system of delayed avc used in the Motorola Golden Voice receiver in which the delay voltage is amplified and automatically controlled.

Some receivers employ a type of avc system in which the control voltage is both amplified and delayed. In Fig. 7-22, for instance, the circuit of the 1936 Motorola Golden Voice avc system is shown. The resistor R_6 , through which the plate current of the 6R7 tube flows, provides a negative bias for the diode rectifier and the control grid of the 6R7. As soon as the signal level reaches a value sufficient to overcome this bias, current flows in the diode circuit, increasing the negative bias on the 6R7 grid and consequently decreasing the plate current as well as the current through R_6 . Thus the delay voltage due to the voltage

locations; in others, a switch is provided to remove the squelch voltage so that simple avc action takes place.

Fig. 7-23 shows a representative avc circuit of the blocked-audio type. This is the circuit used in the Philco Model 810 PA receiver. You will note that the diode section of the first 75 tube is used as the second detector and also as the avc tube. The avc voltage is fed to the controlled tubes through the filter, $R4-C3$, while the negative voltage which is applied to the grid of the triode section of the 75 is taken directly from the high side of the volume control $R3$. The plate of the triode section which serves as the "Q" tube, is connected to a positive point on the voltage divider through $R2$. The triode section of the second 75 tube is employed as a first a-f amplifier and is controlled. The diode section of this tube is not used. Connecting the cathode to a positive point on the voltage divider enables a negative bias to be applied to the control grid of the 75 a-f tube equal to the voltage drop across $R3$.

Noise suppression is accomplished in the following manner: when the input signal to the detector diode is high, a high negative voltage is present across $R3$. Since the grid of the "Q" tube is connected to this point this high negative voltage reduces the plate current through $R1$ to a very low value. Consequently there is practically no voltage drop across $R2$ and the negative bias on the first a-f grid remains at its normal value. However, when the signal input to the diode is low, the bias on the "Q" tube grid is likewise low, plate current flows through $R2$ and the bias on the a-f grid is increased. Since this is a high- μ tube, a small increase in the negative bias is sufficient to reduce the signal amplification to zero.

Once the operation of the circuit is thoroughly understood, signal tracing procedure becomes almost self-evident. We know that the modulated i-f signal should be present at points 1 and 2, so we check it at these points. Since the diode load is bypassed by $C1$ and $C2$, the intermediate-frequency signal should be very small at point 3. However, the a-f component will be large, because $C1$ and $C2$ are too small in capacity to by-pass the a-f signal. At point 4, we can check the filtering of the a-f component.

At point 5 we can test the operation of the noise-suppression

action by noting if the d-c voltage at point 5 becomes less positive as the modulated signal applied to the receiver is increased. It should be noted that the d-c bias voltage will be normally positive with respect to ground though negative with reference to the cathode because the cathode is connected to a positive voltage point on the voltage divider. It is assumed, unless otherwise stated, that the voltage measurements are being made with reference to ground. All measurements are made with the switch across $R2$ open—when this switch is closed $R2$ is shorted out, therefore the grid voltage at point 5 cannot change and noise suppression does not take place.

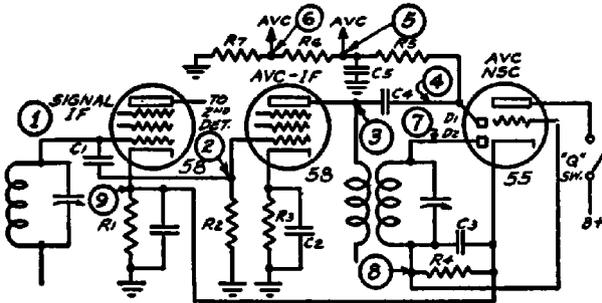


FIG. 7-24. A system of noise suppression which acts by blocking the signal i-f amplifier stage. This is done by the voltage drop across $R1$ due to the large plate current of the triode section during periods of low input signal.

The circuit shown in Fig. 7-24 is a partial schematic showing the noise suppression and avc system employed in the RCA Model R-78 receiver. Two i-f stages are used, one to feed the second detector and the other to amplify the signal voltage which feeds the avc rectifier. When a modulated signal is fed to the receiver input, the i-f signal at point 1 is coupled to the control grid of the avc-i-f tube at point 2. The amplified i-f signal at point 3 is fed to $D1$, a diode plate of the 55 tube and the avc voltage is developed across the network composed of $R5$, $R6$ and $R7$, as points 5 and 6.

The noise-suppression circuit is composed of the diode $D2$ and the triode section of the 55 tube. The amplified i-f signal at point

3 is coupled to $D2$ by means of the i-f transformer. This signal is checked at point 7. The resulting negative voltage across the diode load $R4$ serves to bias the grid of the 55 tube. Since the cathode of the 55 returns to ground through the cathode resistor of the first i-f tube, any increase in cathode current in the 55 tube will cause an increase in the control-grid bias of the first i-f tube. When the signal level at point 7 is low, the negative bias on the grid of the 55 tube is low and the plate current is high. Therefore, for weak signals the cathode voltage at point 9 is greatly increased; thus the amplification of the i-f tube is reduced and the signal applied to the second detector becomes very low. On strong signals the cathode voltage at point 9 is low and the gain of the first i-f tube depends only upon the regular *avc* action.

In checking this circuit by signal tracing, we need only follow the normal course of the signal to points 4 and 7 and then check the resulting d-c potentials which form the control voltages at points 5, 6, 8 and 9. These tests should be made with the plate-circuit switch of the 55 closed, since noise-suppression action cannot otherwise take place.

There are a great many other noise-suppression, or *qavc* circuits, some of which operate on the second detector tube, but all function fundamentally in the manner of the two described above. The analysis of these circuits, as well as those of the simpler *avc* circuits previously described, should enable the more difficult problems which arise in the servicing of such circuits to be solved more easily.

It should not be assumed that all the operations described in the testing of each of these circuits should perforce be followed in every servicing job which involves these circuits. The simplest and quickest tests which give the information required, based on the symptoms or the customer's complaint, are usually all that is necessary. Most of these simple preliminary tests can be made by giving the receiver an operating test on a standard broadcast signal.

Suppose, for instance, that the customer complains that in tuning from one station to another, the signal temporarily disappears, then gradually builds up to normal volume. This may be caused by a change in the time constant of the *avc* filter network. We can check the time constant by tuning quickly from a strong

station to a weak station and noting if too much lag is evident in the operation of the avc. If such is the case, then our tests must be applied directly to the avc filter circuit or the individual grid filters, first checking the components to make sure they are of the value specified by the manufacturer. The reason for this check is that the receiver may have been serviced and a condenser or resistor of the wrong value may have been substituted for the one originally installed.

A quick check of avc operation can be made by simply placing the voltmeter probe upon the control grid of one of the controlled tubes, and noting the change in voltage which should take place in tuning from a strong broadcast signal to a weaker one.

Signal tracing in avc circuits can be done with an oscillator and output meter. In such cases, the output meter should be placed at a point such as point 4 in Fig. 7-23, and the signal voltage should be applied to points ahead of the filter circuit. For instance, by feeding a strong audio signal at point 3 and measuring the audio output at points 3 and 4, the effectiveness of the filter in reducing the audio signal can be determined. The output meter for such work should be of the vacuum-tube type, of high input impedance, since its input capacitance is in parallel with the circuit to which it is connected. In using the test oscillator for diode circuit testing, the modulated signal preferably should be fed through a blocking condenser to the primary of the last i-f transformer. If connected directly across the diode, the test oscillator attenuator will short-circuit the diode lead and misleading results will be obtained.

SIGNAL TRACING IN AUTOMATIC FREQUENCY CONTROL CIRCUITS

Modern broadcast receivers, particularly those which employ broad-band i-f transformers, are often mistuned by inexperienced owners. When the desired station may be heard over a wide range of adjustment of the tuning dial, as is often the case with sensitive sets having automatic volume control, it may be difficult to determine the precise point of resonance. Yet, if the receiver is not precisely tuned, distortion results and the performance of the receiver suffers. Inaccuracies in tuning also result from oscillator drift and mechanical difficulties in electric and other auto-

matic tuning systems. Automatic frequency control is a means for correcting such errors in tuning. This correction is accomplished automatically by special circuits designed to shift the frequency of the superheterodyne oscillator so that the proper i-f signal results even when the oscillator is mistuned nearly 10 kc.

Automatic frequency control operates upon the oscillator of the superheterodyne receiver because the tuning of this circuit is far more critical than that of the r-f or mixer sections. When this circuit is tuned approximately to the correct frequency, automatic frequency control (abbreviated *afc*) serves to raise or lower the oscillator frequency until the correct intermediate frequency results.

To understand how *afc* functions, let us first consider the properties of an inductance. We know that if a given inductance has a certain impedance at one frequency, it will have a higher impedance to a slightly higher frequency and a lower impedance to a slightly lower frequency. Now, if we can make a vacuum tube vary in impedance with frequency in the same manner as an inductance, the vacuum tube can be used in a circuit in place of a variable inductance. This is accomplished in *afc* circuits by varying the grid bias on a tube which is arranged to act as an apparent inductance which varies automatically in accordance with changes in frequency above or below the desired point so that the tube impedance varies with frequency.

The tube which is thus transformed into an apparent inductance is called the *oscillator control tube* and the tube which causes the oscillator control tube to perform in this manner is termed the *discriminator*. The proper functioning of any *afc* circuit is based upon proper performance of these circuits, so let us see how they operate.

A typical discriminator circuit is shown in Fig. 7-25. The inductance $L1$ is tuned by C_p to the intermediate frequency used in the receiver and is inductively coupled to the secondary coils $L2$ and $L3$. The secondary is likewise tuned to resonance with the intermediate frequency. When an i-f signal is present, this signal voltage causes a rectified d-c voltage in the secondary circuit to be developed across $R1$ and $R2$. The signal voltages applied to the two diodes are equal and opposite because the secondary of the discriminator transformer is center-tapped.

Since $R1$ and $R2$ are likewise equal, the resulting d-c voltages across $R1$ and $R2$ are equal.

A portion of this i-f signal voltage is also fed to the secondary of the discriminator transformer through the condenser, C , and the phase relations of this signal voltage $E1$, with respect to $E2$ and $E3$ change with frequency so that the control voltage, at

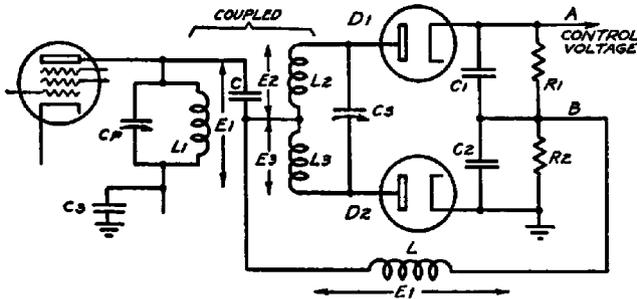


FIG. 7-25. A basic discriminator circuit used in afc systems to provide the voltage required for controlling the oscillator frequency.

point A , changes in a positive or negative direction as the i-f signal varies above or below the proper frequency. This control voltage is applied to the control grid of the oscillator control tube, causing its impedance to vary in accordance with the changes in the applied control voltage. Since the oscillator control circuit is shunted across the local oscillator in the receiver, these changes in impedance serve to vary the oscillator frequency. When properly adjusted, the afc circuit will compensate for errors in the oscillator frequency due to mistuning by automatically changing the oscillator frequency to the value required to produce the desired intermediate frequency.

Fig. 7-26 shows the oscillator control tube and oscillator circuit of a typical afc system. The afc control voltage is applied to the oscillator control tube grid through the filter network $R5-C5$ and $R4-C4$, which performs the same functions as similar filters in avc systems. The network $R3-C4$ is used to apply the oscillator signal to the oscillator control tube so that it draws a lagging current from the oscillator tuned circuit. The magnitude of this lagging current is controlled by the afc bias voltage applied to the

control grid. When the bias voltage changes in a positive direction, the plate current of the oscillator control tube is increased and its apparent inductance is decreased. When the bias voltage becomes more negative, the plate current is decreased and its apparent inductance is increased. Thus the oscillator control tube acts as a variable inductance shunted across the oscillator tuned circuit.

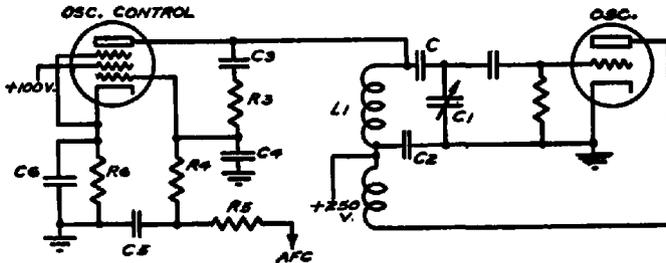


FIG. 7-26. A basic oscillator control circuit showing the connections to the oscillator circuit.

Since this apparent variable inductance is shunted across the oscillator coil, it acts to reduce the effective inductance of the circuit. When the inductance in any circuit is lowered, its resonant frequency is raised, and when the inductance is increased, the frequency is lowered. When all circuits are properly adjusted, the local oscillator should produce the proper beat with the r-f signal to give the desired intermediate frequency. Then, should the oscillator deviate from this frequency, the resulting intermediate frequency will change by the same amount. This brings the afc control voltage into action, changing the bias on the oscillator control tube grid in either a negative or positive direction, as required to increase or decrease the effective inductance of the circuit and thereby restore the proper oscillator frequency. A complete discussion of the manner in which this is accomplished is given in the book "Automatic Frequency Control Systems" by John F. Rider.

We have seen that the operation of afc circuits has much in common with that of avc circuits. In superheterodyne receivers, the i-f signal serves to operate each type of circuit. In each, the i-f signal is applied to a rectifier and the resulting d-c voltage is used to control another circuit. In avc circuits, the gain of con-

Signal tracing is done by first checking the signal frequency at point 1. This frequency should conform to the intermediate frequency specified by the manufacturer. These tests are made with a tuned vacuum-tube voltmeter. Then move the v-t voltmeter probe to point 2. Presence of a strong signal at this point indicates that the coupling condenser C2 is functioning properly. The i-f signal likewise should be present at points 3 and 4, and when the discriminator transformer is properly center-tapped, these signal voltages should be equal. The signal should be very weak at point 5, since the r-f choke and by-pass condenser form a filter circuit, and should be still further attenuated at point 6, due to the action of the resistance-capacity filter. Points 7 and 8 are by-passed both for intermediate and audio frequencies, so no signal voltages should be present at any of these points. At points 10 and 11, the oscillator frequency, representing the sum of the intermediate and r-f signal frequencies, should be present. Note that the control grid of the oscillator control tube is by-passed with only a 5- μ f condenser; therefore the test probe and its cable should be so designed that very little capacitive load is placed on this circuit or the oscillator signal will be by-passed when the tuned v-t voltmeter is connected. This effect is likewise an important consideration in the testing and adjustment of any tuned circuit, since even the slightest capacity so introduced will serve to detune the circuit to some extent. Any conditions observed during the progress of this signal tracing procedure which are not in accordance with the normal results specified above call for investigation of the components involved at the point where the trouble is first noted.

As has been pointed out before, the rectified d-c voltages across the cathodes of the discriminator 6H6 are normally equal and of opposite polarity. This means that the d-c voltage from point 9 to point 8 should equal that from point 9 to point 7 when the discriminator transformer secondary is accurately tuned to the intermediate frequency. Since these voltages are of opposite polarity with respect to point 9, the voltage at resonance between points 7 and 8 should be zero. Point 7 will become either positive or negative with respect to point 8 as the intermediate frequency increases or decreases. This varying voltage is applied to the control grid of the 6J7 control tube at point 10.

In checking these voltages, it is assumed that one terminal of the voltmeter is connected to ground. Since both points 8 and 7 return to a point on the voltage divider which is 3 volts negative with respect to ground, the normal voltage reading at each of these points is -3 volts. This negative voltage forms the fixed control grid bias for the oscillator control tube.

In aligning the afc circuit by means of voltage measurements, the first step is to align the r-f, oscillator and i-f stages in the conventional manner with the afc rendered inoperative by closing the afc switch. Then, with a strong signal applied to the receiver input terminals, the set should be tuned to resonance and the afc switch opened. With the voltmeter probe connected to point 7 and ground, the voltage reading should be noted. Since the preliminary test on a broadcast signal would indicate the need for alignment, the voltage reading at point 7 will be greater or less than -3 volts. Whatever reading is secured, adjust $C1$ until it is a maximum. The primary of the discriminator transformer is then properly aligned.

The secondary circuit is then aligned by simply adjusting $C3$ until the voltage reading at point 7 is -3 volts. Then, when the afc switch is opened and closed the voltage reading should not change. If it does, then the fixed bias voltage is not -3 volts and the voltage divider should therefore be checked. In any event, the discriminator secondary tuned circuit is properly adjusted when the voltage reading from point 8 to ground is the same as that from point 7 to ground.

The afc circuit shown in Fig. 7-28 is employed in the Midwest Model 18-37 receiver. The discriminator circuit is somewhat simpler than the one just described, the filter network being omitted. The control-grid bias for the oscillator control tube is obtained by biasing its cathode rather than by using a fixed voltage in series with the afc voltage. A resistance-capacity filter in the plate circuit of the oscillator control tube serves to isolate the power supply from the oscillator control circuit and to provide hum filtration for the oscillator control tube plate.

Signal tracing and alignment proceed along the same lines as for the previously described circuit. Since one cathode of the 6H6 discriminator is at ground potential, the discriminator secondary circuit will be precisely aligned when the voltage reading

The most successful results, with any system of testing, are obtained when the operation of the circuits involved is thoroughly understood. Therefore particular attention should be devoted to the study of the circuit itself rather than to following blindly the test routine prescribed. In this manner, short cuts will suggest themselves, time will be saved and more work will be turned out with less effort. To enable you to do just this is the purpose of this book.

AUTOMATIC VOLUME EXPANSION

During the broadcasting of a program at the studio, the audio output which modulates the transmitter is constantly monitored by the control man so as to insure the greatest efficiency in operation and the widest station coverage. In some transmitters, too, this monitoring is done automatically by a system known as volume compression. During periods when the average sound level of the music being broadcast is high, the gain of the modulation amplifier must be reduced to prevent overmodulation of the carrier. On the other hand, when the average audio level is low, the gain of the amplifier must be raised so that the level of the music will be greater than the noise and hum level of the carrier. Thus the overall volume range of the transmitted program is compressed within a limited range so that the program as received in the home is not precisely of the same range as that heard in listening to the broadcasting orchestra in the studio.

Volume expansion circuits compensate for this reduction in volume range at the transmitter by automatically raising the volume in accordance with the average audio level. An ideal type of volume expander would be one in which the degree of volume expansion exactly compensated for the amount of compression at the studio so that the resulting audio output of the receiver is exactly the same as the signal reaching the studio microphone. This cannot be attained, since the degree of monitoring varies in different studios and often on different programs in the same studio. However, volume expansion is very satisfactory in the reproduction of records, since the amount of volume compression during recording does not vary so greatly.

There are various ways of securing volume expansion, but nearly all are based on some method of varying the gain of an

audio amplifier tube so that the stage gain is increased as the signal strength increases and decreased as the signal strength decreases. One exception is a method which uses a network of linear and non-linear resistances in the form of a bridge, which is shunted across the voice coil and output transformer secondary. This bridge is so arranged that the output power delivered to the voice coil increases with an increase in applied signal to a greater degree than would occur if the network were not used. By the same action, weak signals are made weaker than they otherwise would be.

A fundamental circuit showing the first-mentioned type of volume expander, which is most widely used, is shown in Fig. 7-29. This one is described in an application note issued by the RCA Manufacturing Company, Inc. The 6L7 acts as an audio

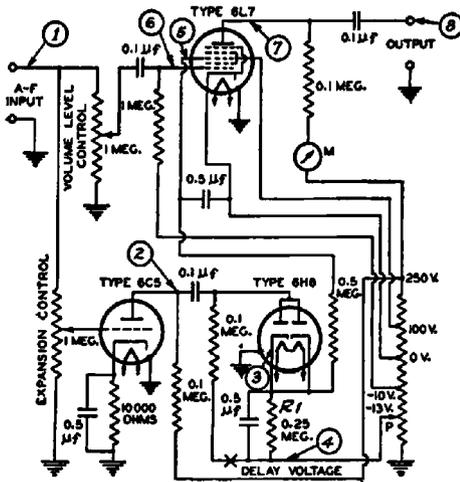


FIG. 7-29. An automatic volume expansion circuit. The gain of the 6L7 is automatically controlled in accordance with the average volume level.

amplifier and its amplification is controlled by the expander section, consisting of the 6C5 amplifier and 6H6 rectifier. In operation, when the expansion control is at minimum setting, the 6L7 functions as an ordinary audio amplifier. When the expansion control is advanced, a portion of the audio signal voltage which is fed to the 6L7 is likewise fed to the 6C5. This signal voltage is amplified by the 6C5 and applied to the 6H6 rectifier. As a result of rectification, a d-c voltage is developed across $R1$ of

positive polarity with respect to ground. This positive voltage is applied to $G3$ of the 6L7 and serves to reduce the normal negative bias voltage for this grid. As this grid voltage becomes less negative, the mutual conductance of the 6L7 is increased, thus increasing its gain. Since this increase in gain is greater as the signal voltage applied to the 6H6 is increased, the result is that strong signals are amplified more than weak ones. In effect, this means that during reception of music, if one note normally were received at twice the audio signal level of another, more than twice the audio signal level would appear at the output terminals of the volume expander. The amount by which the differences in level between two signals is amplified depends upon the position of the expansion control. Maximum expansion occurs when the expansion control is at maximum setting, since then the widest variations in signal and control voltages result. The signal level at which volume expansion starts to operate may be delayed by inserting a negative voltage in series with the diode return at the point marked (x) in the diagram.

For a preliminary operating test, an audio signal should be fed to the a-f input terminals of the expander. If the expander circuit is a portion of a radio receiver, a modulated r-f signal may be applied to the receiver input terminals. The audio component, after detection, will then serve to actuate the volume expansion circuit. With the expansion control at minimum setting, advance the volume control until the signal as reproduced by the speaker is of moderate volume. Then advance the expansion control. The sound volume should increase, providing the applied signal voltage is high enough to overcome the delay voltage, if any, used in the expansion circuit. A signal level at point 1 of the order of 1 volt should be adequate for most test purposes. If no increase in volume results from this test, the circuit should be checked.

In signal tracing, the audio signal should first be checked at point 1. Then, with the expander control advanced to maximum setting, check the signal at point 2. The signal voltage should be several times greater at this point—the actual gain will depend upon the design of the particular circuit employed. At point 3, no audio signal should be present, but the d-c voltage drop across $R1$ from rectification in the diode circuit should create a voltage which is positive with respect to point 4. This represents the

control voltage applied to the 6L7 and can be checked directly at point 5 on the diagram. The change in this control voltage should cause a corresponding change in the signal level at point 7. The audio signal therefore should be checked at point 7 and also at point 8 to check the blocking condenser. The location of faults by this method of testing follows along the same lines as was previously described for other control circuits.

An example of the use of another type of volume expansion in a radio receiver is shown in Fig. 7-30. Basically the method of operation will be clear from the small insert diagram. A 100,000-ohm resistor in series with the plate resistance of the 6K7G expander tube forms a voltage divider across the input to the power amplifier stage. As a result of this connection, the grid of the output stage receives only the voltage which is developed across the plate resistance of the 6K7G, represented in the small diagram (a) by a resistor within a circle. Automatic expansion of volume is achieved in this circuit by automatically varying the value of the plate resistance in accordance with the average audio or modulation level. During periods when the modulation level is high, the bias on this tube is likewise high, and consequently the plate resistance of the 6K7G also is high. The average volume level is therefore increased because of the voltage-divider action, of which the plate resistance of the 6K7G tube forms the lower portion.

On the other hand, when the modulation percentage is low, the bias on the 6K7G tube is likewise low, its plate resistance is decreased and the fraction of the total audio voltage which reaches the grid of the output stage is likewise small. In this way, an automatic expansion of the volume is secured.

Let us now examine the function of the several circuit components in somewhat more detail. Referring again to Fig. 7-30, the audio voltage produced across the volume control in the full-wave diode-detector load circuit is amplified by the triode section of the 6Q7G, and the output of this stage is fed to the grid of the 6N6G output tube through a resistor-condenser network. Automatic biasing of the 6K7G, in accordance with the average output level, is accomplished by feeding the audio voltage across the output of the 1st a-f stage through a .006- μ f condenser and a 1-meg resistor to the grid of the 6J7G expander-amplifier. This

tube acts as a rectifier-amplifier and produces a pulsating d-c voltage across the 470,000-ohm resistor in its plate circuit. This rectified d-c voltage is filtered by the 1-megohm resistor and 0.2- and 0.3- μ f condensers before being applied to the suppressor grid of the 6K7G expander.

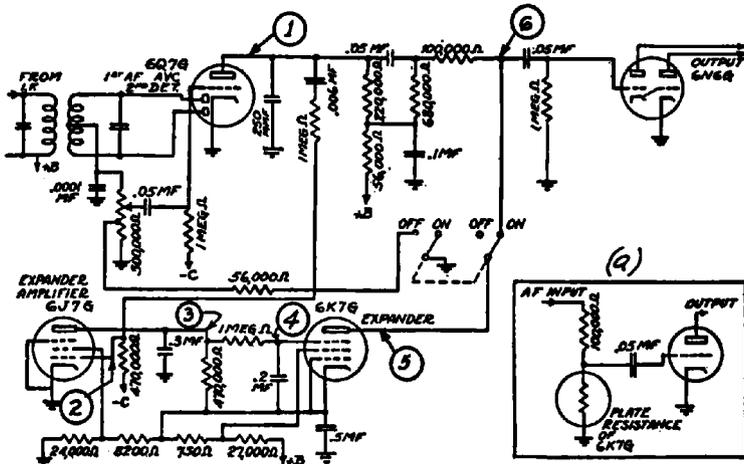


FIG. 7-30. An automatic volume expansion circuit. The plate resistance of the 6K7G is varied automatically to control the input signal to the 6N6G output stage.

As the signal level applied to the 6J7G increases, the rectified voltage across the plate resistor of the tube increases, thereby increasing the negative d-c bias on the suppressor grid of the 6K7G. This increasing suppressor grid bias causes the plate resistance of the 6K7G expander tube to increase correspondingly as the percentage modulation of the broadcast signal increases and the final audio voltage reaching the output tube grid increases beyond the value it otherwise would have without expansion.

The double-pole double-throw switch makes operation of the expansion circuit optional. When the volume expansion switch is in "off" position, a 56,000-ohm resistor is shunted across the tapped section of the volume control and the plate of the expander tube is disconnected from its coupling to the input circuit

of the output tube. This serves to equalize the volume level with the switch in either position.

Assuming that the signal has been traced through the rectifier circuit, we may check the audio gain at point 1. A test at point 2 which indicates the presence of the signal at this point is evidence of proper coupling between points 1 and 2. The a-f signal should be weak at point 3, due to filtration by the .3- μ f condenser, but the d-c voltage resulting from rectification may be checked at this point and point 4. Increasing the receiver input signal level or the percentage modulation should cause a corresponding decrease in d-c voltage at point 4. The a-f signal will appear at point 5. Doubling the input signal voltage should cause far more than double the signal voltage at point 5. Proper functioning of the switch connection may be determined by tracing the signal from point 5 to point 6. The signal levels, with volume expansion operating, should be the same at these two points.

Automatic Bass Amplifier

In receiving musical broadcast programs at low volume levels, it is a characteristic of the human ear that the low notes seem to be reproduced at lower volume than the high notes. Yet, when the overall volume level is raised, the proper proportionate strength is established. Automatic bass control is a means of automatically providing increased bass response at low volume levels to correct for this psychological condition, and proportionately less increase as the overall volume level is increased. In addition, a manual adjustment is provided which enables the listener to vary the amount of bass amplification in accordance with his own preferences. The latter adjustment then becomes in effect a bass tone control, although the manner of operation is essentially different from the conventional tone control.

The manner in which the automatic bass control action functions is evident when the simplified diagram of Fig. 7-31 is analyzed. A portion of the output of the 6F6G driver stage is coupled to the diode plates of the 6R7G and this audio signal is rectified. The resulting d-c voltage across the 500,000-ohm diode load is filtered through the 1.0-megohm resistor and .45- μ f condenser and fed over to the 6K7G bass amplifier tube. In this way the d-c bias on the 6K7G is made to vary in accordance with the

A signal check should be made at point 2 and the signal level of the main amplifier raised by adjusting the volume control until a d-c measurement at point 2 shows a slight increase in the negative bias voltage. Then check the audio signal at point 3. The signal strength should be a maximum at this point. Now again advance the volume control setting of the main amplifier. This should cause an increase in the negative d-c bias voltage at point 2 and a corresponding decrease in gain of the a-f signal at point 3.

Now place the test probe at point 4 and advance the bass amplifier control to maximum setting. Low-frequency notes in broadcast program reception should appear more pronounced than the higher ones at this point because of the high-frequency filtering action of the series resistor *R1* and shunt condenser, *C1*, employed in the coupling to the grid of the 6J5. At point 6, the signal from the main amplifier combines with that of the bass amplifier and a portion of the main amplifier signal voltage also will be present at point 5. To isolate the bass amplifier signal, the plate load resistor of the 6R7G may be open-circuited, thus preventing any signal voltage from the main amplifier from reaching point 6. The output of the bass amplifier may then be checked independently at either point 5 or point 6.

SIGNAL TRACING IN INVERSE FEEDBACK CIRCUITS

Inverse feedback, which is also known as negative feedback or degeneration, is a method of improving the performance of an amplifier by feeding back a portion of the output signal voltage to an input circuit in such manner that the feedback voltage opposes the phase of incoming signal. As a consequence, the frequency response is made more uniform, the stability is increased and harmonic and phase distortion are reduced. In output circuits, inverse feedback produces a desirable damping action on the speaker when high plate-impedance output tubes are used. This damping action is similar to that which would result if the best triodes were used and enables the speaker voice coil to reproduce rapidly changing frequencies more faithfully. This improved performance is obtained at a sacrifice of amplifier gain, so additional gain is often incorporated in such amplifier designs when needed.

Inverse feedback is the opposite of regeneration, hence the name "degeneration". In regeneration, the feedback voltage aids the input signal voltage and consequently the overall gain of a tube and circuit is increased. In degeneration, the feedback signal bucks the incoming signal so stage gain is decreased. Since the feedback signal becomes stronger, and therefore the bucking action becomes greater, as the stage gain increases, inverse feedback tends to equalize the gain over the frequency range of the amplifier. This effect is often further increased by designing the inverse feedback network so that the feedback voltage is greater in proportion to the increase in amplifier gain at certain frequencies so that maximum compensation for non-uniform frequency response is secured with minimum loss in amplification. Since the feedback voltage contains any hum or distortion which may originate at the point where it is derived, such faults are also bucked out by this method. The measure of improvement depends upon the amount of feedback which is introduced; complete compensation cannot be secured since there must always be some fault in the signal before the feedback system can operate to correct it. But a considerable improvement in fidelity results over that which is normally secured with the same components without inverse feedback.

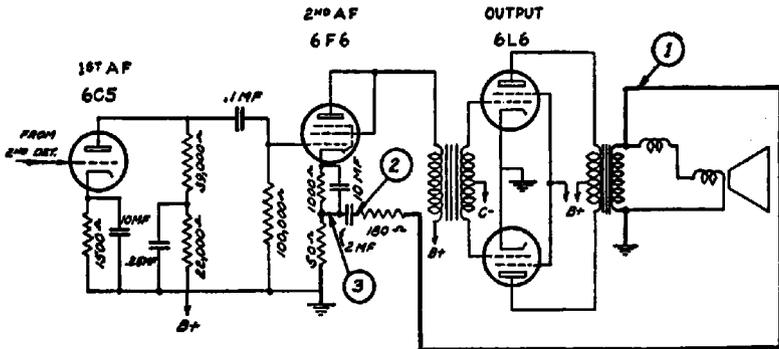


FIG. 7-32. An inverse feedback circuit in which the feedback signal is fed from the output circuit to the cathode of the second audio stage.

You will find in Fig. 7-32, the inverse feedback circuit used in the G.E. type E-155 receiver. The path of the feedback voltage

is indicated by the heavy lines. The audio signal voltage, which appears across the secondary of the output transformer, is fed back to the cathode circuit of the 6F6 driver tube through a 180-ohm resistor and 2- μ f condenser and is impressed across a 50-ohm resistor in series with the 1000-ohm cathode biasing resistor. At high frequencies, the reactance of the 2- μ f coupling condenser is low so that the feedback voltage introduced in the cathode circuit is high, amounting to approximately 20 percent of the audio voltage present at the output transformer secondary. At low frequencies the reactance of the coupling condenser is high so that the feedback voltage developed across the 50-ohm resistor becomes small. Since the gain of the amplifier is reduced as the feedback voltage is increased, we see that at higher frequencies where the amplifier gain is normally high, the feedback voltage tends to reduce the gain considerably while at low frequencies, where the amplifier gain normally decreases, the decrease in feedback voltage causes only a small reduction in overall gain. Thus a degree of additional compensation is introduced which increases the normal improvement in frequency response which results from inverse feedback.

In signal tracing, the feedback signal voltage cannot easily be checked independently of the incoming signal when both are present simultaneously in all circuits because they differ only in phase and magnitude. We should require special equipment to check the phase of these voltages. The simplest method of testing this inverse feedback circuit is to check its operation by noting its effect on the gain of the amplifier. If we open the inverse feedback network at either points 1 or 2 in Fig. 7-32, the amplifier will function without inverse feedback. Under such conditions, the overall gain should be increased. By applying an audio signal to the 6C5 grid, or by feeding a modulated r-f signal to the receiver input circuit, and noting the output voltage across the voice coil with and without the inverse feedback network in operation, it is possible to tell if the circuit is in operating condition.

A more accurate test may be made by opening the inverse feedback network at point 1 and connecting the lead to the 180-ohm resistor to a variable-frequency audio oscillator. By checking the audio voltage at point 3, with the oscillator voltage maintained constant, the frequency characteristic of the feedback net-

work may be determined. In this circuit, the audio voltage from point 3 to ground should be approximately 3 percent of that applied at point 1 when the frequency fed to the network is 50 cycles and should increase to approximately 20 percent as the frequency is increased to 5000 cycles. Since this is merely a test of the frequency characteristic of the network, the amplifier need not be in operation while this test is made.

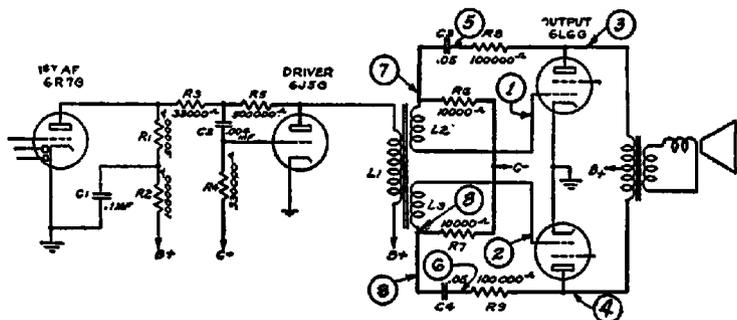


FIG. 7-33. Inverse feedback is used in both the driver and output stages as shown by the heavy-line circuits.

In Fig. 7-33 the audio amplifier section of the Philco Model 38-116 receiver is shown. In this circuit negative feedback is employed both in the driver and push-pull output stage. In the driver stage, the signal voltage at the plate of the 6J5G is fed back to the grid of the same tube through the network shown in the heavy lines. $R3$ is used to limit the loading effect of the parallel network consisting of the plate resistance of the 6R7G tube and its load resistor, $R1$. The combined effect of this load across the input circuit of the driver reduces the inverse feedback voltage to approximately 8 percent. The reduction in gain resulting from this feedback voltage may be checked by comparing the output signal voltage at the plate of the 6J5G plate, with the 500,000-ohm resistor disconnected—thereby rendering the feedback circuit inoperative—with that secured when the 500,000-ohm resistor is in the circuit.

Inverse feedback in the output stage is accomplished by means of the voltage divider network composed of $R8$, $C3$ and $R6$, for

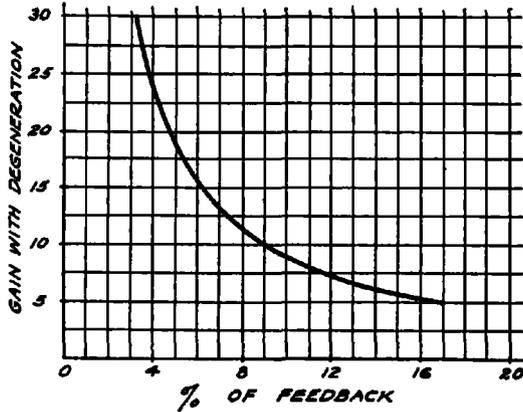
one tube and $R9$, $C4$ and $R7$ for the other tube. When the inverse feedback circuits are performing normally, the signal voltages at points 5 and 6 are equal; likewise at points 7 and 8. Inequalities of the signal voltages at points 1 and 2 and at points 3 and 4 will affect the equality of the feedback voltages at the points mentioned, even though the components are functioning properly. The effect of inverse feedback on the gain of each output tube can be checked in the same manner as was described for the driver stage. This test may be made by opening the feedback network at either point 3, 5 or 7 for the upper network and either point 4, 6 or 8 for the lower network.

Effect of Inverse Feedback on Amplifier Gain

We have mentioned that inverse feedback reduces the gain of an amplifier in which it is used. This reduction in gain is considerable; if 10 percent of the output voltage is fed back by this method to an input stage, the overall gain of the amplifier is reduced to about 9. It makes but little difference what the gain of the amplifier would be without negative feedback. For instance, if the gain were 100 without negative feedback, the gain with 10 percent negative feedback would be 9.1. And, if the normal gain were 200, with 10 percent negative feedback the overall gain would be reduced to 9.5. With greater percentages of negative feedback, the uniformity is even more pronounced. For 20 percent negative feedback, the gain of an amplifier which would be 100 without feedback is reduced to 4.8; yet, if the normal gain were 200, with the same amount of feedback the gain would be reduced to 4.9. With this in mind, then, we can show a graph which gives the approximate amount of gain we should expect in any amplifier in which negative feedback is used and where the normal gain is 100 or more. These gains shown in Fig. 7-34 are figured on the assumption that the normal gain of the amplifier without feedback is 100. When the gain of the stages included in the feedback circuit is greater than 100, the values shown in the figure will still be approximately correct. However, for gains less than 100, and especially for low percentages of feedback, the overall gain will be smaller than that shown by the curve.

The curve given in Fig. 7-34 will serve to make possible a quick check of the gain in any amplifier employing negative feedback and thereby to determine the need for servicing. It is obvious, if

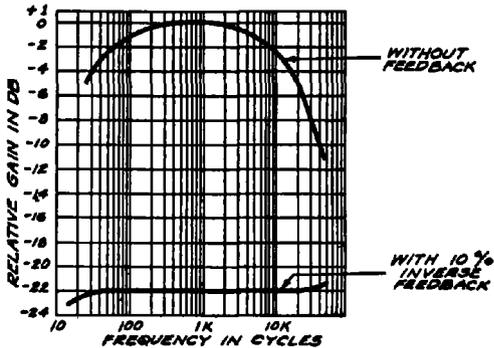
FIG. 7-34. The gain of an amplifier with degeneration decreases as the percentage of feedback increases. This curve is on the basis of a gain of 100 with no feedback.



the negative feedback circuit were inoperative, that the gain in the amplifier would be greatly increased.

The action of negative feedback in correcting frequency distortion is shown graphically in Fig. 7-35. The feedback used was about 10 percent. Note that, without feedback, the amplifier

FIG. 7-35. Response of an amplifier with and without inverse feedback. Note the improved frequency response effected by the use of feedback.



response is down 10 db at 30 kc and 4 db at 30 cycles while with feedback, the response is flat to within $\frac{1}{2}$ db over the same range. The overall gain, of course, is greatly reduced—approximately 22 db below that obtained without feedback.

When inverse feedback is applied to an output stage only, as is illustrated in the push-pull 6L6 stage shown in Fig. 7-33, the reduction in gain is not so pronounced. If the normal stage gain is 15, 10 percent negative feedback will reduce the gain to 6. If the normal gain is 10, the same amount of inverse feedback will reduce the gain to 5. These figures will serve to give an idea of the gain which may be expected in typical amplifiers employing negative feedback.

Chapter VIII

PUBLIC ADDRESS SYSTEMS

A MODIFIED form of the familiar audio-frequency amplifier to be found in all radio receivers is the basis of public address systems. Essentially, a public address system is nothing more than a high-power audio frequency amplifier, to which has been added a microphone, loudspeaker, and perhaps a phonograph pickup. However, public address systems present their own particular difficulties, because they possess certain peculiarities which are not encountered in the audio-amplifier end of a receiver. Nevertheless, signal tracing is equally applicable to public address systems and the application of signal tracing enables the rapid localization of defects.

The application of signal tracing to voltage and power amplifiers has already been described and thus there is no need to enter into a further discussion of such equipment at this point. In view of the fact, however, that the magnitudes of the signal voltages which appear in the audio-frequency section of a radio receiver differ considerably from those found in a public-address amplifier, it will be helpful to examine the magnitude of the a-f signal at various points.

In general, the block diagram in Fig. 8-1 may be considered a representation of a typical public address system. The relatively small output of the microphone is applied to a pre-amplifier stage which is used exclusively for the preliminary amplification of the signal produced by the microphone. The term "pre-amplifier" is occasionally used to signify an amplifier which is separated from the main amplifier. We are here using it in its broader meaning, namely, to signify any amplifier which is employed to raise the initially low voltage level of the microphone. The output of the

pre-amplifier goes to a mixer to which there is also fed the output of a phonograph pickup, and, in some cases, the detector output of a radio receiver. Whether or not all of these units are employed is immaterial to our discussion and accordingly we show a mixer which is adapted for use with a single microphone and a single phonograph pickup.

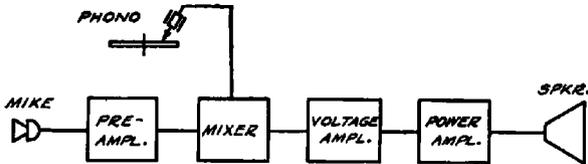


FIG. 8-1. Block diagram of a simple public address system.

After passing through the mixer, either the microphone signal voltage or the phonograph signal voltage, or both, depending upon the relative gain of these as determined by their respective volume-control settings, are fed into a voltage amplifier. After suitable amplification, the signal is delivered to a power amplifier which converts the voltage applied to its input circuit into electrical power which is then supplied to a loudspeaker. The loudspeaker transforms this electrical power into acoustical power, so that an amplified version of the original sound wave which actuated the microphone is produced.

In the foregoing we have dealt only in generalities and have limited ourselves to a qualitative picture of the signal amplitudes. We shall now concern ourselves with a quantitative view of a public address system; that is, we shall examine the magnitude of the signal voltage at various points in the system. The circuit, as shown in Fig. 8-2, is a simplified diagram of a commercial portable sound system. The modifications consist mainly in the elimination of certain portions of the circuit such as the power supply and tone control circuits, with which we are not concerned at the moment. This amplifier circuit is quite representative of modern p-a systems and has an average overall gain, for use with microphone input, of 128 db, and a gain, for use with a phonograph pickup, of 86 db.

Throughout this discussion we are describing the signal voltages appearing throughout the amplifier under working conditions. In testing an amplifier an a-f oscillator would replace the microphone in order to supply a voltage of constant amplitude to the amplifier.

Modern high-fidelity microphones, as ordinarily employed, supply the control grid of the input tube with approximately a one-millivolt signal. This signal level is supplied when the microphone is connected directly to the input circuit as would be the case with a crystal microphone, or through a transformer for a velocity or dynamic microphone. A voltage of this magnitude is generally too small to be capable of measurement with the instruments that are ordinarily available to the serviceman. Accordingly, even though the p-a system is in perfect working order, no measurable signal will appear at point 1.

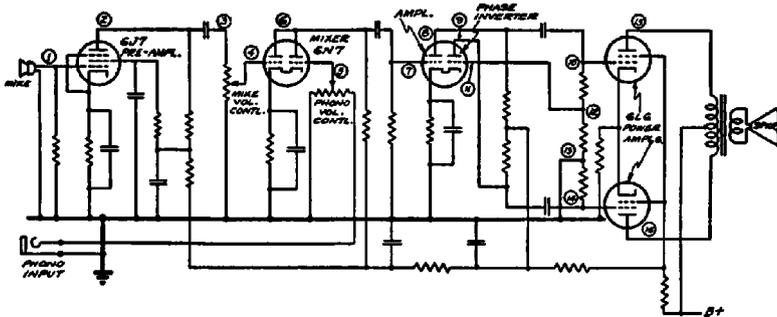


FIG. 8-2. Simplified diagram of a commercial portable sound system. The distribution of signal levels throughout the amplifier is discussed in the text.

The voltage gain of the 6J7 stage of amplification is about 100, so at point 2 we may expect to find a signal voltage of one-tenth of a volt. Since negligible loss occurs through the coupling condenser, we therefore obtain a signal voltage of one-tenth volt at point 3. The signal voltage at point 4 will depend upon the setting of the volume control potentiometer and will range from zero to one-tenth volt. We shall assume a setting which will give a one-tenth volt reading at point 4.

At 5, likewise, the setting of the phonograph volume control potentiometer will determine the signal level at this point. This will range from zero to the maximum output voltage furnished by the pickup. In general a one-volt signal will be obtained from the pickup, whether connected directly to the amplifier as in the case of a crystal pickup, or indirectly when a magnetic pickup is employed in conjunction with a transformer. We shall assume that the phonograph pickup volume control potentiometer is set to provide one-tenth of a volt at point 5.

This first 6N7 tube is called a mixer stage since, by varying the voltage applied to the "microphone" grid at point 4 and the "phonograph" grid at point 5, the relative amplitudes of the microphone signal and phonograph signal may be varied, so that either one alone or both simultaneously will appear at the loudspeaker.

Under the conditions of mixer operation the 6N7 has a voltage gain of about fifteen and a signal voltage of approximately 1.5 volts will result at point 6. Again there is no loss in the coupling condenser and consequently a 1.5-volt signal is obtained at point 7. The amplifier section of this second 6N7 tube, namely, the left-hand section, has a voltage gain of twenty. Accordingly a signal voltage of 30 volts will appear at point 8, and this in turn is transferred to point 10.

We shall now digress momentarily in order to describe the phase-inversion action which occurs in the right-hand portion of the second 6N7. As was explained in the description of push-pull amplifiers earlier in this book, the signal voltage applied to the grid of one of the push-pull tubes must be 180 degrees out of phase with that applied to the grid of the other push-pull tube. This condition will be met if the signal voltage at points 7 and 11 are 180 degrees out of phase.

In the chapter on amplifiers we have explained that the signal voltage at the plate of a vacuum tube is 180 degrees out of phase with the signal voltage applied to the grid of this same tube. Accordingly, if to point 11, namely, the grid of the phase inverter section of the 6N7, we apply a signal that is 180 degrees out of phase with the signal voltage at point 7 we shall fulfill this requirement. This could be accomplished by taking the signal

voltage from point 8, since the signal voltage at point 8 is 180 degrees out of phase with that at point 7.

Another requirement must be met, namely, the amplitude of the signal voltages applied to each of the push-pull grids must be equal. Therefore, instead of taking the signal voltage directly from point 8, we employ a voltage divider network 10-12 and 12-13. The magnitudes of the resistors between 10-12 and 12-13 are adjusted so as to give a voltage at point 11 which is equal to that at point 7, namely, 1.5 volts. Consequently the signal voltages at 8 and 9 are equal in magnitude (30 volts) but 180 degrees out of phase. Similarly, the signal voltages applied to the grids of the push-pull tubes at points 10 and 14 are equal in amplitude and 180 degrees out of phase, namely 30 volts.

Assuming a voltage gain of six for the 6L6 tubes, the plate of each tube, as points 15 and 16, will show a signal voltage reading of 180 volts above ground potential. Of course the signal voltage across the voice coil will depend upon the voice coil impedance, as we explained in connection with power amplifiers.

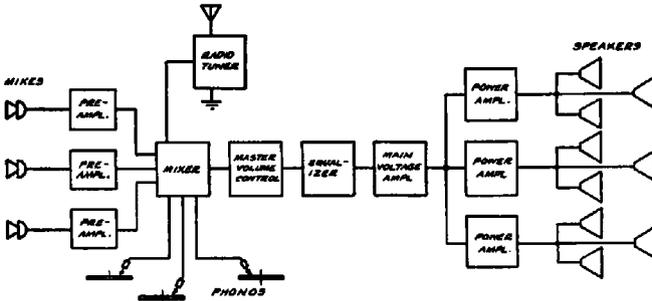


FIG. 8-3. Block diagram of a public-address system. Provision is made for three separate microphone and phonograph channels.

Let us now consider the block diagram shown in Fig. 8-3. This represents a public-address system that is more complicated than those which we have previously considered. Besides providing for the reception of radio programs, three separate phonograph channels as well as three separate microphone channels are provided. The three microphones permit picking up announcements

from different sources. Two of the phonographs are used in order to provide for continuous phonograph reproduction and to prevent the interruption that would occur at the end of each record if but one phonograph pickup and turntable were employed. The third phonograph is utilized for the injection of sound effects.

The radio tuner and the phonograph and microphone circuits are all connected to a mixer which regulates the relative amplitudes of the signals from the various components. The output of the mixer then goes to a master gain control which controls the overall gain of the entire system. From here the signal enters an equalizer which is nothing more than a tone control circuit designed to give an accurate control of the frequency response of the system. The signal now enters the main voltage amplifier where the signal voltage is stepped up sufficiently to be delivered to the power amplifiers.

The question might be asked why one power amplifier, rather than three, is not used to supply all the loudspeakers. There are two principal reasons for this. A single power amplifier which was capable of supplying the same power output would be considerably more than three times as expensive as the three separate amplifiers. Furthermore, the use of three amplifiers, rather than one, introduces an element of safety. Where a single power amplifier is used its breakdown would terminate operation of the entire system. However, when three separate power amplifiers are used the breakdown of one of them does not cause the entire system to become inoperative but only those loudspeakers connected to the defective power amplifier.

Although this system appears much more complicated than the circuits previously discussed, actually this is not the case, at least, insofar as signal tracing is concerned. It is true that the number of test points is increased, but the signal tracing method of trouble localization is exactly the same.

We are not here concerned with the minute details of public address systems and the many modifications in design and layout which occur. Our major interest is in the application of signal tracing in such systems. Only the broad outlines of this technique have been described in this chapter and the reader is referred to Chapter Two for a more detailed treatment of amplifiers.

Chapter IX

LOCALIZING DEFECTS BY SIGNAL TRACING

IN THE preceding chapters we have discussed the manner in which the various receiver tubes and circuits function so as to provide a broad, general foundation for the application of signal tracing. Once we understand the purpose of each tube and circuit and know how they should perform when a signal is present, we can readily tell by tracing this signal just how well each is doing its assigned task. We can make these tests circuit by circuit, stage by stage, along the natural path of the signal from the antenna post to the voice coil. When we reach a point along this signal path where the signal is not as it should be, we know that some component of the receiver which influences the operation of that particular tube or circuit under test is not properly performing its assigned function. No matter how well the stages which follow are operating, if the signal is defective at the point under test, succeeding stages merely amplify the defect. Thus our search for the cause of defective operation is limited to tests of those few components which influence the signal at the point where *the signal first becomes affected* and not to a time-wasting, haphazard check of all receiver components.

These signal-tracing tests can be made quickly, as fast as you can move the test probe from one point to another, and are applicable to any receiver of any type, age or description, no matter what kind of tubes are employed nor how many elements are used. Further, this system can be used to embrace major sections of the receiver with a single test. That is, you can touch a probe to a given test point and immediately isolate the trouble to a section of the receiver either ahead of or following the second

detector. A simple preliminary test identifies major troubles in the power supply circuit. Once the defect has been localized to one section of the receiver, the fundamental stage-by-stage tests can be applied until the point where the signal is first affected is located. Tests of a few individual components then serve to isolate the fault. It is as easy as that!

Preliminary Tests

Before we proceed with our signal-tracing tests, we must make certain that the receiver is in condition for testing. Obviously, if there is a major short circuit or an open circuit in the power supply system, the voltages on all tubes will be seriously altered or totally absent. Under such conditions, attempting to operate the receiver while making signal-tracing tests may result in damage to some components which have not already been affected.

A preliminary test of the power consumption of the receiver will immediately reveal any serious condition of this type. This need not be a precision measurement of the wattage consumed by the receiver; if any major short or open circuit exists in the power supply, the power consumption will be far above or below normal. Small variations from normal do not concern us, since they do not interfere with the signal-tracing procedure.

The power consumption test may be made with a wattmeter or wattage indicator. To avoid damage to the wattmeter due to overload, the power supply of any receiver which blows fuses or in which the power transformer overheats should be immediately checked for short-circuits *before* a power consumption test is attempted. The power test may also be made by a current-measurement method which may be interpreted in terms of watts by calibrating the instrument on a basis of the average power factor encountered in radio receiver transformers. This latter method has the advantage of speed, convenience and a safety factor which eliminates any possibility of damage through accidental overload in normal use.

This preliminary test is particularly advisable when the receiver under test is weak or inoperative, since such troubles frequently result from breakdown of the power-supply system.

It is also good practice, particularly with older receivers which are brought in for servicing, when the receiver is noisy or oscillating, to clean and tighten the gang-condenser rotor wipers, and to make certain that all grounding and other contacts are mechanically and electrically good before proceeding with signal-tracing tests. Noisy controls may cause intermittent operation; these and other obvious troubles should be first corrected.

The Signal Source

A good test oscillator will be needed for most signal-tracing tests. Such an instrument provides a signal which can be controlled as to strength and frequency and also permits a steady modulating voltage. However, in making aural observations of distortion in receiver circuits, a broadcast signal is preferable because it is easier to note distortion in music or speech than on the single-tone modulation which is so universally used with test oscillators. In using an oscillograph for distortion testing, the single-tone signal is necessary, since the departure from a pure tone is readily noted on the oscillograph screen while a varying complex tone would be impossible to check. For gain-per-stage measurements in audio-frequency circuits, a steady modulation is likewise essential.

In checking for noise, hum, oscillation, and other troubles which are present when no signal is being fed to the receiver, the noise, hum or oscillation itself constitutes the signal and is traced in the same manner. In such cases, you do not need an external signal source.

The test signal frequency should be adjusted to some point near the low-frequency end of the standard broadcast band, such as 600 kc. If some local broadcast signal causes interference when the test oscillator is connected to the receiver and the set is tuned to 600 kc, then the test oscillator may be readjusted to a point either higher or lower in frequency, where no interference occurs.

It is apparent that a signal-tracing test at a frequency within the standard broadcast band is applicable even to an all-wave receiver, for the purpose of trouble localization. If the trouble is common to all bands, then it may be localized by testing on the standard broadcast band. If the trouble is present only on a short-wave band, then it must be due to some defect in the r-f,

mixer or oscillator sections, since all other sections of the receiver function the same on all bands. The oscillator and mixer sections may be separately checked, thus narrowing the search for the defective component to the few remaining parts in the r-f section.

A test signal frequency in the vicinity of 600 kc is chosen because the gang condenser tuning capacity will be high at this frequency and the slight additional capacity which is added when a test probe is connected to the circuit will cause negligible detuning effect.

A dummy antenna, such as is recommended for alignment purposes in servicing, is desirable though not essential for signal tracing. A small, fixed condenser of the capacity recommended for aligning by the manufacturer of the receiver under test is satisfactory.

Signal Tracing in Inoperative Receivers

Now, let us assume that we have before us on the test bench an inoperative receiver. Since the receiver will not reproduce any signal which is fed to its input circuit, we know that at some point along the normal signal path, some defect exists which causes the signal to disappear. This trouble may be present in the very first circuit we test; in that case, no matter how well stages which follow may be performing, the signal will not be passed along to them. Again, the trouble may occur at the fourth or fifth test point, or even at the last point of test. Then we shall find the signal normal at all preceding points along our test path. Our signal-tracing tests continue stage-by-stage as long as we find a normal signal present at each test point. But when we reach the point where no signal is present, we check the components which affect the signal at that point until the defect is located. This stage-by-stage test enables us to uncover many faults which otherwise might pass unnoticed, since we can make certain that each tube and circuit is performing as it should be proceeding to the next test point.

In Fig. 9-1, we show a partial schematic of this receiver which we are to test by signal tracing. This is a diagram of a conventional a-c superheterodyne employing an r-f stage, a combination mixer-oscillator, one i-f stage and a dual-function second detector and avc diode. This receiver normally operates over the

standard broadcast band, from 540 kc to 1700 kc. Variations of this circuit will be discussed later.

Since this receiver is inoperative, we shall assume that a wattage consumption test has already been made and has shown that no serious trouble exists in the power supply. Therefore we can apply our signal-tracing tests. Connecting our test oscillator leads to the antenna and ground terminals of the receiver, we tune both the receiver and the test oscillator to 600 kc. We make

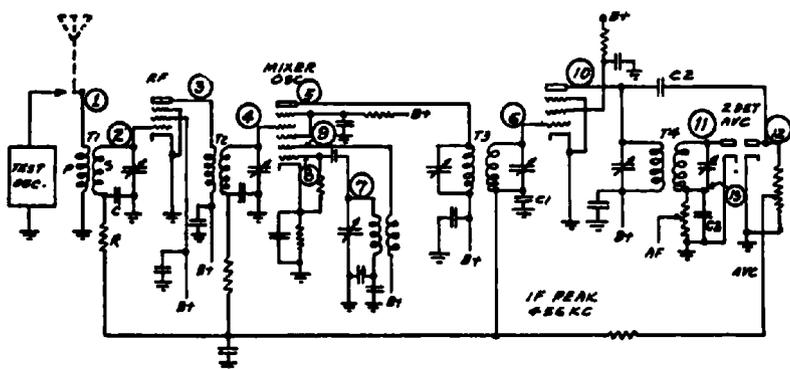


FIG. 9-1. Partial schematic of a typical receiver which is analyzed in the text from a signal-tracing viewpoint.

certain that the signal is actually being applied to the receiver by placing the isolating probe of our tuned v-t voltmeter upon the antenna terminal and tuning the voltmeter to the test signal frequency. The test-oscillator attenuator is then adjusted until an indication is obtained on the tuned v-t voltmeter output indicator. The indication so obtained should be one that can be readily duplicated; if a channel "eye" is the indicating device, the eye should just close. If a meter indicator is used, the pointer deflection should be noted. This indication is termed the "reference level" and will be required for gain-per-stage measurements.

If we have previously used the test oscillator and tuned v-t voltmeter on a normally operating receiver, we know just about where the test-oscillator attenuator should be adjusted to produce this reference level. It is possible that when we connect the test

oscillator to an inoperative receiver we shall not be able to obtain sufficient signal output from the test oscillator to produce this reference level. Let us see what could cause this condition. Examining the diagram, we note that the test oscillator is supposed to be connected across the antenna and ground terminals of the receiver, which in turn are across the primary of the antenna transformer. Now, if this antenna coil is shorted or the antenna post has become grounded in some manner, we shall be unable to obtain our desired reference level. Therefore, the input to the receiver is short-circuited and this trouble must be cleared before the receiver can operate.

If the antenna transformer primary circuit is open, then we shall obtain our reference indication when checking the signal at point 1, but this signal will not be present at point 2, which is the next point of test along the natural path of the signal. The test at point 2 may be made by placing the test probe either on the control-grid cap of the first r-f tube or on the stator of the tuning condenser. The latter test point is more conveniently accessible when the receiver employs single-ended tubes, such as the 6SK7. At point 2, the signal should be stronger than at point 1, since there is a voltage step-up in the antenna transformer. We can measure this gain in signal strength, but in the case of an inoperative receiver we are primarily interested in finding the point where the signal disappears completely and not in the actual gain.

Absence of the signal at point 2 could be caused by a shorted tuning or trimmer condenser, control-grid to cathode short in the r-f tube, or open-circuited antenna transformer secondary. If the signal is absent at this point, we check this portion of the circuit by visual examination and ohmmeter measurements until the fault is located. If the signal is present, we continue tracing the signal.

The next point of test may be either point 3, the r-f tube plate, or point 4, the mixer control grid or the stator of the tuning condenser. The latter point is usually more accessible. If the signal is absent at point 4, we can check back to point 3. If present at point 3, then the trouble must be in the mixer input circuit, and could be caused by defects similar to those enumerated above. No signal at point 3 would indicate some trouble in the r-f tube circuit, such as an open transformer primary, open or shorted

voltage supply to the screen grid or plate, open cathode, or some defect in the tube itself.

If the signal is present at point 4, then we may proceed to check the set oscillator at point 7 in the manner described in Chapter 5. The oscillator signal frequency should be 1056 kc when the receiver is tuned to 600 kc, thus combining with the incoming signal to produce the required intermediate frequency, 456 kc. If the oscillator is functioning properly, signal tracing continues by testing the i-f signal at either point 5 or point 6, followed by tests at point 10 and point 11. Since the intermediate signal frequency is 456 kc, the tuned tube voltmeter should be adjusted to this frequency when checking the i-f amplifier circuits.

Sectional Trouble Localization

If the i-f signal is present at the second detector plate, this is conclusive evidence that the r-f, mixer, oscillator and i-f sections of the receiver are in operating condition. When the receiver under test is inoperative, such as we are considering now, presence of the i-f signal at point 11 immediately localizes the trouble in the detector or a-f system. By the same token, absence of the i-f signal at point 11 indicates that the source of trouble exists in or ahead of the second detector. For rapid trouble localization in inoperative receivers, it is often convenient to check the signal at point 11 *first*, thus confining stage-by-stage tests to a limited number of stages. This test is applicable to any superheterodyne receiver, whether or not avc is employed.

In receivers employing avc, a measurement of the avc voltage which should result from a strong signal applied to the receiver input can likewise be used to localize the cause of failure to operate. Failure to obtain an avc voltage reading indicates that stage-by-stage tests of the sections ahead of the avc tube are necessary, while the presence of avc voltage indicates that all sections ahead of the avc tube are functioning. Signal tracing, in the latter case, can then start at the second detector.

Tracing the A-F Signal in Inoperative Receivers

Now that we have followed the signal through the r-f, mixer and i-f stages to the second detector, the next step is to trace the signal through the audio system. A typical detector-audio sys-

tem is shown in Fig. 9-2. The audio signal should first appear across $R1$ and $R2$. To test this signal, we shall require a test instrument or channel capable of indicating a-f voltages and having an input impedance which is high in comparison with that of the circuit under test. Suitable apparatus for the purpose is described in Chapter 12.

The normal path of the audio signal corresponds to the numerical order of the numbered points on the diagram, Fig. 9-2. To

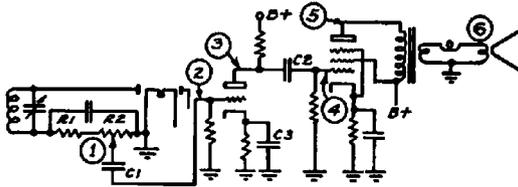


FIG. 9-2. A typical second detector-audio system. Signal tracing in this circuit is discussed in the text.

trace the audio signal, place the a-f probe on point 1, making certain that the volume control is at maximum. If no audio signal is present, (indicated by failure of the test instrument to show a reading), check the components in this circuit. If the signal is present at point 1, continue signal tracing by placing the probe on point 2, thus checking the signal transfer through the a-f coupling condenser $C1$. Absence of the signal at point 2 indicates an open circuit, since a short-circuit would likewise eliminate the signal at point 1.

At point 3, the signal will normally be amplified and will be so indicated on the a-f test instrument. The amount of amplification or gain which thus results is of no consequence for this test, since our primary concern with an inoperative receiver is in finding the point in the normal signal path where the signal *first* disappears, and not the relative strength of the signal at the various test points. When this desired point is reached, we test the components affecting the operation of that particular circuit under test until the defective component is located, just as was described in signal tracing through the r-f and i-f sections. At point 3, absence of the a-f signal might indicate an open plate resistor, an

open cathode resistor or a grounded plate in that specific stage. The same reasoning applies in signal testing at any other of the numbered test points in the amplifier circuit. If the signal is present even at the last test point, 6, we know the speaker circuit is at fault, since no sound results.

Signal Tracing in Weak Receivers

If the receiver operates but the sound volume is below normal, we know that the signal must be present at all points along its normal path but that some portion of the set is not functioning at full efficiency. Our first test, as with inoperative receivers, is to measure the wattage consumption. Power supply overload, resulting from a short-circuit in some portion of the voltage distribution net work, will be indicated by excessive wattage consumption, if of sufficient magnitude. Minor breakdowns, such as by-pass condensers in resistance-capacity filters, will not cause sufficient increase in power consumption to be readily recognized in this preliminary test, though such breakdowns are quickly detected by signal tracing. If the power consumption is excessive, the first step is to check the power supply system. If no excessive wattage reading is obtained, we trace the signal along the same path as for inoperative receivers.

In tracing the signal in an inoperative receiver, our interest is confined to determining whether or not the signal is present at each test point. In weak receivers, however, we are interested in the *strength* of the signal at each of these test points. We know that r-f, i-f and a-f amplification, and mixer conversion gain in a superheterodyne receiver, are determining factors in the ultimate strength of the signal which is fed to the speaker. Therefore our tests must include a measurement of the gain which occurs in each amplifying stage. In modern receivers, precision measurements of gain-per-stage are not necessary in servicing, since the sensitivity normally available is usually considerably in excess of that actually required for satisfactory reception. When reception is weak, then it usually means that a very great reduction in gain, or even a loss, occurs in one or more amplifying stages. Just what the normal gain per stage should be varies widely in different receivers, but the table of average gain-per-stage values given on page 279 will provide sufficient guidance to determine if

any serious trouble is present in the tubes or circuits under test. After each receiver is repaired, it is a good idea to mark the stage gain on the schematic for future reference.

Let us refer again to the partial schematic shown in Fig. 9-1. We shall assume that the test oscillator is connected to the antenna and ground terminals of the receiver and a 600-kc signal, modulated at an audio frequency, is being fed to the operating receiver. After tuning the set to 600 kc, the tuned v-t voltmeter probe is placed upon the antenna post, point 1, and the signal reference level is determined in the manner described before. This reference level is noted on the channel indicator eye or meter, if a Rider Chanalyst is used, or on the indicating device provided in whatever other type of instrument is being used for this test.

When we place the probe on point 2, an *increase* in signal strength should be indicated by the testing device. This signal amplification or gain is produced entirely by transformer action when the secondary circuit is tuned to resonance with the signal frequency. Therefore, this gain should be indicated even if the receiver power switch is turned off, since no tube amplification takes place in the antenna circuit. The gain from point 1 to point 2 will vary between 2 and 10 in home receivers, averaging around 5.

If a loss, instead of a gain, is indicated at point 2, then some trouble must be present in this circuit. If the by-pass condenser *C* were shorted, no AVC bias would be applied to the r-f tube control grid; consequently, grid current would flow when a signal voltage reached the grid. This condition would reduce the gain by loading the secondary circuit. A simple check is to turn the set off while noting the signal level at the control grid. If the gain increases appreciably, then some loading effect is taking place. A slight change in gain, while making this test, is normal because of the slight change in tube input capacitance which results when the r-f tube is not operating; this may be corrected by re-tuning the secondary circuit.

An open-circuited secondary will cause a severe loss in signal strength, though the capacity-coupling through the tube and transformer will provide a faint signal which will be amplified and reproduced by the speaker. If the signal gain is normal at point 2, we continue our tests by placing the probe at point 4. At this

point, we are measuring the overall gain from point 1 to point 4, which embraces the gain in the antenna coil previously measured plus the gain of the r-f tube and T_2 . There should be a slight increase in signal level at point 4, above that obtained at point 2. The actual gain will be dependent upon the strength of the incoming signal, since the r-f tube is controlled by avc. To obtain the true gain, the avc tube should be removed or the avc rendered inoperative in some other manner. When this is done, the overall gain should increase. If the gain to point 2 were 5, then the overall gain to point 4 should become 50 or more. This means that the r-f tube and circuit would contribute a gain of 10 or more. With the avc acting, and an input signal of 5 to 10 millivolts at the antenna, the overall gain will range from 10 to 30 or more.

Our primary interest in checking the gain at point 4, however, is to find out if the signal strength increases or decreases at this point, over and above the reading obtained at point 2. If a slight loss is indicated, then the r-f tube and alignment may require checking. Poor tracking, however, seldom causes sufficient loss to cause weak reception since the first effect is to decrease the avc voltage, which in turn increases the gain. A severe loss, though, indicates a major defect in the operation of the circuit and warrants a test of the voltages and components affecting the operation of this circuit.

Assuming that a normal signal is found at point 4, the next step is to check the i-f signal at point 5 or point 6. This test is made by tuning the tube voltmeter to 456 kc and measuring the signal level. As a result of conversion gain in the mixer, the i-f signal should be stronger than the r-f signal at the mixer control grid. Again, the conversion gain will be decreased by avc action, and in case little or no gain is obtained, the avc voltage should be measured. (Complete information on avc testing is given in Chapter 7.) If a conversion loss is indicated when the i-f signal is measured at point 6, place the test probe on point 5. If conversion gain is present at point 5, then the loss is due to some trouble in the coupling circuit. Normally, there is no gain in the i-f transformer and in many designs a slight loss is normal. But if the signal level at point 6 is considerably below that at point 5, the circuit is not operating properly. Perhaps the trouble

is simply misalignment. (In this connection, remember that the application of the test probe has some detuning effect, which may be appreciable with some tuned v-t voltmeters in which the probe capacity is in excess of 1 or 2 $\mu\text{f.}$) A decrease in the coupling between the primary and secondary coils of *T3*, loosening or shorting of turns in the secondary winding, loading due to grid current in the i-f tube; these are a few possible causes.

Conversion loss, as measured at point *5*, the mixer plate, may result from misalignment, incorrect voltages on the mixer tube elements, open screen or B-supply by-pass condensers, low oscillator voltage, or a defective mixer tube. Another cause, often difficult to locate by other test methods, is lowering of the i-f transformer efficiency due to moisture absorption. If the possible sources of difficulty mentioned previously, have been eliminated, the i-f transformer should be checked by substitution. By signal tracing, we localize the trouble to the specific circuit.

A quick test of the screen by-pass condenser in the mixer circuit can be made without removing the condenser or unsoldering leads. This is done by placing the test probe of the tuned v-t voltmeter on the screen socket terminal and checking for the presence of the i-f signal at this point. If the screen by-pass condenser is open, a strong i-f signal will be noted; if the by-pass condenser is functioning properly, the i-f signal will be by-passed, hence little or no signal will be indicated, depending upon the sensitivity of the test instrument. In making this test, some signal pickup will be noted when the probe is held near, but not on, the screen socket terminal, due to the stray field and capacity-coupling to the plate lead. This signal level should be greatly reduced when the probe is actually in contact with the by-passed terminal, though some slight pickup may still be noted. This functional test of by-pass action can be applied in any portion of the radio receiver and is particularly useful in a-f circuits, where stray pickup effects are not present.

Continuing our signal-tracing tests, we check next the i-f signal at point *10*. There should be considerable amplification in this i-f stage, as indicated in the gain-per-stage values given on page 279. Therefore, the signal level should be much higher at point *10* than at point *6*. Low gain can be investigated in the same manner as we have just discussed above. At point *12*, we

check the i-f signal transfer from the plate of the i-f tube to the avc diode rectifier. Absence of any signal at point 12 would make the avc system inoperative; this trouble could be caused by a short-circuit in the avc diode plate circuit or an open-circuit in C2 or its connecting leads to the diode plate and the i-f plate.

The signal transfer to the second detector diode is checked at point 11. The loading effect of the diode on the i-f transformer secondary causes the signal level at the diode plate to be normally less than at the i-f tube plate. This step-down in voltage ranges from approximately 1.5 to 1 to 3 to 1. The i-f signal should be by-passed by C3, so no i-f signal should be present at point 13. If C3, or its connecting leads are open, a strong i-f signal will be noted when the i-f test probe is placed on point 13. Possible causes of low gain in the i-f stage are similar to those discussed previously and may be checked in like manner.

Tracing the A-F Signal in Weak Receivers

If tests of the r-f and i-f sections of the receiver have shown a strong signal at the second detector, then in all probability the audio amplifier is not providing sufficient gain so that the speaker can operate properly. If the speaker field is in shunt with the power supply, we can make a preliminary check for field excitation by placing a screwdriver or other magnetic metal object against the speaker core and noting the magnetic attraction which should result. If this check indicates field excitation is present, then we may proceed with gain measurements in the a-f system.

The A-F Reference Level. The first step is to obtain an a-f reference level. With the signal generator still feeding a modulated r-f signal to the receiver input, turn the receiver volume control to maximum and place the test probe of the a-f test instrument on point 1 in Fig. 9-2. Adjust the sensitivity of the test instrument to maximum and adjust the attenuator of the test oscillator until sufficient audio signal is present at point 1 to give a reference indication on the a-f indicating device.

Now move the test probe to point 2. The signal level should remain substantially the same as at point 1. If the signal is appreciably weaker, check for grid current at point 2, using an electronic or v-t voltmeter designed to measure d-c. Grid current will cause a negative voltage to be developed at point 2, due

to rectification. This condition would be caused by a shorted cathode by-pass condenser *C3*, or a cathode-heater short in the first a-f tube.

If the signal is normal at point 2, place the a-f probe on point 3. If the first a-f tube is a high- μ triode, we should expect a gain of about 30 at this point. (See Table of Average Gain-per-Stage Values, page 279.) Low gain at this point could be caused by a defective tube, incorrect cathode or plate voltage, or some trouble in the plate load circuit. A shorted coupling condenser *C2* could cause this trouble, since then the plate voltage would be applied to the power tube grid, causing grid current and thus loading the output circuit of the a-f tube.

The a-f signal at point 4 should be substantially the same as that at point 3. A severe drop in signal voltage would result from a high-resistance joint in the coupling condenser lead connections or at other junctions between points 3 and 4. This condition could likewise be caused by a shorted cathode bias on the power tube, resulting in grid current and rectification of an applied signal. A gassy power tube would also cause a decrease in signal level at point 4. Grid current due to rectification causes a voltage drop in such direction that the power tube grid becomes *negative* with respect to the grid return point; grid current due to gas causes the grid to become *positive* with respect to the grid return point.

If the signal is normal at point 4, check the signal level at point 5, the power tube plate. The signal should be further amplified at this point. Normally, the gain will range from 8 to 20 when pentode power tubes are employed. Decreased gain will result from faults in the power tube, incorrect voltages, short-circuited turns in the output transformer primary or a shorted secondary winding.

The maximum signal voltage is developed at the output tube plate. This signal voltage is stepped down by the output transformer, since the speaker voice coil is a low-impedance circuit. Therefore, the signal voltage at the voice coil is much lower than at the plate. A voltage step-down of at least 25 to 1 is normal, when checking from a power pentode tube plate to a 10-ohm voice coil. Transformer losses, which are especially high in low-priced receivers, will lower still further the voltage at the voice coil.

If the signal is normal even at the last test point, the trouble must be in the speaker voice coil in its connections to the output transformer secondary, or in the field.

Tracing Noise

When noise is present in a receiver, the noise is our signal and we require no test oscillator signal. We trace the noise just as we would trace a radio signal, with the object of finding out just where, along the normal path of the signal, the noise *first* appears.

It is better to trace noise by means of an aural test, by plugging phones in the output jack of the test instrument, since the character of the noise heard in the phones can be compared with that reproduced by the speaker and the noise can then be definitely identified.

Referring again to Fig. 9-2, the test probe is placed on each test point in numerical order until the presence of noise is indicated. In r-f and i-f sections of the receiver, the tuned v-t voltmeter is used, while for power-supply and a-f checking, the a-f v-t voltmeter is employed. If noise is found at the plate of an amplifying tube, check the noise level at the B-plus terminal. If the noise level is the same at both points, the power supply should be checked for noise. If the noise level is high, fluctuating voltages will result which will cause noise in all stages of the receiver. By checking the power-supply components, the defective component or connection can be located.

In receivers employing AVC, it is often possible to make a general localization of the noise by simply turning the volume control from maximum to minimum setting and noting if the noise level changes. If the noise disappears with the volume control at minimum setting, then the trouble is not in the power-supply section which feeds the a-f tubes. If the noise is equally loud at both volume control settings, then the trouble is in the a-f or power-supply sections.

If noise is found at the plate terminal of a socket but not at the grid, the tube may be at fault; this can be checked quite simply by substituting another tube. In transformer-coupled a-f stages, the interstage transformer occasionally may cause noise due to electrolysis or other defects. This trouble is readily localized, once the tube has been eliminated as a possible cause. When the

noise is not present at the tube grid, but is noted at the plate, check the noise level at the B plus and plate terminals of the transformer primary winding. If the noise is much stronger at the plate, the transformer is at fault. If the noise is equally strong at the B plus and plate terminals, the trouble is not in the transformer. The secondary circuit may be checked in like manner. This same type of test is applicable to r-f, i-f and a-f transformers.

Tracing Hum

The cause of excessive hum is likewise located without the use of a test oscillator. Either headphones or the cathode-ray oscillograph may be plugged into the a-f test instrument output jack. The relative hum levels at various points may then be determined, thus checking the efficiency of hum filtration circuits.

Since the cause of excessive hum is most likely to be found in the power-supply circuit, it is best to start testing at its point of origin—at point 1 in Fig. 9-3. At this point, the hum level should be highest and at all subsequent test points in the filter circuits the hum level should decrease.

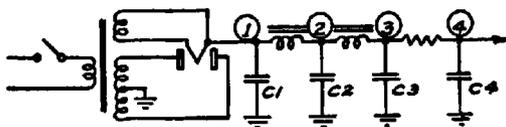


FIG. 9-3. The hum levels in this power supply circuit are discussed in the text.

In tracing hum, place the a-f test probe on point 1 and note the hum voltage registered on the test instrument indicator or adjust the input control of the test instrument until a moderate hum level is heard in the phones or indicated on the oscillograph, depending upon the method of observation used.

When the probe is moved to point 2, the hum level should be lower. If not, check the filter condenser $C1$ and if necessary the first filter choke. An open condenser or a shorted choke could cause this trouble. Severe overload of the power supply may likewise cause excessive hum; this condition will be revealed by a

power consumption test which should precede a hum signal-tracing test.

Continue testing until a point in the filter circuits is found where no appreciable reduction in hum level occurs. Checking components at that point will quickly locate the trouble.

It should be noted that the hum level in midget receivers is normally considerably higher than in console sets. In the former, the speaker and baffle are so small that a higher hum level is permissible since it will not be reproduced efficiently.

The foregoing discussion covers the location of hum troubles in the main section of the power-supply high-voltage filter circuit. Hum which arises from defects in such filter systems is general throughout the receiver and objectionable whether or not a signal is being received. A similar effect will result from defective or improperly-adjusted hum balancers in receivers employing older filament-type tubes. Such devices, if present in the receiver under test, should of course be adjusted before proceeding with the tests. If adjustment does not affect the hum level, each hum balancer should be checked. This can be done by testing for shorts or opens with an ohmmeter.

Most of the principal remaining causes of hum, which result from tube defects such as cathode leakage, shorted or open elements, poor ground connections, induction hum, shorted hum-bucking coils, and leaky coupling condensers can be localized by following the procedure for tracing noise. Carrier hum can be localized by feeding an *unmodulated* signal from the test oscillator and also tracing as for noise. The line by-pass condensers should also be checked. Also check the grounding of the power-transformer electrostatic shield, if the transformer is equipped with a shield.

Tracing Distortion

The signal generator or a broadcast signal will be required to test for distortion; likewise headphones or a cathode-ray oscillograph. If headphones are used, then a broadcast signal is preferable, since distortion of music or speech is more apparent than on a 400-cycle modulated signal. Alternatively, a signal generator modulated by recorded music or speech from an electrical pickup and amplifier may be used for headphone distortion tracing. If

a cathode-ray oscillograph is available, single-tone modulation as supplied with most test oscillators is essential. This modulation should be substantially free from distortion.

Distortion Tracing with the Oscillograph (R-F and I-F Circuits). Let us first consider the application of the tuned v-t voltmeter in connection with the oscillograph for distortion tracing. The receiver is set up for test in the manner already described for signal tracing. Instead of checking the signal level at each test point, we examine the waveform of the signal as it passes from stage to stage. This waveform is compared with an initial image, representing that of the signal at the receiver input. Should the two waveforms differ, some receiver circuit is adding distortion. Components affecting the operation of the receiver, at the point in the normal signal path where distortion is first noted, are then checked until the trouble is located. By using the oscillograph in connection with the tuned v-t voltmeter and the isolating probe, it is possible to test for distortion in tuned circuits without disturbing the circuit under test.

With the test oscillator feeding a 600-kc modulated signal to the receiver input, our first step is to obtain our initial reference waveform. The oscillograph is connected to the output jack of the tuned v-t voltmeter, the test probe of the latter is placed on point 1 of Fig. 9-1 and a strong, modulated signal is fed to the receiver. The oscillograph vertical-amplifier gain control is then adjusted until an image of convenient height appears. The horizontal sweep is then adjusted until the wave is synchronized. This is the initial reference waveform.

We can now check the signal waveform at any point in the r-f or i-f system. To save time, it is convenient to test first at readily accessible points, such as the control grid of each tube in the r-f, mixer and i-f sections. At each of these test points, the signal should become progressively stronger. Therefore, the image on the oscillograph will correspondingly increase in height. DO NOT change the oscillograph amplifier adjustments; maintain an image of constant height by readjusting the input controls to the tuned v-t voltmeter or by decreasing the signal from the test oscillator, if the receiver under test is not equipped with avc. This is done to avoid overloading of the tuned v-t voltmeter. It is desirable to maintain a fairly strong signal, when the

receiver employs *avc*, since distortion is often caused by defective *avc* action and this condition will not be evident on weak signals.

To proceed with our testing, place the test probe on the input to the following stage at point 4. After adjusting the oscillograph image height, examine the image for distortion and note if the image is perceptibly different from that of the initial reference waveform. If regeneration is present, or if the input grid is drawing current, the waveform will be altered. Other defective conditions can likewise cause distortion at this point. Checking *avc* voltage, tube voltages, wiring and components affecting the operation of this stage will reveal the cause.

Distortion Tracing with Headphones (R-F and I-F Circuits). The procedure for tracing distortion with headphones in place of the oscillograph is substantially the same as that described above. Our initial reference signal should be a weak but clear signal in the headphones, as picked up at the receiver antenna post when the set is connected to a good antenna and a broadcast program is being received. If the set employs *avc*, the volume control should be set at minimum while checking the r-f and i-f systems, to avoid masking the signal by the operation of the loudspeaker. Alternatively, the speaker voice coil circuit may be opened or shorted. The latter will be desirable when a set without *avc* is being tested and for a-f system tests.

Testing follows the usual signal-tracing order. The character of the signal at the point on which the test probe is placed is compared with that at the antenna post by simply replacing the probe on the antenna post from time to time, and readjusting the input controls of the tuned v-t voltmeter to keep a constant signal level.

Distortion Tracing (A-F Circuits)

To localize distortion in a-f systems, the a-f v-t voltmeter or channel is used in connection either with headphones or an oscillograph as a distortion indicator. The reference audio signal is developed first across the diode load and should be observed at a point corresponding to point 1 in Fig. 9-2, in the receiver under test. This a-f signal should be of sufficient intensity to be clearly audible in headphones connected to the output of the a-f testing device.

If the reference a-f signal is distorted, then there is trouble in the circuit under test or in the character of the modulated signal

produced by the test oscillator. The test oscillator signal may be checked by noting the character of the modulation as indicated by a test in the r-f system of the receiver, as described in r-f and i-f testing procedures given before. If there is slight distortion in the test oscillator signal, this will not preclude its being used for test purposes. We need merely to note any *increase* in distortion which occurs during the signal tracing tests.

If we have our test probe on point 1 in Fig. 9-2 and we have determined that distortion is present, let us see what the cause might be. We note that point 1 is coupled to point 2 by means of the coupling condenser C1. Then any distortion which may be present at point 2 will likewise be noted at point 1. If the cathode by-pass condenser C3 were shorted, then there would be no grid bias on the first a-f tube. Consequently, any a-f signal applied at point 2 would cause the grid to draw current on the positive half of the signal wave, thereby causing distortion. If there were no plate voltage on the first a-f tube, the same effect would be noted; for then there would be no plate or cathode current, therefore no voltage drop across the cathode resistor would appear and consequently there would be no grid bias voltage for the first a-f tube. So distortion results, just as in the preceding case.

The same condition occurs when the a-f test probe is placed on point 3. Any defect which causes the power-tube grid to draw current in this type of circuit will cause distortion at point 3 as well as at point 4. In any case where distortion is noted, it is well to check for grid current, using a microammeter or an electronic voltmeter. Care should be taken that the circuit is not being overloaded by using too high a test signal voltage. In such cases, grid current will show even if the circuit is normal. If the cathode bias or the grid-bias voltage is normal, then the tube is being overloaded. If the tube is gassy, a *positive* rather than a *negative* voltage will appear at the power tube grid, with no signal input. This voltage is positive with respect to the grid return point and tends to buck the normal negative bias; therefore it limits the signal voltage which may be applied at point 4 without causing distortion.

Another cause of a positive voltage at point 4 is leakage in C2. A simple method of differentiating between these two causes of

positive voltage at this point is to connect an electronic or v-t voltmeter to point 4, with the set turned off. When the set is turned on, if the positive voltage is the result of condenser leakage, then the voltage will appear as soon as the receiver power supply operates; if the voltage is due to gas, it will take some time to reach a maximum, usually several minutes.

Tracing Oscillation

Oscillation may occur in either the r-f, i-f, or a-f sections of the receiver as a result of incorrect operating conditions in a single circuit or from coupling between two or more stages. If oscillation occurs in a single r-f stage, it may appear that the entire receiver is oscillating since the resulting r-f oscillation is heterodyned by the set oscillator, passes through the i-f stages, and often has sufficient amplitude to affect the operation of the a-f stages. Oscillation in a single i-f stage will likewise affect the entire a-f amplifier and perhaps the a-f system.

A preliminary operating test will suffice to give a general localization of the oscillation. If i-f oscillation is present, it will be unaffected by the tuning of the r-f system. Thus, rotating the gang condenser over the tuning range will not affect the characteristics of i-f oscillation. If r-f oscillation is present, however, the oscillation will be stronger at one point than at another; in some cases, oscillation will be present at one end of the band but not at the other.

In some cases, oscillation occurs only when a signal is applied to the receiver. When this is the case, a test oscillator should be used to supply the signal so that the dynamic operating conditions under which the difficulty is observed, are present during the test.

Before tracing the oscillation, the usual preliminary service adjustments should be made. These have been mentioned previously and include cleaning and tightening gang condenser wiping contacts and corroded ground connection; checking tubes; and a rapid check to see that no wires are obviously misplaced. Make certain that the antenna lead does not run close to the amplifying stages or tubes of the receiver; often coupling in this manner will cause oscillation which is not present in normal operation.

Assuming that r-f or i-f oscillation is present with no applied test signal, then the trouble is localized by tuning the v-t voltmeter to the approximate frequency of the r-f circuit—600-kc if the receiver is tuned to that frequency—and noting where the strongest signal is picked up. If there are several r-f or i-f stages, the oscillating stage will usually develop the highest signal voltage. So the test probe is placed on each tube grid or plate until this point of highest signal voltage is located. It will usually be found that a strong signal will be picked up when the probe is held anywhere in the vicinity of the r-f amplifier, but this stray pickup will not interfere with the tests. When the probe is placed upon a signal test point, and the sensitivity of the v-t voltmeter is properly adjusted, the effect of this stray pickup is largely overcome.

If oscillation is due to common coupling between stages, then the relative signal voltage due to the oscillation will not prove an accurate guide to localization of the trouble. However, if common coupling is the cause, the localization of the oscillation is usually quite simple. With the test probe connected to a signal test point in one stage, simply ground the control grid (through a large condenser, 0.1 μ f, for instance) of each of the other stages in turn until the oscillation ceases. Coupling is then present between the tube under test and the tube with the grounded grid.

The cause of the trouble is located by checking each of the components and circuits which are common to each of the oscillating stages, with particular reference to ground connections, open by-pass condensers, misplaced leads, and loose coil shields.

Tracing Audio Oscillation

Motor-boating, or intermittent blocking, is often caused by defective decoupling of filter circuits in the power supply, by open grid circuits in amplifying stages, or by feedback due to improper placement of leads or components. To locate the cause of motor-boating when present with no applied signal, ground or short-circuit the control grid of one of the a-f tubes so that the trouble is no longer present. Then check the condensers in the power supply and decoupling filter circuits, following the routine described for locating open condensers. If any by-pass or filter condenser is open, the hum filtering action will be absent or

greatly reduced, so a relatively high hum level will be noted at the point which is normally by-passed. Open grid circuits are most easily located by shunting a resistor corresponding to the value normally used in such circuits from each grid in turn to ground or to its normal return point. When the resistor is shunted across the open grid circuit, the trouble will disappear.

Spurious oscillations are occasionally encountered in pentode and beam-power tube output circuits. This can be checked in the same way as noise but the channel eye or meter indicator should be used rather than headphones, since the oscillations are often above audible frequencies. When the test probe is placed on the grid or plate terminal of the affected tube, a high signal voltage will be registered due to the oscillation. If the stage components are in normal condition, and substitution of another tube does not eliminate the oscillation, the filter components and especially the plate by-pass condensers should be checked.

Signal Tracing in Phase Inverter Circuits

A typical phase inverter circuit is shown in Fig. 9-4. If the phase inversion is operating properly, the signal voltages applied to each push-pull grid will be equal but opposite in phase; that

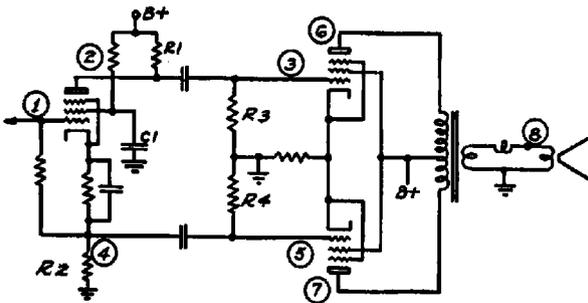


FIG. 9-4. A typical phase inverter circuit. Signal tracing in circuits of this type is discussed in the text.

is, at the instant when the signal reaches a maximum on the positive half of the cycle at point 3, it reaches a maximum on the negative half of the cycle at point 5. In this type of circuit, $R1$

equals R_2 and R_3 equals R_4 . The coupling condensers are likewise identical.

In signal tracing, the audio signal voltage at point 2 should be measured and compared with that at point 4. These signal voltages should be equal. Minor differences in the readings are of no consequence, but a large difference means trouble in the circuit. A change in value of R_1 or R_2 , or of R_3 or R_4 , would cause inequality of signal voltage; likewise, an open- or short-circuited coupling condenser between points 2 and 3, and between points 4 and 5. Slight unbalance in the signal voltages applied to the push-pull grids is usually corrected at the output plates, points 6 and 7. While these tests do not take into consideration the phase relations between the voltages applied to the push-pull grids, the tests indicated are adequate to determine if the circuit is performing properly and to localize troubles when present.

Signal Tracing With a Signal Generator

In preceding chapters, we have discussed alternative test methods in many circuits by which the test signal is introduced at some point other than the input terminals of the receiver under test. It is possible to test sections of the receiver in this manner, though most signal generators designed for service work do not permit such tests to be made with the accuracy and convenience which is possible with special signal-tracing instruments. Further, some circuits cannot be directly tested because of the loading effect of the signal generator output circuit upon the circuit under test. Gain-per-stage measurements are possible only if the signal generator attenuator is accurately calibrated, which is seldom the case with low-priced instruments. Despite these and other limitations, this method has its place in signal-tracing procedure and can be used to supplement standard signal-tracing apparatus in special cases.

In making the tests to be described, it is assumed that the signal generator to be employed is an all-wave type, equipped with a calibrated attenuator and with facilities for providing not only modulated r-f signals but also a pure a-f signal which may be varied as to voltage. Alternatively, an audio oscillator may be used for signal tracing in the a-f portions of the receiver.

An output meter, capable of reading low a-c voltages, will be

required as an output level indicator. This meter should be preferably a v-t voltmeter, such as is used for a-f testing in standard signal-tracing apparatus, though any other standard output meter will suffice.

In signal tracing by this method, testing starts at the *last* stage of the receiver rather than at the first stage, as with standard signal-tracing apparatus. Therefore, in Fig. 9-5, which represents a typical superheterodyne receiver circuit, the test points are

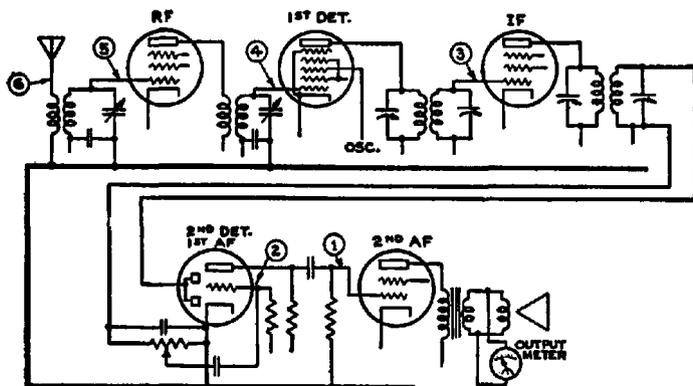


FIG. 9-5. Skeleton diagram of a typical superheterodyne receiver. The operation of the receiver is checked by determining the signal level, at each of the stages, which is required to produce a standard reference output at the voice coil.

numbered consecutively with the first test point at the last a-f grid. The output meter is connected across the speaker voice coil.

The first step is to feed an audio signal, which may be a 400-cycle note, to the last a-f grid. The attenuator on the signal generator or audio oscillator should be adjusted to give a convenient reading on the output meter, though care should be taken that the signal voltage is not so high that the output tube is overloaded. The resulting reading on the output meter is the *reference level*.

Once this reference level is obtained, the signal is then fed to point 2, the first a-f grid. If the first a-f stage is operating normally, the output meter should increase. Now reduce the attenuator setting on the signal generator or audio oscillator until the original reference level is indicated on the output meter. The ratio of the signal voltage required to produce the reference level

at point 1 to that giving the same reference level reading when connected at point 2 represents the gain of the first a-f stage. Thus, if a 5-volt a-f signal were required to give the reference level reading at point 1, and a 0.1-volt signal produced the same output reading when the signal was introduced at point 2, the gain in the first a-f stage would be $5/0.1$, or 50.

At point 3, the signal is to be fed to the last i-f tube grid. Therefore it will be necessary to use an i-f signal, which must be modulated so it will be detected and amplified in the a-f amplifier and then appear across the output meter. This i-f signal must correspond in frequency to that of the i-f amplifier employed in the receiver under test. If the signal were 100 percent modulated, and the diode detector linear, then the signal gain in the last i-f stage would be determined in the same manner as that described for the a-f stage. Thus, if 0.1 volt, or 100,000 microvolts were required at point 2 for our reference output reading and 1000 microvolts, 100 percent modulated, were required at point 3 to produce the same reading, then the gain from point 3 to point 2 would be about 100. When the percentage modulation is lower, more signal voltage will be required at point 3 to give the same output meter reading, though the gain of the stage is the same. Thus, at 50-percent modulation, all other conditions remaining the same, 2000 microvolts would be required at point 3 when the gain is 100; at 25-percent modulation, 4000 microvolts would be required.

This dependence upon the percentage modulation in determining gain cannot be eliminated by introducing the i-f signal voltage across the diode load, because the signal generator would then be shunted across the diode load: even if a blocking condenser were used, the loading effect would be so great as to make the measurement useless. The limitations of the signal-generator output-meter method of signal-tracing in diode-circuit testing apply only to such circuits in which the diode load is in series with the detector input. In all other types of detector circuits, where the detector input circuit returns to ground or in which detection takes place in the plate circuit, gain in the last i-f stage may be measured in the same manner as in any other stage.

At point 4, either an i-f signal or an r-f signal can be used. If the r-f signal is employed, the conversion gain may be determined

as has already been described in Chapter 6. If an i-f signal is used, the result is an indication of the i-f gain of the mixer tube and circuit, but it does not establish whether frequency conversion is taking place.

The gain of the r-f stage is determined by the ratio of the r-f signal required at point 4 to give the reference output meter reading to that required at point 5 to produce the same reading. The antenna transformer gain is measured similarly by comparing the r-f signal ratios at points 5 and 6.

In making gain-per-stage measurements, it is desirable to ground the avc system, if accurate measurements are desired. For simple signal tracing, to locate inoperative stages, this is unnecessary.

If the grid returns in any of the circuits under test are not made directly to ground in the receiver, a blocking condenser should be used between the signal generator output lead and the point under test. In a-f and i-f circuits, an 0.1- μ f condenser should suffice; in r-f circuits, a .00025- μ f condenser is satisfactory. Neither of these values is critical.

In making tests of inoperative or very weak receivers, where gain measurements are not necessary for trouble localization, the test routine described above will provide a simple and quick method of localizing trouble.

Gain Measurements in Short-Wave Receivers

When the frequency range of the tuned v-t voltmeter employed for signal-tracing tests does not include short-wave bands, it is possible to combine the signal-generator gain test method with that of the straight signal-tracing method. This will not be necessary, of course, in commercial all-wave receivers, because failure to operate over a short-wave band when operation is secured on the broadcast band is conclusive evidence that the trouble is in the r-f or oscillator section. The latter is checked independently, as described in Chapter 5.

However, there are many special purpose receivers which operate only over short-wave bands. In such cases, r-f stages may be checked for gain by first feeding the test signal to the mixer grid, point 4 in Fig. 9-5, while the tuned v-t voltmeter is connected to some point in the i-f system, preferably the mixer plate. The

tuned v-t voltmeter is adjusted to the intermediate frequency and the test oscillator to some frequency within the tuning range of the receiver. The receiver is then tuned until an i-f signal is indicated on the tuned v-t voltmeter. A reference level is obtained in the same manner as for normal signal tracing. The signal generator is then connected to point 3, without changing the signal generator attenuator setting. The signal level indicated on the tuned v-t voltmeter should increase. By readjusting the level controls on the tuned v-t voltmeter until the reference level is again obtained, the gain of the r-f stage is determined by noting the reading of the v-t voltmeter level controls. This process may be repeated stage-by-stage, by moving the signal generator test probe to points 3, 4 and 5 and the overall gain of the r-f amplifier determined.

In cases where the intermediate frequency employed is likewise beyond the range of the tuned v-t voltmeter, an audio output meter may be employed. In order to avoid overload of the detector or a-f tubes, it is well to connect the output meter at the plate of the power tube, where a high signal level is permissible, and, for the initial reference reading, to use a relatively low output-meter reading. After the gain of one stage has been determined, and the signal generator is connected to a preceding stage, readjust the signal generator attenuator until the output meter indication returned to its initial reference reading. For example, with the test signal being fed to one stage, our output meter reading may be 5 volts. If the same value of test signal is fed to the preceding stage, and the output meter reading then becomes 50 volts, the stage gain is $50/5$ or 10. Now, if the gain in the next stage to be checked were also 10, the output meter reading should increase to 500 volts. This could not occur, however, because the a-f amplifier would be overloaded long before this voltage output was secured. By decreasing the signal voltage after measuring the gain of the first stage, and returning always to the initial reading of 5 volts, overload is avoided.

Signal Tracing in Tuned R-F Receivers

The method of tracing the signal in tuned r-f receivers does not differ from the procedure described for the r-f stages of superheterodynes. However, in multi-stage tuned r-f receivers, as well

as many of the smaller midgets, it will be found that regeneration is present, which will affect gain-per-stage measurements. In many small receivers, regeneration is incorporated purposely to increase gain and thus to improve the sensitivity without adding additional amplifying stages. Often an adjustment to control regeneration is supplied and, before attempting any stage gain measurements it is advisable to see that this adjustment is well below the point where regeneration is evident. In multi-stage r-f amplifiers, imperfect shielding and unavoidable coupling between stages often causes some regeneration even when the receiver is operating normally.

In connecting a signal generator across a tuned r-f stage for the purpose of stage gain measurement, the circuit shunted is very heavily loaded so that regeneration is thereby eliminated. Under such test conditions, the measured stage gain will be less than is actually present when the signal generator is disconnected from the circuit. Even with the isolating probe supplied with tuned v-t voltmeters, some reaction on regenerative circuits will be apparent and will affect the accuracy of stage gain measurements. From a servicing standpoint, however, these effects are of little significance. The primary object of signal tracing is not to make precision measurements of the performance of individual sections of a receiver, but to find troubles which interfere with the customer's enjoyment of the set; such troubles will not be insignificant variations from normal performance—they will stand out prominently. So don't make a hard job out of the signal tracing routine—just run through the procedure quickly, watching for wide variations from expected results and not for trifles.

Receiver Alignment With Signal-Tracing Instruments

If desired, signal-tracing apparatus can be used for broadcast-band receiver alignment without the usual necessity for rocking the gang condenser at the low-frequency end of the range. On short-wave bands, the oscillator operating frequency is definitely established and the danger of aligning to the image frequency is thus avoided.

Aligning Superheterodynes. In aligning receivers with AVC, either a modulated or unmodulated signal may be employed. The

latter is preferable, since some test oscillators provide a broad signal when audio-modulation is used.

1. Place the receiver, tuned v-t voltmeter, and a test oscillator in operation.

2. Make the receiver oscillator inoperative by connecting a clip lead from stator to rotor of the oscillator tuning condenser.

3. Connect the test oscillator to the input terminals of the receiver and tune it to 1400 kc. (Or whatever alignment frequency is specified by the manufacturer for high-frequency adjustment.)

4. With the receiver in operation, turn the tuning knob until the exact alignment frequency is indicated on the dial.

5. Place the isolating test probe on the receiver antenna post and tune the v-t voltmeter to resonance with the test oscillator signal.

6. Now clip the test probe on the mixer socket plate terminal.

7. Adjust the r-f and mixer trimmers until a maximum r-f voltage is indicated by the tuned v-t voltmeter.

8. Adjust the tuned v-t voltmeter to the intermediate frequency specified by the receiver manufacturer.

9. Now remove the shorting wire across the set oscillator tuning condenser, and, without re-tuning the receiver, adjust the oscillator trimmer condenser until a maximum i-f voltage is indicated by the tuned v-t voltmeter.

10. Tune the test oscillator, the voltmeter and the receiver to 600 kc.

11. Make the receiver oscillator inoperative (see step No. 2).

12. With the test probe still connected to the mixer plate, re-tune the receiver until the 600-kc signal voltage is a maximum, as indicated by the tuned v-t voltmeter.

13. Remove the shorting wire from the oscillator section of the tuning condenser, tune the v-t voltmeter to the i-f prescribed by the receiver manufacturer and adjust the oscillator padder condenser until the i-f signal is a maximum.

14. Since the adjustment of the oscillator padder at 600 kc will change slightly the preliminary 1400-kc adjustment, again tune the test oscillator and the receiver to 1400 kc. Using a weak test signal, re-adjust the oscillator trimmer condenser until the i-f signal at the mixer plate is a maximum.

The r-f alignment is now complete. To align the i-f section, continue as follows:

15. Move the test probe to the first i-f plate and adjust the first i-f transformer trimmers until the channel indicates a maximum i-f signal. Reduce the test oscillator signal while making this adjustment, using just sufficient signal to note the effect of trimmer adjustments.

16. Repeat this procedure for the next i-f stage, moving the test probe to the second detector diode if there is but one i-f stage. Continue reducing the signal voltage as the i-f stages are brought into alignment. If one or more broad-band i-f transformers are employed, shunt a 20,000-ohm resistor across the secondary before adjusting the primary trimmer. After the primary has been adjusted, remove the shunting resistor and adjust the secondary for maximum output.

Checking Tracking On Short-Wave Bands

Tracking on short-wave bands can be checked by measuring the set oscillator frequency. Follow the manufacturer's instructions for aligning, then check the oscillator frequency as follows:

1. Tune in a signal of known frequency at the high-frequency end of the band.

2. Check the receiver oscillator frequency (as described in Chapter 4).

3. Note if this frequency is higher or lower than the signal frequency. In most receivers the oscillator frequency should be higher. If not, it is so specified in receiver service notes.

4. Repeat the above procedure for the low-frequency end of the band. The receiver oscillator frequency should bear the same relation to the signal at both ends of the band. That is, if it is higher in frequency at one end of the band, it should likewise be higher in frequency at the low-frequency end of the band.

Note that the final adjustment of the oscillator should follow in accordance with conventional alignment procedure.

Aligning Tuned R-F Receivers

The conventional alignment procedure can be followed, using the a-f voltmeter as a sensitive output indicator. The a-f probe

may be connected at any convenient point in the a-f system where the signal is present.

Localizing Defects In Intermittent Receivers

Unquestionably one of the most difficult and exasperating problems which faces the radio service industry is the servicing of intermittent receivers. When such a receiver "cuts out," the minute electrical charge resulting from touching a test prod to any portion of the receiver will often restore operation for an indefinite period. Even less unstable receivers, which fade slowly, are likely to return temporarily to normal if voltage measurements are attempted. And often the cause of such troubles does not affect receiver voltages. In every case, however, the signal is affected, and with multi-channel signal-tracing instruments, the particular circuits in which the signal level changes are promptly identified without disturbing the set components. The test prods are connected to key points in the receiver circuits and the level controls are adjusted to give predetermined reference levels. Then, when the receiver becomes intermittent, the resulting changes in signal levels tell which receiver circuits are affected and the trouble is localized. Finding the defect is thus greatly simplified.

A block diagram of a typical superheterodyne receiver is shown in Fig. 9-6. The circuit includes an r-f stage, mixer, i-f, detector, and two a-f stages. To test such a receiver with a five-channel signal-tracing instrument, we divide the circuit into five major sections and monitor the operation of each section. If fewer test channels are available, this method may still be employed, but the trouble will not be as closely localized. To do this, proceed as follows:

1. Plug the receiver in the wattage indicator receptacle and note the receiver power consumption. (Or use a standard wattmeter for the purpose.)
2. Connect a signal generator to the input of the receiver and feed a modulated signal of approximately 600 kc to the receiver.
3. Screw on the clips provided for each probe tip. This enables the probes to be fastened to any circuit which it is desired to test.
4. Clip the r-f probe on the stator lug of the variable condenser which tunes the mixer input circuit.

5. Similarly, connect the oscillator probe to the oscillator section of the tuning condenser.

6. Connect the a-f probe to the plate or control grid terminal of the first a-f tube.

7. Connect an electronic or other suitable voltmeter to the avc bus.

8. Tune the receiver to resonance with the signal. Tune the r-f and oscillator channels of the instrument to resonance with the circuits to which they are connected. Adjust the level controls for each channel until a suitable reference level is secured. Note the avc voltage indicated on the voltmeter.

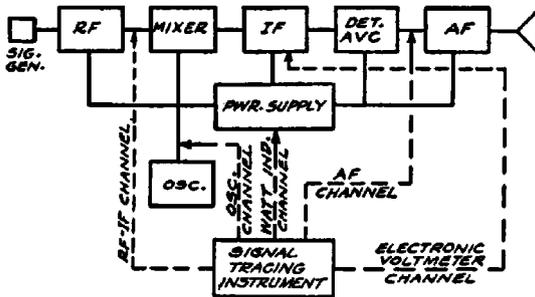


FIG. 9-6. Block diagram of a typical receiver showing how the five major sections of the receiver can be monitored by a multi-channel signal-tracing instrument in order to localize intermittent troubles.

We assume that the set is operating normally after these preliminary monitoring adjustments and connections have been made. Since the signal level in each part of the receiver is now monitored, any change in the operating condition of the receiver will be indicated by a change in the signal level of the stages or circuits affected.

Intermittent Operation of the R-F Section. If the cause of intermittent reception is in some circuit ahead of the mixer tube, the following changes will take place:

1. The r-f signal level at the mixer will be reduced.
2. The a-f signal will also be reduced.

3. The avc voltage will change or, if the defect is of such nature that the power consumption of the receiver is appreciably changed, it will affect the wattage reading. If a short-circuit has occurred, the wattage consumption will increase; if a voltage supply circuit has opened, the wattage consumption will decrease. Minor changes in power consumption will of course not be indicated.

Intermittent Oscillator Operation. If the source of trouble is in the oscillator circuit, whether caused by oscillator drift, intermittent operation or irregular output, the defect will be shown on the channel indicator. Since the r-f stages are not affected (unless avc-controlled) the r-f signal voltage will not change. However, since the signal level in all other portions of the receiver is reduced, the indications will change accordingly.

When the r-f section is controlled by the avc circuit, the indicated r-f signal voltage will increase, because failure of the oscillator reduces the avc voltage on the r-f tubes.

Intermittent Operation in the I-F Stages. In case the source of intermittent operation is due to some defect in the i-f stages, the avc voltage will be decreased causing an increase in signal gain in the r-f stages, and the r-f channel will show the increase in signal voltage. The oscillator channel eye will not change; the a-f channel eye will open; the wattage indication will change as described above if the receiver voltages are appreciably affected.

Intermittent Operation in the Detector or A-F System. When the cause of the intermittent operation is the result of some trouble in the detector or first a-f stage, the a-f channel indicator will be affected. The reference levels of the oscillator channel, voltmeter, and r-f channel will not be changed unless the defect is of such nature that voltages throughout the receiver are appreciably altered. In such cases, the power consumption will likewise change, thus showing the nature of the trouble.

AVERAGE GAIN-PER-STAGE VALUES

The figures on gain-per-stage listed below are based on the assumption that the receiver avc system is not operating. AVC action will reduce considerably the r-f, mixer, and i-f stage gains. For comparison purposes, a weak signal should be used, or the avc circuit temporarily shorted out.

In the a-f section, for resistance-coupled amplifiers, the lower gain figures represent average gains for ac-dc receivers while the higher gains apply to a-c operated receivers.

Radio-Frequency Section:

Antenna to grid of first tube.....	2 to 10
Antenna to grid of first tube—auto radios... ..	10 to 50
R-F amplifier—superheterodynes.....	10 to 40
R-F amplifier—tuned r-f receivers.....	40 to 100

Mixer Section:

Converter grid to i-f grid (1 stage i-f amp.) ..	30 to 60
Converter grid to i-f grid (2 stage i-f amp.) ..	5 to 30

Intermediate-Frequency Amplifier Section:

I-F stage (1 stage i-f amp.).....	40 to 150
I-F stage (2 stage i-f amp.).....	5 to 30

Biased Detector:

Pentodes (Types 57, 6C6, 6J7, etc.).

A 1.0-volt rms signal (20% mod.) at the grid will produce approximately 10 volts rms of a.f. at the plate. Higher modulation percentages will produce correspondingly higher a-f voltages. Thus 40 percent modulation will produce 20 volts rms of a.f.

Note:—AVC voltage may run as high as 40 volts, depending upon the strength of the input signal and the number of tubes under control. In general the greater the number of tubes controlled, the lower the avc voltage for a given input signal.

Audio-Frequency Section:

Medium- μ triodes, resistance-coupled:

Types 6N7, 6C8 (each section).....	20 to 25
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High- μ triodes, resistance-coupled:

Types 75, 2A6, 6F5, 6SQ7, etc.....	40 to 60
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Output Pentodes:

Types 6F6, 2A5, 47, 6V6, 6L6, 6K6, grid-to-plate gain)	8 to 20
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Output Triodes:

Types 2A3, 45, 71A, 6A5G.....	2 to 5
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Service notes on many recent models of receivers manufactured by the General Electric Company contain valuable gain-per-stage data as well as other information applicable to signal-tracing tests.

For Models H-600, 601, 610, 611, 620 and 621, the following information is furnished in the G-E Service Notes:

(1) Stage gains	Gain
Antenna to Converter Grid	2.7 at 1000 kc
Converter Grid to 6SK7 Grid	28 at 455 kc
6SK7 Grid to 6SQ7 Diode Plate	87 at 455 kc

(2) Audio Gain

.05 volts, 400-cycle signal across volume control with control set to maximum will give approximately $\frac{1}{2}$ watt output at speaker. Voice coil impedance equals $3\frac{1}{2}$ ohms at 400 cycles.

(3) DC voltage developed across oscillator grid leak averages 13 volts.

The stage gain ratings given above are average; variations of plus 10 percent or minus 20 percent are normal, according to the service notes.

In the above data the gain from converter grid to the 6SK7 Grid represents the gain of the converter tube and the i-f transformer at the intermediate frequency, 455 kc. This is not the conversion gain but will indicate the performance of the converter as an i-f amplifier.

The watts output may be determined by a voltage reading of the output meter when the speaker voice coil impedance is known. The required voltage reading for a given output in watts is then found by the formula, $E = \sqrt{RW}$. For example, in the above receiver data, the voice coil impedance, R , is $3\frac{1}{2}$ ohms at 400 cycles; the desired watts output, W , is $\frac{1}{2}$ watt. The voltage, E , which will be across the voice coil when the power output is $\frac{1}{2}$ watt, is equal to the square root of ($3\frac{1}{2}$ times $\frac{1}{2}$) . . . about 1.32 volts. This output voltage should preferably be measured with a resistance, equal in value to the voice-coil impedance, shunted across the output transformer secondary in place of the voice coil.

Average D-C Voltage Across Oscillator Grid Leak

The following tabulation gives the average d-c voltage developed across the oscillator grid leak in representative modern all-wave and broadcast-band receivers at various operating frequencies. The tabulated voltages are measured with a vacuum-tube voltmeter and isolating probe, similar to that described in Chapter 12, and therefore represent the actual voltages at the point of test. Ordinary 1000 ohms-per-volt meters are unsuitable for such voltage measurements, due to their loading effect upon the circuit under test.

These are average values in typical receivers; variations of 50 percent are likely to be encountered in other receivers, due to differing design characteristics. Normal variations in tube characteristics will likewise affect the resulting oscillator d-c voltage.

AC-DC Superheterodynes

Frequency (in kc) . . .	600	1000	1400	6000	18,000
E_{osc} (d-c volts)	11	11.5	13	10.5	5.8

A-C Superheterodynes

E_{osc} (d-c volts)	19	19	19	12	14
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Automobile Superheterodynes

E_{osc} (d-c volts)	19	18	19
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Chapter X

SIGNAL TRACING IN TELEVISION RECEIVERS

IN TELEVISION, as in radio, the signal is fundamental. Although in radio the signal represents sound values and in television the signal represents light values, in both cases the information being transmitted is converted into electrical signals. Thus it is to be expected that signal tracing in television receivers will be generally similar to that in radio receivers. For example, the problem of checking the operation of a video amplifier is not essentially different from that of checking an audio amplifier stage since in both instances the same process of amplification of an electrical signal is involved. We do not mean to imply that the procedures are identical but rather to point out that television, as well as radio, deals with the amplification, frequency conversion, detection, etc., of electrical signals, so that television servicing will in general be closely related to radio servicing.

You can readily see that the problems involved in television servicing are more complex than those in radio servicing. This is a natural consequence of the fact that the television signal is exceedingly more complex than the radio signal used in sound broadcasting. Thus the television signal not only must convey information on the light values at each one of the many small elements into which the televised scene is broken down, but the signal must carry the synchronizing information required to reassemble these light values in the proper order. In addition to the complexity introduced by the necessity for supplying the synchronizing information, television receivers are complicated by the presence of other alternating voltages which in a sense can be thought of as signal voltages. In this class can be mentioned the horizontal and vertical deflecting voltages and the comparatively complex circuits associated with the production of these voltages

or signals. In the same way, the synchronizing pulses which are required for the proper synchronization of the horizontal and vertical deflection voltages are also signals in a real sense and further add to the complexity of the television receiver. Add to this, the larger number of stages and component parts in the average television receiver, and you can easily appreciate why television servicing is more complex than radio servicing.

In this chapter we emphasize the part that the signal plays in the proper operation of the television receiver. We shall show how the character of the signal changes as it passes from one stage to another in the receiver and how each stage contributes to the final image which is reproduced on the screen of the picture tube. We shall show how the apparently complex schematic that represents the television receiver is in reality a coordinated scheme in which each part performs a definite function.

Fundamentally, the efficient localization of trouble in a television receiver depends upon a clear understanding of the various types of signals which exist throughout the receiver. It is only when you have acquired this understanding that faulty operation of the receiver can be interpreted in terms of the failure of the signal to have the proper character at one or more points in the receiver. We are here using the term *signal* in its broader sense to include control voltages and other factors which influence receiver operation. For example, an understanding of the fact that the horizontal deflection oscillator requires a sync pulse signal in order to insure proper timing, at once leads one to look for trouble in the sync (and deflection) circuits in the event that the picture obtained is such that improper timing of the horizontal oscillator is indicated. Again, inability of the brightness control to enable cutting off the beam completely, indicates that something is wrong in the bias circuit of the picture tube. Possibly this might be a defective output tube (in the case of direct coupling to the picture-tube grid), but at any rate, the point you should note is that the defect itself or its symptoms provide the clue to the source of the trouble.

The Complete Receiver

In order to show the operation of television receivers let us first examine the general arrangement of stages in a typical receiver.

Fig. 10-1 is a block diagram of a typical television receiver especially arranged to show the general character of the signal through the receiver and the function performed by each section. For convenience we shall assume that the receiver is tuned to the 44-50 mc channel. In accordance with the standards adopted by the RMA (Radio Manufacturers Association), this means that the frequency of the video carrier is 45.25 mc (1.25 mc above the low-frequency end of the channel) whereas the frequency of the audio carrier is 49.75 mc (0.25 mc below the high-frequency end of the channel).

Both these signals, together with their sidebands, are picked up by the antenna and fed through a transmission line to the input of the r-f amplifier. Essentially the function of the r-f amplifier is the same as that of the r-f amplifier in any superheterodyne receiver—to amplify the signal and to reject unwanted signals in adjacent and other channels. In this case, the r-f amplifier is broadly tuned so that both the video and sound carriers, which are separated by 4.5 mc, are amplified equally.

After being amplified in the r-f amplifier, both signals are fed to the *first detector* circuit where the conversion of the signals to the intermediate frequencies takes place. Since there are two radio frequencies, it of course follows that two separate intermediate frequencies are produced.

In accordance with a proposed RMA standard, and general present practice, the oscillator operates at a frequency *12.75 mc above the video carrier frequency*. For the channel being received, the frequency of the oscillator in the receiver is thus equal to 45.25 mc + 12.75 mc, or 58 mc. Since the oscillator frequency is 12.75 mc above the video carrier frequency, it follows at once that the video intermediate frequency produced is equal to 12.75 mc. In the same way, the intermediate frequency of the sound signal is equal to the difference between the oscillator frequency and the sound carrier frequency, 58 mc — 49.75 mc, or 8.25 mc.

Following the first detector, the sound channel is entirely independent of the rest of the receiver and in practically every detail is similar to a conventional broadcast receiver. Thus the 8.25-mc sound i-f signal passes through the sound i-f amplifier (the selectivity of which is broader than usual to minimize the effects of oscillator drift, as mentioned above) and is demodulated at the

sound second detector. The avc voltage is supplied in the usual manner to control the gain of the stages in the sound *i-f* amplifier. The design of the audio amplifier and the reproducer is also conventional so that no further comment is required.

Returning to the video signal, we have seen that a 12.75-mc *i-f* signal is produced by the first detector and that this signal carries the video modulation. As the diagram shows, this signal is amplified in the *video i-f amplifier*, which usually consists of several stages, and finally reaches the *video second detector* where the

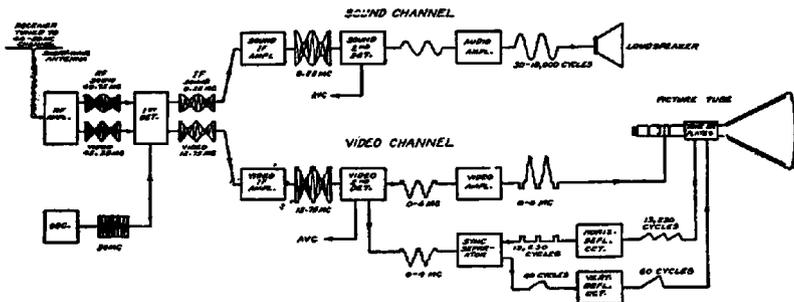


FIG. 10-1. Block diagram of a typical television receiver showing the principal sections of which it is composed. Note the changes in the signal as it passes through the receiver.

signal is demodulated. The video signal recovered at this point is essentially the same as the output of the camera tube so that it contains all the information required to reproduce the picture, and in addition, includes the blanking and sync pulses. The video second detector is followed by the *video amplifier* which, in terms of a sound receiver, corresponds to the audio amplifier. The function of the video amplifier is to amplify the video signal so that its amplitude will be great enough to "swing" the modulation grid of the picture tube. For the average picture tube this requires approximately 25 volts, peak-to-peak.

Note in the diagram that the polarity of the video signal is reversed 180 degrees for a single stage of video amplification and that the receiver is arranged so that the signal which reaches the control grid of the picture tube has a positive polarity. As a result the synchronizing impulses appear in the blacker-than-black (highly negative grid-bias) part of the picture tube char-

acteristic so that the beam is blocked during the retrace part of the line and field sweeps.

In addition to supplying the video signal and the signal which actuates the avc system, the second detector supplies the video signal to the *synchronizing separator*. The purpose of this separator is to remove the picture component from the complete video signal, and then to separate the horizontal sync pulses from the vertical sync pulses. As is shown, the horizontal sync pulses are arranged to control the timing of the horizontal deflection circuit, while the vertical sync pulses are arranged to control the timing of the vertical deflection circuit.

The power supply is not shown in the block diagram. As a general rule, a single low-voltage power supply is used to take care of all voltage requirements throughout the receiver with the exception of the high-voltage requirements for the picture tube. The latter, which may include voltages as high as 9000 volts, is supplied by a separate high-voltage power supply which has its own transformer, rectifier and filter.

R-F Circuits

Since the complete television signal consists of a band of frequencies extending over a 6-mc channel, it is clear that the r-f circuits, including the antenna and transmission line, must be broad enough to pass the 6-mc band. A sharply tuned antenna system is undesirable because it discriminates against the different frequencies present in the signal and as a result produces distortion.

The characteristics of the r-f circuits in television receivers are the same as for ordinary broadcast receivers. As in any superheterodyne receiver, the function of the r-f circuits is to select and amplify the wanted signals and to reject all other signals. As a general rule, most television receivers do not use an r-f stage but rely on the selectivity of the tuned circuit which feeds the signal from the transmission line to the mixer input to provide the required selectivity and image rejection. In some receivers, however, an r-f stage is provided so that additional gain, selectivity and a higher signal-to-noise ratio are obtained.

In most cases you will observe that the r-f tuned circuits as well as tuned circuits in the i-f amplifier are shunted by resistors of

comparatively low value. The function of these resistors is to damp the circuits so that sideband cutting will not take place and so that the complete television signal will be passed. Although these resistors lower the gain, this reduction in gain must be tolerated in order to broaden the circuits sufficiently.

Without exception all commercial receivers use push-button or switch-controlled tuning rather than conventional continuous tuning with a large variable condenser. This is feasible because the short-wave channels which have been assigned for television are limited in number and do not require continuous coverage as is the case, for instance, in the broadcast band. At the present time the lower channels are most in use and will probably be the only ones in use for some time.

As a general rule, a small vernier condenser is provided to permit a fine adjustment of the tuning. This condenser is placed across the oscillator tuned circuit and compensates for drift in the trimmers and other effects which tend to change the oscillator frequency. No external tuning adjustments are required for the r-f circuits since these are not critical of adjustment.

Oscillator Circuits

As has been previously pointed out, the oscillator in a television receiver beats with both the sound and video carriers of the signal to form two separate intermediate-frequency signals: the video i.f. and the sound i.f. According to present standards, the oscillator frequency for any given channel is 14 mc above the low-frequency end of the channel, which in turn makes it 12.75 mc above the video carrier and 8.25 mc above the audio carrier. As a result, the frequency of the signals produced by heterodyning with the oscillator signal is 12.75 mc for the video i.f. and 8.25 mc for the sound i.f.

Combination oscillator and mixer tubes are not satisfactory for the comparatively high frequencies at which the oscillator must operate, because of low conversion gain and because these tubes do not oscillate readily at the high frequencies required. For these reasons a separate tube is generally used for the oscillator circuit. The type 6J5 tube is more widely used than any other tube because of its high mutual conductance, low capacitance, and because it oscillates readily at frequencies up to about 120 megacycles.

In the design of oscillator circuits much attention is given to the problem of minimizing frequency drift. Because of the high frequencies at which the oscillator operates, a comparatively small percentage change in the oscillator frequency, such as might be caused by drift, has the effect of spoiling the picture and causing the sound i.f. to drift out of the range of the sound i-f channel. Although the effect of oscillator drift is minimized because of the comparatively high intermediate frequencies, the problem of oscillator stability and freedom from drift is an important one. In commercial receivers, drift is minimized through proper circuit design and by the use of coils and condensers which are independent of changes in temperature and humidity.

Mixer

As has previously been pointed out, combination oscillator-mixer tubes such as are satisfactory at lower frequencies are not satisfactory at frequencies above 40 mc. It is general practice to use one of the new high mutual conductance tubes in the mixer circuit, such as the type 1852. The 1852 is especially adapted for frequency conversion and provides high conversion efficiency. For proper mixer operation, it is essential that the output of the separate heterodyning oscillator be coupled to the mixer tube and that the mixer receive approximately the same value of voltage from the oscillator on all bands.

Typical R-F, Oscillator, and Mixer Circuits

The circuit shown in Fig. 10-2 is that of the high-frequency section of the Belmont Model X-466 receiver. This receiver does not use an r-f stage but the signal is coupled directly to the grid of the 1851 mixer tube through a double-tuned closely coupled bandpass circuit. This bandpass circuit provides the required selectivity without sacrifice in gain. Five of the assigned television channels are covered, beginning with the 44-50 mc channel, the highest channel being the 84-90 mc channel. The three highest-frequency channels are shunted by resistors having a value between 1000 and 2000 ohms in order to obtain the required pass band. These resistors do not have the loading effect that might be expected offhand, since the loading of the input resistance of the tube is itself of the order of 1000 ohms. In addi-

tion to improving the gain and selectivity of the input circuits, the tuned primary windings of the input transformers aid in proper matching of the transmission line and in eliminating reflections.

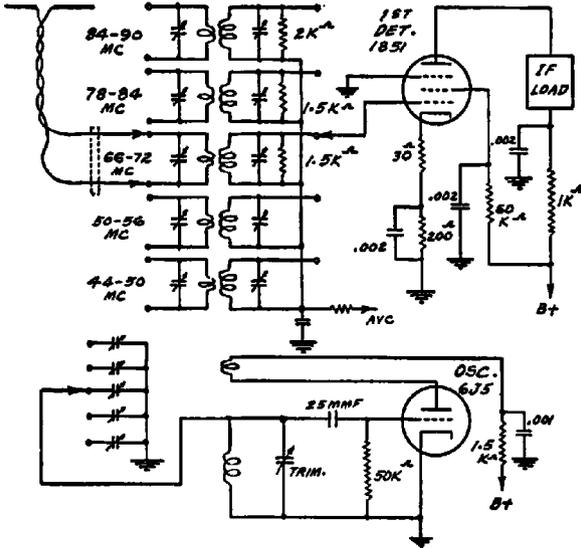


Fig. 10-2. The high-frequency section of the Belmont Model X-466 receiver. The signal from the oscillator coil is inductively coupled to the mixer input coil.

These reflections are undesirable because they tend to produce more than one image on the screen of the picture tube.

The oscillator circuit, which uses a 6J5 tube, is conventional in design, with the tank circuit located in the grid circuit. Note the comparatively small value of the grid condenser, 25 mmf. The major portion of the total capacitance in the tank circuit of the oscillator is selected by means of the 5-position switch which is of course ganged with the r-f selector switch. A small vernier tuning condenser across the grid coil provides an adjustment which compensates for small variations due to oscillator drift. This control appears on the panel and is designated as the tuning control.

A type 1851 tube is used as the mixer tube. This is a pentode having a high mutual conductance, and is similar to the 1852 but

has the grid cap on the top. It is used in preference to a 6J7 because it provides higher gain and a higher signal-to-noise ratio.

There is no direct coupling connection between the oscillator circuit and the mixer; the required coupling is provided inductively by placing the oscillator coil close to the mixer input coil.

I-F Circuits

As a result of the action in the mixer circuit, we have seen that two intermediate frequencies are produced and that one of these—the video i.f.—carries the picture signal, while the other one—the sound i.f.—carries the sound signal. As in the conventional superheterodyne receiver, it is necessary to amplify both of these i-f signals before they are finally demodulated in the second detectors. These functions are performed by the video i-f and the sound i-f amplifiers. In this section we shall discuss the design of i-f circuits for television receivers and illustrate the principles with circuits taken from typical existing receivers.

Signal Output of Mixer. The frequencies which must be handled by the two i-f amplifiers are illustrated in Fig. 10-3. Let

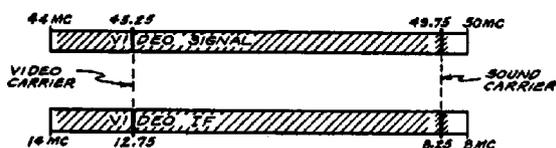


Fig. 10-3. The upper part of this figure shows the make-up of a video signal in the 44-50 mc band. The lower part shows that the same frequency separation is maintained in the i-f signal as in the r-f signal.

us assume that a signal in the 44-50 mc channel is being received. In this channel, the video carrier is at 45.25 mc and the sound carrier is at 49.75 mc; the local oscillator frequency, which is 14 mc above the low-frequency end of the channel, is therefore at 58 mc ($44 + 14$). As a result of beating with the oscillator, the video i-f signal at 12.75 mc ($58 - 45.25$) and the sound i-f signal at 8.25 mc ($58 - 49.75$) are produced. It is important to note, as the figure shows, that whereas the video r-f carrier is lower in frequency than the sound r-f carrier, the video i.f. is higher in

frequency than the sound i.f. However, the relative placement of the various components of the complete signal is the same in the i-f signal as in the r-f signal. Thus the frequency separation between the two carriers is constant at 4.5 mc in both cases as is also the separation from the two ends of the channel.

The intermediate frequencies used in television receivers have a number of desirable qualities which are the result of careful planning by television engineers. Thus the frequencies are high enough to give good image rejection; this is especially important because many receivers do not use an r-f stage. At the same time, the video i.f. is high enough so that there is sufficient space for the sidebands and the sound i.f. is high enough so that the sound selectivity is not too sharp. The effect of too sharp selectivity in the sound i-f amplifier is to make tuning critical, to exaggerate the effect of the slightest drift in the oscillator frequency and to prevent adjustment for the best picture detail without losing the sound signal.

Like any other superheterodyne, television receivers are subject to interference due to pickup by the antenna of frequencies within the range of the i-f amplifier. In the case of broadcast receivers, such interference shows itself in the form of squeals, code signals, and general distortion. Similarly, in the case of television receivers such pickup may distort either the picture, the sound, or both, depending upon the frequency of the interference. The range of intermediate frequencies between 8 and 14 mc has been especially chosen to minimize i-f interference; the fact that the amateur bands lie outside of this range is of considerable assistance in this respect.

Sound I-F Channel. It is the function of the sound i-f amplifier to separate the sound component of the i-f signal from the video component and to amplify this signal before it is demodulated at the sound second detector. Because of the comparatively high frequencies involved, however, the design of a television sound i-f amplifier is somewhat more difficult than that of the conventional i-f amplifier in a radio receiver. Thus there is a greater tendency toward regeneration and more attention must be paid to stray wiring and tube capacitance.

The bandwidth which must be passed is comparatively small and does not present the same problem as does the video i-f

amplifier. Actually, of course, a bandwidth of from 10 to 20 kc is sufficient to transmit all the frequencies present in the audio signal. However, in practice, the bandwidth of the sound i-f amplifier is made approximately 100 kc. Primarily this larger bandwidth is necessary to allow for normal drift in the frequency of the oscillator. The significance of this is that if the bandwidth of the sound i-f amplifier were held to 10 kc, then a change of 10 kc in the oscillator frequency would cause the sound signal to drift completely out of the range of the sound i-f amplifier. However, a change of 10 kc, in an oscillator operating at a frequency of the order of 60,000 kc and up, represents a frequency drift in the oscillator of only one part in 6000, whereas in practice it is not possible to design receiver oscillators which will have a reliable frequency stability of better than one part in 1000. Therefore, instead of resorting to voltage regulation and expensive design to prevent oscillator drift, the bandwidth of the sound

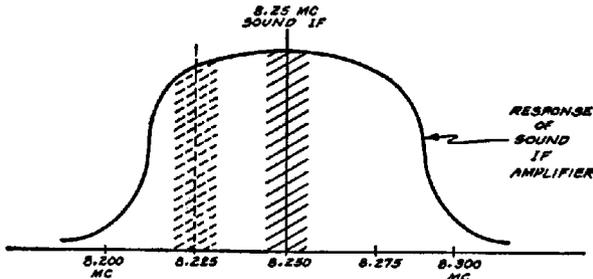


FIG. 10-4. The frequency response of a typical sound i-f amplifier. The dotted signal shows that the sound signal can be detuned appreciably without falling outside the pass band of the amplifier.

i-f amplifier is intentionally made about ten times as great as that required for the sound modulation, thus allowing for reasonable drift in the oscillator. Assuming that the receiver is initially tuned to the center of the sound i-f amplifier, a drift in the oscillator frequency as high as 25 kc will not cause any appreciable change in the quality of the audio signal. This is illustrated in Fig. 10-4, which shows that the effect of a change in the frequency of the oscillator is merely to shift the location of the sound signal within the band passed by the sound i-f amplifier.

Although the bandwidth of approximately 100 kc is sufficiently great to compensate for normal oscillator drift, this bandwidth is still small enough so that the receiver can be tuned by listening to the sound accompanying the picture. At the same time there is enough latitude so that the tuning can be varied slightly in order to improve the detail of the picture without losing the accompanying sound signal. Although we shall see later that a special type of avc circuit is required in the video i-f amplifier, the avc circuits used in the sound i-f amplifier are conventional.

Video I-F Circuits

The design of the video i-f amplifier is more complicated than that of the sound i-f amplifier because of the wide band of frequencies which the video i-f amplifier must pass. Thus the video i-f amplifier often must handle frequencies extending from approximately 8.7 mc to 14.0 mc, a range of over 5 mc. Not only must the amplifier have an almost flat response over this range, but at the same time it must reject interfering signals close to the edges of the pass band.

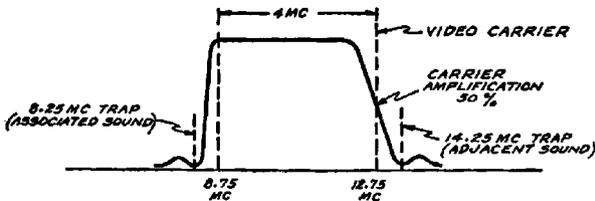


FIG. 10-5. The overall frequency response of a typical video i-f amplifier. Note that the carrier receives only 50% of the maximum amplification.

The use of the so-called vestigial sideband transmission, in which all of one sideband and a small portion of the other sideband are transmitted, makes it necessary for the selectivity of the i-f amplifier to depart from the uniform selectivity which might at first be expected. To avoid overemphasis of the lower video frequencies, which receive contributions from both the upper and lower sidebands, the selectivity of the i-f amplifier is designed to have a sloping characteristic in the neighborhood of the video i-f carrier at 12.75 mc. This is illustrated in Fig. 10-5 which shows a typical *overall* selectivity curve for a video i-f amplifier.

The amplification which the i-f carrier receives is only 50% of the maximum amplification received by the upper sidebands and the lower sidebands, which are only partially transmitted, also do not receive the full amplification. In this way overemphasis of the lower video frequencies is avoided by shaping the overall selectivity so that the contribution of the lower sideband plus the contribution of the upper sideband is equal to the gain for the higher video frequencies. Since the upper video frequencies receive contributions only from the one sideband, the selectivity, as Fig. 10-5 shows, is such that the full gain is received by these frequencies.

If video frequencies up to a maximum of 4 megacycles are to be received, which is usual for the higher-priced sets using large picture tubes, then the i-f amplifier should cut off at about 8.75 mc (12.75—4.0). Since the sound i-f carrier is located close by, at 8.25 mc, it is necessary that this cutoff be sharp in order to prevent the sound carrier and its sidebands from causing inter-

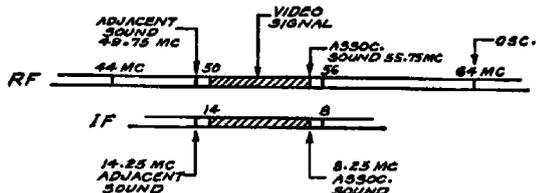


FIG. 10-6. The sound signal of the associated channel at 8.25 mc and the sound signal of the adjacent channel at 14.25 mc are both close to the edges of the video band. Traps are provided to prevent interference from these signals.

ference with the video signal. In practice this rejection of the sound carrier is secured by the use of rejection or trap circuits which generally are part of the video i-f coupling transformers.

In addition to rejecting the sound i-f carrier of the *associated* channel at 8.25 mc, it is desirable that the i-f amplifier have a sharp cutoff at the high-frequency end of the band. This is required in order to prevent the sound signal on the *lower adjacent* television channel from getting through the video amplifier. Because of the reversal of high and low frequencies which takes place in the mixer, the sound carrier of the lower adjacent channel will beat with the oscillator and cause an interfering

signal which is located 0.25 mc above the edge of the channel, at 14.25 mc. These frequency relationships just described are shown in Fig. 10-6. A trap of the same general type as that used to reject the 8.25 mc carrier is used to reject possible interference from the adjacent sound carrier at 14.25 mc.

The maximum gain which can be obtained in a video i-f stage is considerably lower than that in an ordinary broadcast i-f stage because of the wide band of frequencies which must be passed and because of the high carrier frequency. This is true even where high mutual conductance tubes of the 1851 series are used, so that it is not unusual for as many as five separate stages to be used in the video i-f amplifier.

The transformer design is especially complicated in video i-f amplifiers because of the wide pass band of from 2.5 to 4.0 mc which must be obtained. To obtain close coupling so as to increase the pass band, direct coupling of the primary and secondary windings by means of a common inductance is often used. Loading of the tuned circuits with resistors so as to broaden the circuits is very common and will be found in practically all the circuits. Video i-f transformers are further complicated because the rejector circuits for the associated and adjacent sound channels are often an integral part of the interstage coupling transformers. Because of the comparatively high frequencies, the only capacitance used to tune the circuits is often that of the wiring and tube capacitance so that no condenser as such appears on the schematic. Nevertheless this capacitance forms a resonant circuit with the related windings of the transformer and should be taken into consideration. Since the wiring capacitance is an important part of the total circuit capacitance, it is important that no changes be made in the wiring when servicing is required.

AVC is often used in video i-f amplifiers, but as will be explained later under "AVC Circuits," the manner in which the avc voltage is produced differs from that in radio receivers and in the sound i-f amplifier.

Video I-F in Andrea Model 1F5. In the Andrea Model 1F5 receiver, shown in Fig. 10-7, the video i-f amplifier employs two stages of amplification both of which use type 1852 tubes. In order to separate the sound i-f part of the signal from the video part, a separate secondary circuit *L₂-C₂* is tuned to 8.25 mc so that the sound i-f signal appears across this circuit. The sound

i-f signal is fed directly to the sound i-f channel which is conventional and requires no further comment.

The video component of the i-f signal is developed across $L3$. No trimmer condenser is used on this winding and the circuit is heavily loaded by the 6000-ohm resistor in order to pass the required band of frequencies. The video signal is applied directly to the grid of the type 1852 tube used in the first i-f stage. To obtain negative feedback and the increased stability which it makes possible, an unbypassed 70-ohm resistor is placed in the cathode circuit. The other end of this resistor is connected to a variable resistor—the “contrast control”—by means of which the gain of the i-f stage is controlled. Since no avc is used, the control grid is returned directly to ground. The band of frequencies passed by this amplifier is approximately 2.5 mc; this pass band is generally considered to provide sufficient detail for the small picture tube used with this receiver.

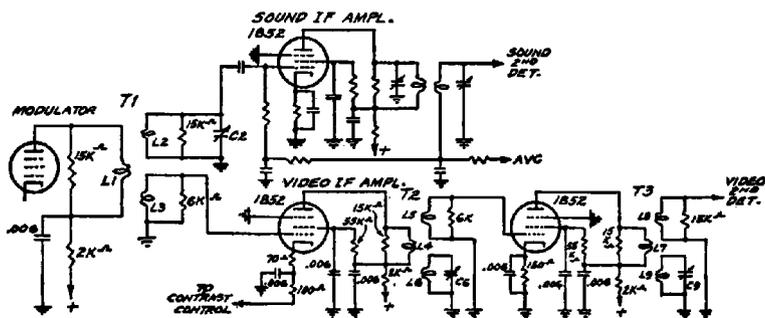


FIG. 10-7. The video and sound i-f amplifiers in the Andrea Model 1F5 receiver.

The signal is coupled to the grid of the second i-f tube by means of the transformer $T2$. The windings $L4$ and $L5$ of this transformer function as the primary and secondary windings of the interstage transformer and are loaded by means of the 15,000-ohm resistor across the primary and the 6000-ohm resistor across the secondary. The only capacitance used to tune these windings is the tube and circuit capacitance.

The third winding $L6$ is tuned to 14.25 mc by means of the trimmer $C6$ and eliminates possible interference from the sound

carrier of the lower adjacent television channel, as was previously shown in Fig. 10-6. This circuit acts as a trap by absorbing all the energy in the neighborhood of 14.25 mc so that it is not passed on to the grid of the following tube.

The second i-f stage feeds directly into the video i-f second detector through the transformer T_3 which is similar to T_2 . The circuit L_9-C_9 is likewise tuned to 14.25 mc so that it acts as a trap circuit for this frequency.

No AVC is used in the video i-f amplifier in this receiver and accordingly the grids of the two i-f tubes are returned directly to ground. The gain is controlled by means of the "contrast control" which varies the bias of both the first i-f stage and the first detector stage.

Video Second Detector Circuits

In a radio receiver the second detector rectifies the i-f signal and as a result the audio signal corresponding to the variations in the carrier is recovered. In the same way, the video second detector in a television receiver rectifies the video i-f signal and as a result the video signal corresponding to the variations in the amplitude of the carrier is recovered. This video signal is of course that produced by the camera tube and contains in addition the pulses required for synchronization.

Generally speaking, video second detectors are similar to the second detectors of the diode rectifier type used in radio receivers and discussed in a previous chapter. However, because modulating frequencies as high as 4 mc (in the larger receivers) must be passed, a lower value of load resistance is used in order to prevent the attenuation of the higher video frequencies. The value of load resistance generally used is of the order of 2500 ohms; on the other hand, the values used in radio receivers are of the order of 250,000, or approximately 100 times as great. Because of the low value of diode load resistance, receivers are generally designed so that the signal level at the second detector is approximately 5 volts or more. This minimizes distortion due to the curvature of the diode characteristic, which is more pronounced when low values of diode load resistance are used.

Video Second Detector in DuMont Models 180-183. The video second detector circuit used in the DuMont Models 180-183

receivers is shown in Fig. 10-8. A full-wave rectifier circuit is used so that both halves of the signal are rectified. Since the cathodes are connected to the ends of the centertapped secondary, each diode will draw current when its cathode is negative with respect to ground (the diode plates both return to ground through the 3000-ohm load resistor). As a result the current flow through the load resistor will be in the direction shown. Thus when a video signal is applied to the primary of the transformer, the plate end of the load resistor will become negative in proportion to the

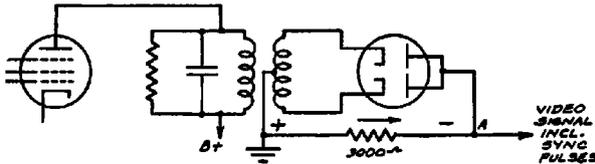


FIG. 10-8. The video second detector circuit in the DuMont Models 180-183. A full-wave rectifier circuit is used.

amplitude of the carrier. When the carrier amplitude is greatest, as it is for the sync pulses, the greatest negative voltage will be produced at *A*. The various shades of white and gray in the signal will produce lesser values of voltage at *A*, zero voltage of course corresponding to whitest white. In accordance with the definition of signal polarity, the video signal produced at *A* is said to have *positive polarity*.

It is worth while noting that if the diode plates, instead of the cathodes, had been connected to the ends of the coil, then the polarity of the video signal would have been reversed. As we shall see in the discussion of video amplifiers, whether or not the diodes are connected to give a signal of positive or negative polarity depends upon the number of stages in the video amplifier. The controlling factor is that the amplified signal which is finally applied to the grid of the picture tube must of course have a positive polarity since a more positive voltage on the grid produces a brighter spot on the screen of the tube.

Video AVC Circuits

Although the ultra-high frequencies used for television are not subject to fading of the same type as that found in the high and

medium radio frequencies, the signal strength may still vary because of swinging of the antenna or the presence of automobiles and other moving objects. Since these variations will cause a change in the contrast of the picture being received, they are undesirable and can be avoided if the receiver is equipped with avc. The use of avc also simplifies the design of both the video gain control circuit and the sync separating circuits because it assures the maintenance of a constant signal voltage at the video second detector.

In the conventional avc circuits used in radio receivers, the control voltage is produced by rectifying the carrier and as a result the control voltage is proportional to the *average* value of the carrier. Because the average value of the carrier in ordinary broadcasting does not change during modulation, it is a measure of the signal strength and hence can be used to control the gain of the receiver.

In television this same system cannot be used because the average value of the video carrier is dependent upon the average illumination of the scene being televised. Thus if the average background of the scene is white, then the average carrier amplitude will be small; on the other hand, if the average background is dark, then the average carrier amplitude will be large. (The above conditions are of course only true for negative modulation which is standard for this country.) Obviously, then, we cannot use the average amplitude of a video signal to obtain the necessary d-c control voltage, because such a control action would vary the gain of the amplifier in accordance with the average background illumination and as a result produce distortion.

However, although the average value of a video signal does not remain constant, the *peak* value always has the same fixed value regardless of the percentage of modulation or the average illumination of the scene. For this reason the peak value of the carrier serves as a convenient reference to establish the strength of the carrier and is the basis of operation of video avc circuits. This peak value is transmitted at the end of each line, that is, 13,230 times in every second, and thus it is available at regular intervals which are frequent enough to make possible the production of an automatic control voltage.

It is of interest to note here that one of the important reasons

for the use of negative rather than positive modulation is that only in negative modulation is this regular succession of peak pulses available for avc purposes. The design of avc circuits where positive modulation is used, is considerably more complicated; for positive modulation the peak values of the signal are not fixed but depend upon the brilliance of the scene being televised.

Satisfactory operation in the smaller and less expensive receivers is often secured without the use of a separate avc system in the video channel. In these receivers, relatively few video i-f stages are used so that the problem of manual gain control is not so difficult. In addition, the first detector is often controlled by the avc voltage produced in the sound channel, so that some degree of automatic control is provided. Since the video and sound carriers are close to each other, they undergo approximately the same variations in transmission from the transmitting antenna to the receiving antenna, but in general these variations are not sufficiently alike to permit the use of sound avc voltages on all the video stages.

Video AVC Circuit in the RCA Model TRK-12. The video second detector and avc circuit used in the RCA Model TRK-12 is shown in Fig. 10-9. When a signal is being received, full-wave rectification takes place in the 6H6 and as a result the demodulated video signal is produced across the 4000-ohm load *R45* in series with the peaking coil *L39*. The polarity of this signal is indicated by the insert wave which shows that point *B* of the load is positive with respect to point *A*; *B* can be considered as being at a fixed reference voltage since it is tied down to -33 volts through the filter resistor *R47*.

The circuit used to obtain the avc voltage from the signal across *AB* is essentially a peak voltmeter using one section of the 6F8-G tube as a diode. As the circuit shows, the grid is used as the diode plate and is connected directly to point *B*; the cathode is bypassed to ground by a 1-mf condenser *C54* and is returned to *A* through a 470,000-ohm resistor, *R46*.

During the sync intervals, the grid of the diode is highly positive with respect to its cathode so that a current flow takes place through *R46* and a positive charge is stored in *C54*. Because the sync pulses are repeated rapidly, 13,230 times per second, this

charge is continually replenished and *C54* remains charged to the peak value of the video signal. If, for example, we assume a 10-volt peak signal, then point *C* would charge up to a potential 10 volts greater than that at point *A* or -23 volts ($-33 + 10$).

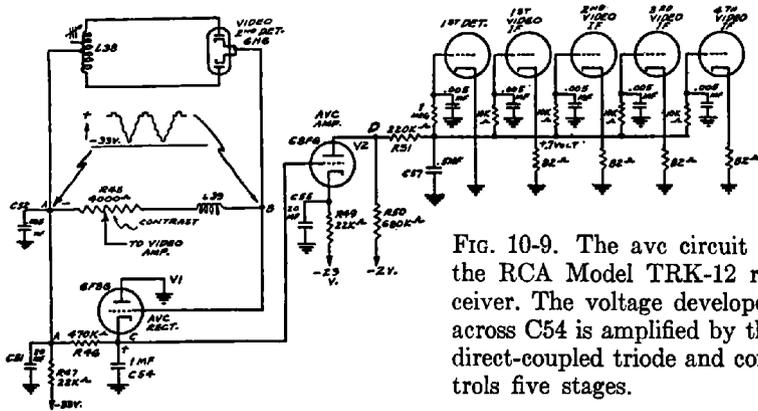


FIG. 10-9. The avc circuit in the RCA Model TRK-12 receiver. The voltage developed across *C54* is amplified by the direct-coupled triode and controls five stages.

Since the voltage produced in this way is proportional to the peak value of the carrier, it is a suitable measure of the signal level at the second detector. However, its polarity must be reversed in order that an increase in signal input will produce a more *negative* rather than a more positive control voltage. This reversal of polarity is effected by means of the second section of the 6F8-G which is used as a d-c amplifier.

This tube receives its plate voltage through a 680,000-ohm load resistor *R50* which is 2 volts negative with respect to ground. Since the cathode is returned to -23 volts on the bleeder, the net plate voltage with no input signal is equal to 21 volts ($-2 + 23$). The grid bias is equal to the voltage at the grid minus that at the cathode or -10 volts ($-33 + 23$). When no signal is present this value of bias is so great that the cathode current is completely cut off and as a result the voltage at point *D* is equal to -2 volts. This is the minimum bias with no signal and in combination with the drop of 0.7 volt across the 82-ohm cathode resistor of each of the controlled tubes, provides a net bias of 2.7 volts for each of the video i-f tubes.

On the other hand, when a signal is being received, *C54* charges up positively to the peak value of the signal and this positive voltage is applied to the grid of the avc triode amplifier. If the signal is strong enough, the plate current will increase, the voltage drop across *R50* will increase, and point *D* will become more negative than -2 volts. The amount of negative voltage produced at point *D* is proportional to the strength of the signal and hence the voltage is available for avc.

A delayed avc action is secured because the negative bias of 10 volts, which exists with no signal, drives the grid of the avc amplifier tube considerably beyond cutoff. Thus the signal level must reach a certain minimum value before the plate current will flow and the avc voltage be produced.

In addition to the delay action, the fact that five stages are controlled results in a very effective avc action which maintains the signal level at the second detector essentially constant.

Video Amplifiers

In the same way that the audio signal in a radio receiver requires amplification before it has sufficient power to drive the speaker, so the video signal in a television receiver requires additional amplification following the video second detector before it has sufficient amplitude to swing the grid of the picture tube. This amplification is supplied by the video amplifier which works between the video second detector and the grid of the picture tube.

The problems associated with the video amplifier, like most television problems, are considerably more difficult than the corresponding problems for a radio receiver. Thus the video amplifier must amplify uniformly frequencies ranging from a few cycles to frequencies as high as 2 to 4 mc. Whereas phase shift is not important in an audio amplifier, in a video amplifier all the frequencies in the signal must take the same time to pass through the amplifier from input to output. This is important because distortion of the waveform, and hence of the picture, is produced when the different video frequencies do not all take the same time to pass through the amplifier. This type of distortion is illustrated in Figs. 10-10 (a) and (b) which show the difference in waveform produced when a 3000-cycle wave is retarded half a

cycle in passing through the amplifier. That the uniformity of time delay plays an important part can be seen from the fact that it takes only approximately seven one-millionths of a second for the cathode-ray beam to move one inch across the screen of the picture tube. Thus even a small non-uniformity in time delay can cause serious distortion of the image.

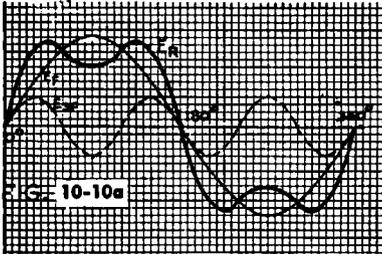
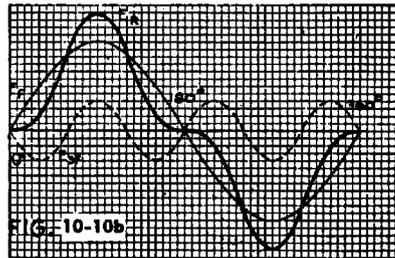


FIG. 10-10(a). The resultant wave E_R is obtained when a 1000-cycle sine wave E_F is combined with a 3000-cycle sine wave E_{3F} which is in phase with the fundamental.

FIG. 10-10(b). The resultant wave E_R is distorted when the phase of the third harmonic E_{3F} is shifted by a half cycle. Compare with E_R shown in (a) above.



The video amplifiers being used in television receivers now on the market have successfully met the problems outlined above. By using low values of load resistance, the shunting effect of tube and circuit capacitances has been minimized and the upper frequency limit extended. Fig. 10-11 shows how the use of a low value of plate load resistance, although it lowers the maximum amplification obtainable, makes possible a more uniform gain over a wide range of frequencies. The sacrifice in gain accompanying the use of low values of load resistance has been partially compensated for by the use of the new high mutual conductance tubes which provide approximately three times as much amplification for a given value of load resistance, as was previously possible with the older tubes.

The most common method for obtaining uniform gain is to use so-called "peaking coils" in series with the plate load resistor. These are small inductances of the order of 100 microhenries, which are resonated with the tube and wiring capacitance near the high-frequency limit of the video amplifier. Peaking coils permit higher values of plate load resistor for a given uniformity of amplification, and consequently make possible reasonably high gains per stage.

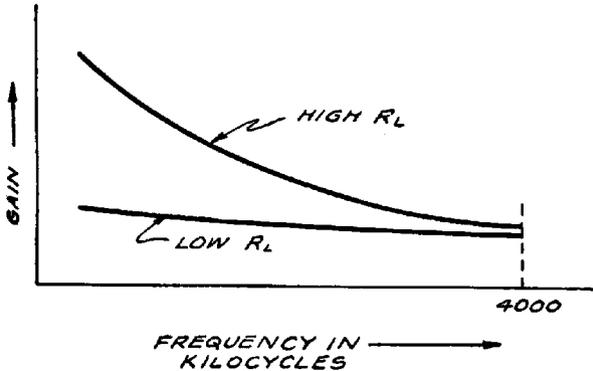


FIG. 10-11. The use of a small value of load resistance provides a more uniform gain over a wide range of frequencies, although the maximum gain is decreased.

In most video amplifiers, filter resistors and condensers are used in the plate and screen leads to provide low-frequency compensation for both gain and time-delay. These filter resistors and condensers are more critical in value than they are in a radio receiver where the primary purpose is to reduce hum and prevent circuit interaction through the common power supply. For this reason, whenever replacement becomes necessary, the resistors and condensers should be replaced with the correct value. Although a larger plate filter condenser, for example, will cause no harm and may even do some good in reducing hum in a radio receiver, the same procedure followed in a video amplifier may cause serious distortion of the picture.

Average Brightness and D-C Restorer Circuits

In discussing the video signal, we can look upon this signal as containing a series of voltage values each of which correspond

to a particular value of light intensity in the televised image. We can consider that in the same way that light values can be reckoned from black as a reference level, so a particular voltage value can be assigned to black and then each light value represented electrically by assigning a higher (or lower) voltage to the signal, depending upon the brightness of the light value at the scanned area. This method of looking upon a video signal is shown in Fig. 10-12 (a), in which it is clear that all light values are with reference to the black level—which is taken as the zero-voltage axis.

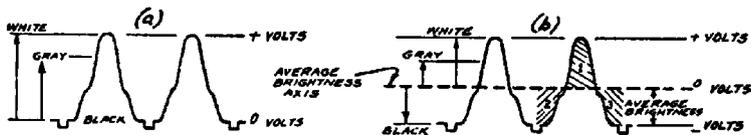


FIG. 10-12. The light values in a video signal can be reckoned in two ways: In (a) the various light values are described with reference to the black level, whereas in (b) the same light values are described with reference to the average brightness of the signal.

Insofar as video amplifier operation is concerned, the important thing about Fig. 10-12 (a) is that it shows that a video signal is inherently a pulsating d-c voltage. In other words (as in the case of a rectified a-c voltage which is also a pulsating voltage) all the light values are represented by electrical values on one side of the zero-voltage axis. The video signal must therefore contain both a d-c and an a-c component in the same way that a rectified a-c voltage representing the output of a power supply contains a d-c component—the d-c voltage of the power supply, and an a-c component—the hum ripple of the power supply.

Physically what does it mean to say that a video signal contains a d-c as well as an a-c component? Actually it is only another way of looking at the signal, as Fig. 10-12 (b) clearly shows. In this figure we describe the signal by saying that the light values are represented by fluctuations in both directions from an average level which we can call the “average brightness,” or the “picture background.” Thus instead of describing the light value at any point in the scene by stating how much brighter it is than black, as in (a), in (b) we accomplish exactly the

same thing by stating how much brighter or blacker is the particular light value than the *average brightness*. In (a) we use the black level as the reference level whereas in (b) we use the average brightness as the reference level.

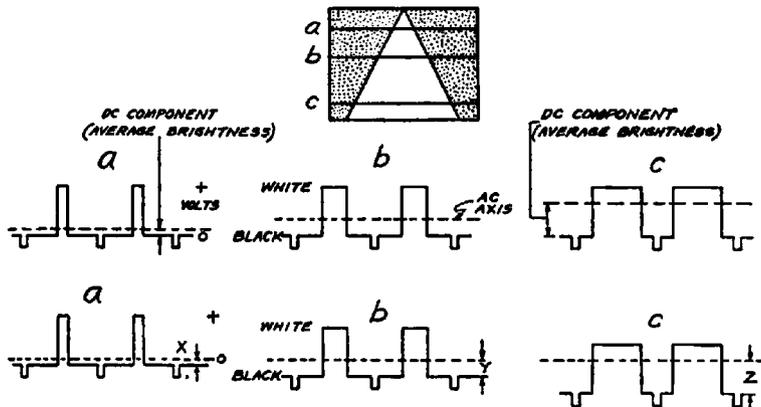
Electrically speaking, the average brightness level represents the average value of the video signal or in other words the d-c component of the signal. On the other hand, the fluctuations in the signal on either side of the average brightness level, which is electrically the a-c axis of the signal, represent the a-c component of the signal. An important characteristic of the average brightness or a-c axis is that the area between the positive part of the cycle and the a-c axis is equal to the area included between the negative part of the cycle and the same a-c axis. This is shown in Fig. 10-12 (b), where it can be seen that area 1 is equal to $area\ 2 + area\ 3$.

From the preceding it will be clear to you that proper operation of the picture tube requires that both the d-c and a-c components of the video signal be passed by the video amplifier. For if only the a-c component reaches the grid of the picture tube, then the picture tube will have information only on the fluctuations in light values *with reference to the average brightness level* but it will have no information whatsoever on the value of this average brightness level. Thus the picture cannot be reproduced accurately since the same variations (represented by the a-c component) might be superimposed on say either a dark or light background of any shade. The average brightness, or the d-c component of the video signal, must be present before the picture can be reproduced.

D-C Restorer Circuits

Unfortunately it is not possible to transmit the d-c component of any signal without using a direct-coupled amplifier. However, the use of direct-coupled amplifiers is not practical in television receivers because of their comparative instability and high cost. For this reason, television engineers have developed circuits which make possible the use of conventional a-c amplifiers with condenser coupling and at the same time provide for the restoration or *re-creation* of the d-c component after the a-c component has been amplified by itself.

It will be helpful at this time to consider several video signals which have different values of average brightness and to describe the action which takes place when these signals pass through an amplifier which employs a blocking condenser as a coupling element between stages. It is because of the presence of the blocking condenser that only the a-c component is passed and that the d-c component is lost.



FIGS. 10-13 (top), 10-14 (bottom). Fig. 10-13 shows the video wave reduced when two lines are scanned at a, b, and c, of the white triangle on a black background. Since the black level is the same for all three cases, this signal contains the d-c component. Fig. 10-14 shows the same signal after it has been passed through an a-c amplifier so that the d-c component has been lost.

In Fig. 10-13 the picture being scanned is a white triangle on a black background, with the vertex of the triangle near the top. Part (a) shows two lines scanned near the top of the picture; part (b), near the middle of the picture; and part (c), near the bottom. Thus (a), (b) and (c) represent three sections of the picture where the average brightness is low, medium, and high respectively. Fig. 10-13 can be said to represent the signal as it is at the output of the camera tube or as it is recovered at the video second detector. Of special importance is the fact that all the blacks are lined up so that the d-c component of the signal is represented in all cases. Note that the d-c component, like the average brightness which it represents, is successively larger in (a), (b), and (c).

Now what happens to this signal when it is passed through an a-c amplifier which contains coupling condensers and therefore will not pass the d-c component? This is clearly illustrated in Fig. 10-14 which shows that the blacks are no longer lined up, but instead the separate average-brightness or a-c axes are all lined up. In other words, when the d-c component is lost, only the fluctuations on either side of the average brightness are transmitted and this axis must of necessity be the zero voltage axis in all instances because no d-c component can get through the amplifier.

Having investigated the video signal both with and without the d-c component, let us now examine the manner in which the picture tube is affected by the presence or absence of the d-c component. In Fig. 10-13, we see that black in every case corresponds to the same definite voltage value and that is also true for white and every intermediate shade between black and white. Thus when the voltage of Fig. 10-13 is applied to the grid of the picture tube, the picture will be reproduced without any distortion.

This, however, is not true of the signal in Fig. 10-14, from which the d-c component has been removed. Black no longer corresponds to the same value in all instances, but instead the signal voltage associated with black takes on a value which is entirely dependent upon the average brightness of the strip being scanned. In the same way, this figure shows that white, and in fact every intermediate shade as well, has a different voltage value which is also dependent upon the average brightness of the strip being scanned. A little reflection will show you that this gives rise to serious distortion because the same light value in different parts of the picture does not correspond to the same voltage value in the signal. Thus, for example, the grid of the picture tube receives a *different voltage for the same shade of gray* in (a), (b) and (c) of Fig. 10-14 and as a result this shade is reproduced differently in the three instances.

In order to remove this source of distortion, it is apparent that the average brightness or the d-c component must be restored. At first glance this seems impossible, for how can the d-c component be restored after it has once been lost in the video amplifier? As a matter of fact, it is generally not possible to restore the d-c

component of a pulsating wave after the d-c component has been lost in transmission, because no information relative to the d-c component is contained in the a-c component; the two are entirely independent of each other. Fortunately, however, the sync pulse is transmitted at the end of each line, *and the pedestal on which the sync pulse stands corresponds to a definite black reference level.* These facts make it possible to restore the lost d-c component. Thus to restore the d-c component to the signal of Fig. 10-14 it is only necessary to modify the signal so that all the synchronizing pulses are lined up. When this is done, the signal in Fig. 10-14 is exactly the same as that in Fig. 10-13 and the d-c component has been completely restored.

The solution of the problem depends upon finding this varying d-c voltage and adding it to the signal. This is accomplished in a very simple manner by using a diode to rectify the "black" half of the a-c video signal (which contains the sync signal) and in this way the required voltage is produced. Thus in Fig. 10-14 at (a) this rectification produces the voltage x ; at (b) it produces the voltage y ; and at (c) it produces the voltage z . In general, the addition of this varying d-c voltage lines up all the pedestals to produce the original signal (Fig. 10-13) with the d-c component restored.

Basic D-C Restorer Circuit

In Fig. 10-15 we show a straightforward circuit which is used to restore the d-c component in the video signal before the signal is applied to the control grid of the picture tube. The video signal is developed across the 3000-ohm plate resistor $R1$ and fed to the control grid through an 0.1-mf coupling condenser $C1$. As the sketch shows, the signal has the required positive polarity both at the plate of the video amplifier and the grid of the picture tube. However, the d-c component is not present at the plate side of $C1$, whereas the diode circuit shown in heavy outline has restored the d-c component on the grid side.

Let us see just how the diode circuit restores the d-c component. Considering the series circuit composed of the video voltage across $R1$, the .005-mf condenser $C2$, and the diode in shunt with a 1-meg resistor,—we can see that the following takes place: On the positive half of the cycle the cathode of the diode is swung

positive with respect to its plate so that no current flows in the diode circuit. On the negative half of the cycle, however, the cathode is swung negative with respect to the diode plate, and current flows in the diode circuit through R_3 . It is this current flow which charges C_2 and makes the cathode end of R_3 positive, and as a result provides the d-c restoring bias.

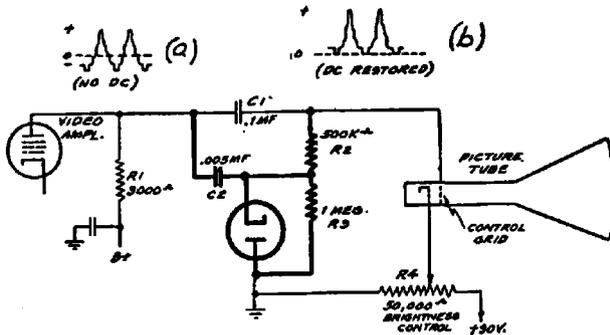


FIG. 10-15. The heavy outline shows a typical d-c restorer circuit which replaces the d-c component in the video signal before it is applied to the grid of the picture tube.

Note that the d-c voltage across R_3 satisfies all the conditions required to line up the sync pulses so as to restore the d-c component. Essentially the action in the diode circuit is such that the *negative* part of the video wave is rectified and that the diode current charges C_2 positively to a value equal to the amount by which the sync pulses in Fig. 10-15 (a) are depressed below the a-c axis. Since the grid of the picture tube is returned to this d-c voltage through the 50,000-ohm resistor R_4 , the d-c voltage is added to the video signal at Fig. 10-15 (a) and "raises" the pedestal so that it lies along the zero-voltage axis, as shown at Fig. 10-15 (b).

Now suppose, as in Fig. 10-14 (c), that the average brightness is higher than that shown at (a) in Fig. 10-15. This results in the pedestal being more negative with respect to the a-c axis, so that the diode produces a more positive voltage which again raises the pedestal to the same zero-voltage axis as at (b) in Fig. 10-15. Thus the action is entirely automatic so that all the pedestals are

lined up at the grid of the picture tube, *regardless of the value of the average brightness.*

It is important to understand that the voltage produced at the cathode varies constantly throughout the scanning and that its value at any time depends upon the average brightness of the *portion* of the picture being scanned at that particular time. The time constant (RC) of the diode circuit is designed so that $C2$ in Fig. 10-15 will not discharge appreciably during the interval between successive sync impulses. At the same time, the time constant is sufficiently small so that when the average brightness changes, the condenser is able to change its charge rapidly enough to respond to the new conditions.

Insofar as the grid of the picture tube is concerned, it receives the a-c component of the video signal through $C1$, and *only* the d-c component through $R2$. Although the a-c component is also present at the cathode of the diode, $R2$ acts as a filter resistor to prevent that portion of the video signal present at the cathode from reaching the picture-tube grid through $R2$.

Brightness Control

We have just seen how the d-c restorer circuit automatically lines up all the sync pulses so they are at the same voltage level. For correct operation of the picture tube, the bias on the picture

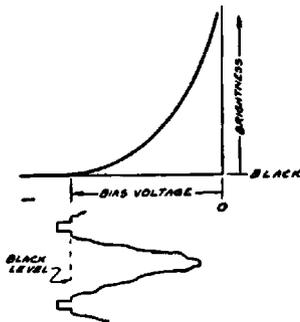


FIG. 10-16. The effect of variation in the bias voltage on the brightness of the image.

tube must be so adjusted that these aligned pedestals occur at the cutoff or black level. The sync pulses will then lie in the blacker-than-black region and the various shades of gray and white will be reproduced correctly.

Fig. 10-16 shows the illumination characteristic of a picture tube and the manner in which the brightness of the scanning spot depends upon the bias voltage on the control grid. Referring again to Fig. 10-15 you can see that the cathode of the picture tube is returned to a potentiometer which makes it possible to vary the bias voltage from 0 to 90 volts.

When the bias is highly negative, the tube is cut off and the spot intensity is zero. As the bias becomes more positive, the intensity of the spot increases. For correct operation, the brightness control should be adjusted manually so that the pedestals occur at the black or cutoff points. Once the brightness control has been set, the d-c restorer circuit automatically keeps the pedestals in alignment so that no further adjustment is required.

Grid Leak—Condenser Restorer

Another type of d-c restorer circuit which is very widely used is shown in Fig. 10-17. In this circuit the output video amplifier tube is operated at zero bias and the grid-cathode elements are used as a diode to insert the missing d-c component. To prevent the loss of the newly restored d-c component which would occur if condenser coupling were used in coupling the plate to the picture tube, the plate is coupled *directly* to the picture tube grid.

From the explanation already given of the process of d-c restoration, it is easy to understand how circuits of this type operate. The waveform of the video signal on the left side of $C1$ is shown at (a); at this point the signal has a negative polarity and of course the d-c component is missing. When this a-c signal is impressed on the grid of the output tube through $C1$, the positive parts of the video cycle (including the sync pulses) place the grid positive with respect to its cathode so that grid current flows through $R1$. The direction of this grid-current flow is such that the grid becomes negative with respect to ground.

When the average brightness of the signal is small, the a-c axis of the signal will be near the black level, the positive peaks will be small in amplitude, only a small value of grid current will flow, and consequently the grid will be displaced only slightly negative. On the other hand, when the average brightness is great, the a-c axis is away from the black side, the positive peaks will be large in amplitude, a relatively large flow of grid current will take

place, and the grid will be made highly negative. In each instance, the grid will be made more negative by an amount equal to the height of the sync pulses above the a-c axis of the wave. As a result of this action all of the pedestals in the signal are depressed by an amount sufficient to align them to the same zero-voltage level at the grid. This is shown by the signal waveform at Fig. 10-17 (b). Essentially the action here is the same as that previously described for the circuit using a separate diode. The condenser $C1$ performs the same function of storing the grid charge as in the previous method.

At the plate of the output tube, the polarity of the video signal is reversed and as Fig. 10-17 (c) shows, the signal at this point has the required positive polarity. Since no blocking condensers are interposed between the plate and the grid of the picture tube, the sync pulses remain in alignment.

As in the previous circuit, provision must be made for initial adjustment of the bias of the picture tube so that the pedestals of the signal will occur at cutoff (black level) on the picture-tube

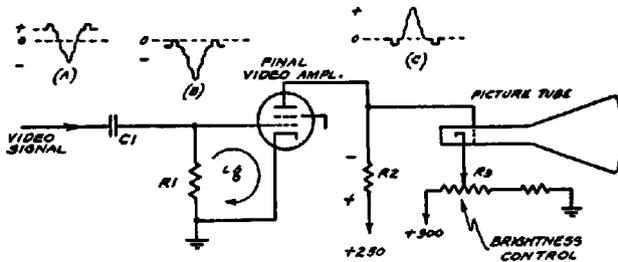


FIG. 10-17. A widely used type of d-c restorer circuit in which the video amplifier output tube is operated at zero bias so that the grid-cathode elements function as a diode to reinsert the d-c component.

characteristic. To accomplish this, the cathode of the picture tube is returned to a bleeder-potentiometer which makes it possible to place up to a maximum of +300 volts in the cathode. Since the grid can at most have a potential of +250 volts, this makes a bias of -50 volts available on the grid of the picture tube. Under actual operating conditions, the voltage drop across $R2$ makes the grid more negative; this is compensated for by

making the cathode of the picture tube less positive by adjusting the brightness control R_3 .

When the receiver is first turned on, there is no voltage drop across the plate-load resistor R_2 until the output video tube warms up and draws plate current. The final adjustment of the brightness control therefore should not be attempted until the receiver has been turned on for a few minutes. In particular the brightness control should be all the way to the left (with the rotor at +300) until the receiver has warmed up; this is done to avoid possible damage to the picture tube because of excessive beam current.

The Contrast Control

The "contrast control" is the gain control which determines the magnitude of the video signal applied to the grid of the picture tube. Its counterpart in a sound receiver is the volume control, and in the same way that the sound volume control determines the range of intensities between the loudest sound and the softest sound, so the video contrast control determines the range of light intensities between the highlights and the shadows of the picture. Referring to Fig. 10-16, the setting of the contrast control determines how much of the picture tube characteristic is used and how bright will be the brightest element of the scene. When the contrast control is not advanced far enough, the picture lacks brilliance and the highlights are comparatively dark; when the contrast control is advanced too far, the picture becomes blurred, there is a loss of detail in the highlights, and in general the intermediate shades are lost.

Synchronizing Circuits

The circuits devoted to synchronization in a television receiver are those which remove the sync information contained in the complete video signal and utilize it to control the timing of the horizontal and vertical deflection oscillators. To perform these functions, the sync part of the signal must first be separated from the picture part of the signal. In addition the vertical sync pulses must be separated from the horizontal sync pulses so that each can be applied to the respective deflection oscillator which it controls.

The circuits used to separate the synchronizing pulses from the picture portion of the signal are called "sync separators" or "clippers." These circuits are designed so that they are responsive only to the sync pulses which lie above the pedestals; thus they reject the picture portion of the signal. The clipper or sync separator is generally followed by additional amplification and finally the sync signal is fed to a frequency-selecting circuit which separates the horizontal sync pulses from the vertical sync pulses. This separation is accomplished by circuits which depend for their action upon the difference in the time duration of the two types of pulses.

To illustrate the principles involved in sync circuits, we shall describe the circuits used in the RCA Model TRK-12 receiver.

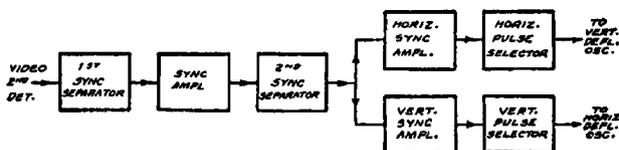


Fig. 10-18. Block diagram of the sync circuits used in the RCA Model TRK-12 receiver.

As the block diagram in Fig. 10-18 shows, the video signal is taken directly from the second detector and passes through the *first sync separator* which removes most of the video signal from the sync signal. The sync signal is then amplified in a *sync amplifier* stage and fed to a *second sync amplifier* stage which completes the separation of the sync signal. The output of the second clipper is fed to two separate stages, the horizontal sync amplifier and the vertical sync amplifier. The output of the horizontal sync amplifier feeds the sync pulses to a circuit—the *horizontal pulse selector*—which selects the vertical sync pulses; the output of the vertical sync amplifier also feeds the sync pulses to the *vertical pulse selector* which selects the vertical pulses.

On the whole, the block diagram presents quite an imposing array of circuits considering that it represents but a small part of all the circuits in the complete receiver. However, synchronization is so important in the operation of the television system that great care must be taken to make the synchronization positive in action.

As in the d-c restoring circuits, the time constant of the input circuit is sufficiently large so that the bias is maintained during the interval between sync pulses.

The signal produced in the plate circuit of the first sync separator no longer contains the picture part of the signal but instead the latter has been removed because of the sharp cutoff of this

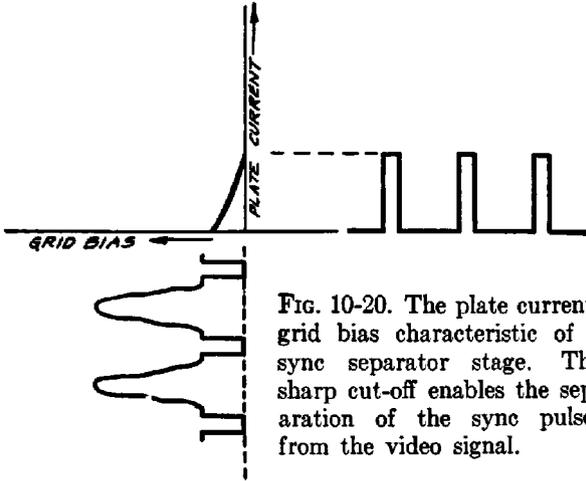


FIG. 10-20. The plate current-grid bias characteristic of a sync separator stage. The sharp cut-off enables the separation of the sync pulses from the video signal.

stage. A term often used to describe the action of a circuit similar to the first sync separator is the term "clipper." This term is appropriate because the stage can be thought of as clipping the video portion of the signal and leaving only the sync pulses.

The clipped sync signal is next fed to the grid of the second triode of the 6N7 which is arranged to function as an amplifier. For this reason a high value of plate voltage, 200 volts, is used. Note that the sync pulses have been reversed in polarity so that the grid of the amplifier tube goes negative on the peaks of the sync pulses. However, the operating characteristics of the amplifier stage are such that the sync pulse waveform in the plate circuit of the sync amplifier is simply an amplified version of the signal in the grid circuit. The polarity of the signal is of course reversed 180 degrees so that the sync signal in the grid circuit of the following clipper tube is negative in polarity.

The action in the second sync separator is similar to that in the first sync separator. A screen grid tube is used with the screen placed at a higher voltage than the plate and with both these voltages comparatively low. Thus the screen voltage is only 25 volts and the plate voltage about 6 volts. Under these conditions the stage has a very effective clipping action on both the positive and negative peaks of the sync pulse. In this way, if any video signal still remains it is clipped sharply by the plate-current cut-off; at the same time, the positive peaks of the sync pulses are again clipped as in the previous sync separator. As a result of this second clipping of the sync pulses, the waveform is made flat and any noise components that may have been added to the signal are removed. Thus noise is prevented from interfering with the synchronization.

The output of the second sync separator feeds the sync pulses to two separate amplifier stages, a vertical sync amplifier and a horizontal sync amplifier. These individual stages provide further amplification of the sync pulses and at the same time act as buffer stages to isolate the vertical sync circuits from the horizontal sync circuits. The circuits used in the output of these stages are frequency-selecting circuits which differentiate between the two types of sync pulses by making use of the fact that the duration of the vertical sync pulses is greater than that of the horizontal sync pulses.

Horizontal Sync Selector

The signal is coupled to the horizontal sync amplifier through the 820-mmf condenser *C84* in Fig. 10-19. The amplified signal appears across *R87* and is fed to the *selector circuit* consisting of *C87* (150-mmf) and *R90* (470 ohms). This circuit separates the horizontal sync pulses, which appear across *R90*.

The manner in which this selector circuit operates requires some explanation. Essentially the current which passes through *R90* is limited by *C87* because of the small value of capacitance and the low value of resistance. As a result the current through *R90* is proportional to the rate of change of the sync pulse voltage and in this way sharp voltage pulses are produced across *R90*. This is clearly illustrated in Fig. 10-21 which shows the input sync signal during the interval between successive fields. Note that at

each edge of the sync signal where the waveform changes abruptly, this rapid change results in a pulse of current through *C87* and *R90*, which produces the voltage drop across *R90* shown in the figure. As explained later, only the positive pulses across *R90* are effective in synchronizing the deflection circuit; those

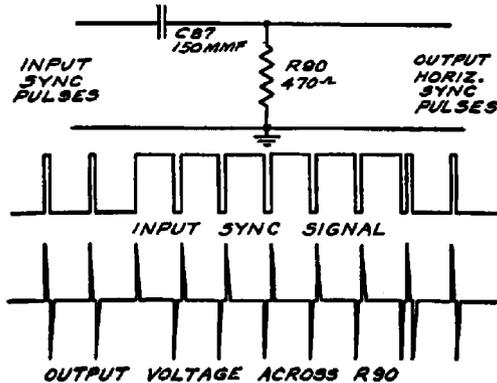


FIG. 10-21. Circuit used for separating the horizontal sync pulses from the complete sync signal. The waveform of the sync signal at the input and output of the separator are shown below the circuit.

below the axis have no effect. As Fig. 10-21 shows, horizontal sync pulses are also produced during the vertical blanking period because the leading edge of each vertical sync pulse represents a rapid change of voltage and therefore produces a pulse through *R90*.

Vertical Sync Selector

The complete sync signal is also fed from the second sync separator into the grid of the vertical sync amplifier. The amplified sync signal appears across *R99* of Fig. 10-19 and is fed to the selector circuit consisting of *R101* and *C98*. Two additional sets of resistor-condenser combinations are used in series in order to increase the effectiveness of the vertical pulse selection.

The action of *R101* and *C98* in differentiating between the vertical and horizontal sync pulses is a direct result of the longer duration of the vertical pulses. Thus Fig. 10-22 shows that each

one of the sync impulses, including the horizontal impulses, contributes a small amount of charge which is stored in the condenser. The greater the duration of the pulse, the greater the voltage across the condenser. During the transmission of the long vertical sync pulses, the accumulation of charge on the condenser is greater than during the transmission of the short line sync pulses. As a result, the voltage across the condenser *C98*

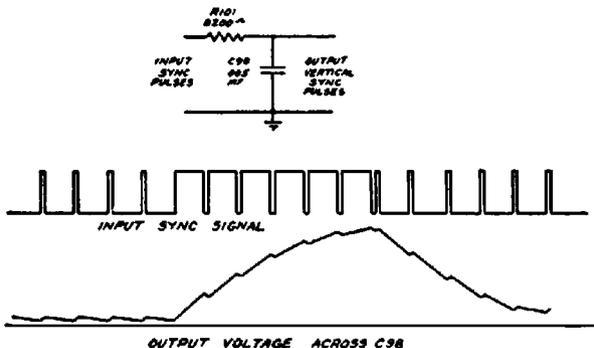


Fig. 10-22. Circuit used for obtaining the vertical sync pulses for field synchronization. The input and output waveforms are shown below the circuit.

builds up to a peak once during each field or 60 times in each second. As the figure shows, the vertical pulse builds up to a maximum at the end of the last vertical sync pulse and then steadies down to an average value of voltage which remains constant until the beginning of the next field pulse.

To increase the circuit effectiveness, two more similar resistor-condenser combinations are used in series as shown in Fig. 10-19. These circuits accomplish a further selection of the two pulses so that a sharper pulse is produced once during each field. The peak of this pulse is used to synchronize the vertical deflection oscillator.

For exact interlacing it is important that the vertical pulses produced at the output of the vertical selector circuit be the same on alternate fields. The equalizing pulses, previously described, accomplish this by making the conditions exactly the same before and after the transmission of the actual broad vertical sync

pulses. As a result, the condenser charges up to the same value of peak voltage on both the odd and even fields so that the vertical oscillator is maintained in perfect timing.

Deflection Circuits

The block diagram of Fig. 10-23 shows the essential parts of a common type of deflection circuit for television. From the sync separator described in the previous section, horizontal sync pulses

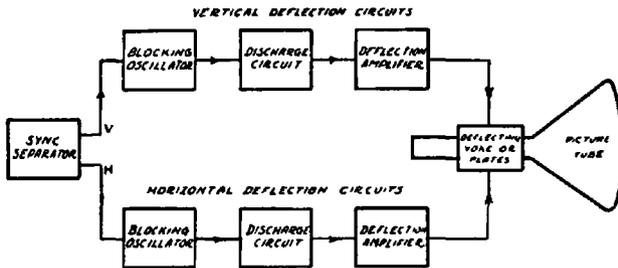


FIG. 10-23. Block diagram of the essential parts of a widely-used type of deflection circuit.

are applied to the horizontal deflection circuits and vertical sync pulses to the vertical deflection circuits. Both sets of deflection circuits contain the same type of elements, the principal difference being the operating frequencies.

The sawtooth waves required for deflection of the electron beam are formed in the *discharge circuit*. This circuit includes a condenser which is slowly charged from the B supply and then rapidly discharged through a vacuum tube. The voltage across this condenser varies in such a way as to form a sawtooth voltage wave. The exact moment at which the discharge tube operates is determined by the *blocking oscillator* which provides pulses to the grid of the discharge tube of sufficient amplitude to "trip" it. The frequency of the blocking action is itself synchronized with the incoming signal by pulses from the *sync separator*. The sawtooth voltage wave formed in the discharge circuit is amplified in the *deflection amplifier* and then applied to the deflecting yoke or plates which cause the scanning action of the beam in the *picture tube*.

Circuits for Electromagnetic Deflection

The schematic, Fig. 10-24, shows the deflection circuits used in the RCA Model TRK-12 and Westinghouse Model WRT-703 receivers. These are examples representative of circuits for use with a picture tube deflected by the electromagnetic method.

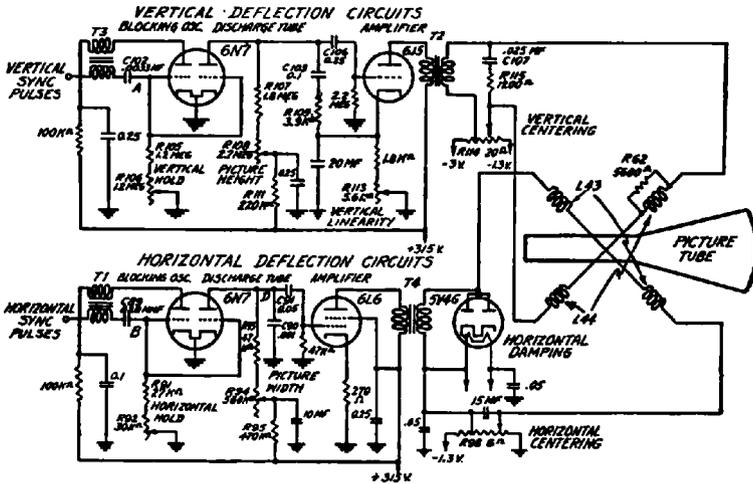


Fig. 10-24. Deflection circuits used in the RCA Model TRK-12 receiver. Compare with the block diagram in Fig. 10-23.

To describe the formation of the sawtooth wave, let us assume that the grids of the 6N7 tube (in the horizontal circuit) are biased to cutoff so that the tube is non-conducting. The plate voltage starts to charge the .001-mf condenser C_{90} through resistors R_{93} , R_{94} and R_{95} in series. The voltage across C_{90} (from D to ground) rises to form the trace part of the deflection voltage. About 65 microseconds later, a positive pulse of voltage is applied to the grids of the 6N7 and the tube "trips" or starts conducting. The triode section, whose plate is connected to D , then acts as a short to ground and discharges C_{90} in about 11 microseconds. The voltage across C_{90} falls rapidly to form the retrace part of the deflection voltage. The discharge is stopped after 11 micro-

seconds by a sudden blocking of the grids, and the charging cycle starts again. The relatively short time allowed for the charge and discharge of condensers *C90* (horizontal) and *C103* (vertical) assures that the sawtooth wave will be essentially linear.

Blocking Oscillator. The periodic blocking and tripping of the 6N7, which has just been mentioned, is accomplished by the blocking oscillator. In connection with the latter, the question naturally arises as to why the sync pulses could not be used directly to trip the discharge tube. Actually, the sync pulses could be used directly, but it has been found more satisfactory to use the blocking oscillator circuit being described. The blocking oscillator provides a steep pulse of high amplitude which is more readily adapted to the control of the discharge tube than is the sync pulse itself. The necessary timing of the blocking oscillator is of course obtained from the sync pulses.

As the name implies, the blocking oscillator is a regenerative oscillator in which the feedback is so large that the oscillator is blocked on the first cycle of oscillation. Thus when oscillation starts, the amplitude is so great that the negative charge which accumulates on the grid condenser drives the tube to cutoff. Before the oscillations can start up again, the charge on the grid condenser must leak off. The rate at which this charge leaks off determines the rate at which the steep pulses are produced by the blocking oscillator. Because the circuit constants are such that the natural frequency at which the oscillator attempts to work is higher than the frequency of blocking, the pulse produced when oscillations start has a very steep waveform which is advantageous in controlling the discharge tube.

The rate of blocking, and hence also the rate at which the pulses for the discharge tube are produced, is controlled by *R91* and *R92*. The lower the value of this grid resistance, the more rapidly the charge leaks off so that the oscillations can begin again and produce another pulse. The "free-running" frequency of the blocking oscillator is thus controlled by the value of *C89*, which determines the amount of charge stored in the grid circuit, and *R91* and *R92* which determine the rate at which this charge leaks off.

In practice, the free-running frequency is adjusted by means of the *horizontal hold control R92* so that it is lower than the line

frequency of 13,230 cycles. The application of the horizontal sync pulse to the grid circuit, as shown, will then introduce a positive pulse into the grid circuit and cause the blocking oscillator to start operating slightly before the instant when it would normally resume operation. In this way the sync pulse keeps the blocking oscillator exactly in synchronism with the frequency of the scanning at the camera tube.

The circuit for the vertical deflection operates in the same manner. In this case *R106*, the *vertical hold control*, is adjusted so that the free-running frequency of the vertical oscillator is slightly less than 60 cycles. The introduction of the vertical sync pulse trips the oscillator just before it would otherwise resume oscillation so that the frequency is kept in synchronism with the vertical sync pulses.

Width and Height Controls. The peak value of the sawtooth voltage which is developed across *C90* depends on the setting of *R94*. Since the peak value of the voltage across *C90* determines the magnitude of the horizontal scan and therefore the picture width, *R94* is called the *picture width control*. Similarly *R108* controls the vertical sawtooth amplitude and therefore is called the *picture height control*.

The *vertical linearity control R113*, which is in series with the vertical wave-forming condenser *C103*, corrects the waveshape so that a sawtooth wave of current will be obtained through the deflecting coils.

Centering. As a result of the circuits described, accurately timed sawtooth voltages are available at points *C* and *D* of Fig. 10-24. These waves are amplified and coupled to the deflecting coils *L44* and *L48* by transformers *T2* and *T4* respectively. The picture is centered on the picture-tube screen by sending a small direct current through the deflecting coils. Potentiometers are provided for making the vertical and horizontal centering adjustments.

Damping Tube. The 5V4G diode shunted across the secondary of *T4* is provided so as to prevent transient voltages being set up when the scanning current changes abruptly. This diode acts as an automatic switch so that the transformer is loaded only during the trace period, and the load removed during the retrace period. It is not possible to use a permanently-connected resistor load in

place of the diode switch because this continuous loading would tend to prolong the retrace period by an excessive amount.

Electrostatic Deflection

In electrostatic deflection systems for television, it is usual to use the same type of sawtooth-wave generator as is used for electromagnetic deflection. The output systems, however, are quite different. To avoid distortion of the raster and defocusing of the spot, the sawtooth waves on each plate of any pair must be alike but 180 degrees out of phase. A balanced amplifier using a phase inverter is used to furnish these deflecting voltages. The force acting on the electron beam is thus due to the difference between the potentials of the two plates, since at any one instant the positive voltage on the one plate attracts the electron beam at the same time that the corresponding negative voltage on the other plate repels the electron beam. Thus, if at any instant the deflecting voltage on one plate is $+50$ volts, then the voltage on the other plate is -50 volts and the effective deflecting voltage is the sum or 100 volts.

Electrostatic Deflection Circuits. Fig. 10-25 shows the output

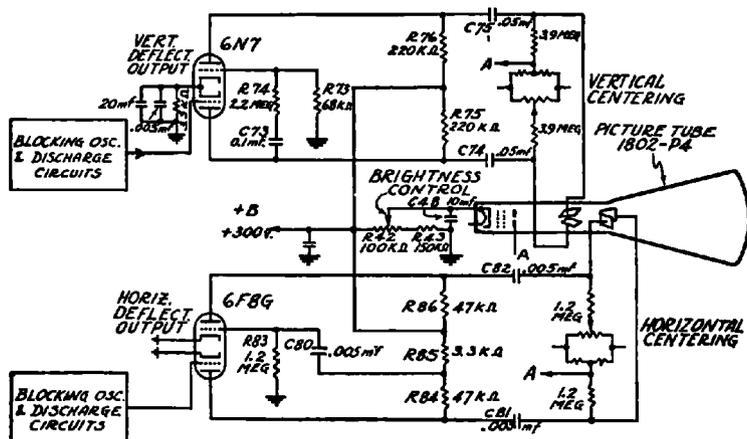


Fig. 10-25. Circuits used for electrostatic deflection in the RCA Model TRK-5 receiver. Note the push-pull output in both the horizontal and vertical channels.

circuits of the electrostatic deflection circuits used in the RCA TRK-5 and Westinghouse WRT-701 receivers. The blocking oscillator and discharge circuits are shown in block form because they are similar to those shown in Fig. 10-24. In the vertical circuit the signal across *R75* is fed to one of the vertical deflecting plates through condenser *C74*. This same signal is also fed to the grid of the phase inverter section of the 6N7 tube through condenser *C73* and a voltage divider consisting of *R74* and *R73*. The signal across the phase inverter load *R76*, which is 180 degrees out of phase with the signal across *R75*, is fed through condenser *C75* to the other vertical deflecting plate. The voltage divider *R74*, *R73* is used to compensate for the gain of the phase inverter section of the 6N7 so that the signal amplitude applied to each deflecting plate is the same except for the phase reversal. In the case of the horizontal deflecting circuit, the action is similar; here the voltage divider consists of *R84* and *R85*.

Centering Control. Fig. 10-25 also shows the type of centering circuit used with electrostatic deflection. One plate of each pair is returned to the second anode through a high resistance. The second plate is returned through a high resistance to the potentiometer which permits a d-c voltage, either zero, plus or minus with respect to the first plate, to be applied to the second plate in order to center the raster on the screen of the picture tube. These potentiometers, called *centering controls*, are usually adjusted during installation and seldom need readjustment. The details of this type of circuit are shown in Fig. 10-26 in the following section on power supplies.

Power Supplies

As a general rule, two separate rectifiers are used to supply the d-c voltages for television receivers. A low-voltage supply provides approximately 300 volts for the tubes associated with the amplifier, deflection, and sync circuits of the receiver. A separate high-voltage power supply provides the high voltages—from approximately 2000 to 10,000 volts—required for the picture tube.

Since the low-voltage power supplies are very similar to those used in radio receivers, a separate low-voltage schematic is not shown here. The regulation in a television low-voltage power supply is generally better than that in a radio receiver because

of the importance of preventing variations in the numerous circuits from interfering with each other and with the picture. The hum level is also kept down to a lower value because of the large number of circuits and stages, and because hum which would be inaudible in a sound receiver may cause appreciable distortion of the picture.

Unlike the low-voltage power supply, a half-wave rectifier is invariably used in the high-voltage supply. The advantages of the half-wave rectifier are that the transformer does not have to be as large and that the peak voltage is reduced to about one-half the value required for full-wave rectification. Ordinarily the half-wave rectifier is not used in radio receiver power supplies because its output is harder to filter and because it cannot supply as much current to the load as the full-wave rectifier. However, these characteristics are not disadvantages in television receivers because only a very small current is drawn and a resistor-condenser filter can be used.

High-Voltage Power Supply in RCA TRK-5, Westinghouse WRT-701

The high-voltage power supply used in the RCA Model TRK-5 and Westinghouse WRT-701 receivers is shown in Fig. 10-26. A type 879 high-voltage half-wave rectifier is used, the complete path of the rectified current being from the low-voltage end of the secondary, through the secondary winding, the 879 rectifier tube, the first filter resistor $R91$, the second filter resistor $R92$, and the bleeder resistors from $R93$ to $R98$, inclusive, and back to the low-voltage side of the secondary.

$R91$ acts as a filter resistor and also limits the voltage and current through the first filter condenser $C86$. Good filtering is secured by using a high value of filter resistance; $R92$ is 470,000 ohms, and in combination with the two .05-mf condensers provides adequate filtering. Note that large values of filter resistance rather than large values of capacitance are used to obtain the required filtering. The advantage of this is the reduced cost and size of the condensers; in addition, the smaller the size of the filter condenser, the less is the danger of fatal shock if one accidentally comes in contact with a charged or partly-discharged condenser. Nevertheless, the high-voltage filter condensers should

The high-voltage supply is not entirely independent of the low-voltage power supply in the sense that the entire high-voltage power supply is returned to ground through the brightness control in the low-voltage power supply. If the connection to the brightness control at $R42$, Fig. 10-26, were broken, then the entire high-voltage power supply would "float." In actual operation, the potential at the cathode is approximately 200 volts above ground potential, depending upon the setting of the brightness control; as a result the low end of the high-voltage rectifier circuit, including the cathode of the picture tube, is above ground potential by this same amount. The control grid of the picture tube, which is tied to the plate of the 6V6 video output tube, is approximately 175 volts above ground potential so that the proper average brightness can be secured by means of the setting of $R42$.

Grounding of High-Voltage Power Supply. The high voltage difference required between the cathode and second anode of the picture tube can be obtained with either the positive or negative side of the high-voltage power supply near ground potential. In receivers using the electromagnetic method of deflection, it is usual for the negative side of the power supply to be grounded since this enables coupling the video output tube to the modulation grid without the use of a high-voltage condenser. This same system is also used in some receivers which use electrostatic deflection, as for example in the RCA Model TRK-5 receiver. Where electrostatic deflection is used, however, high-voltage blocking condensers are required in the circuits which couple the deflection output tubes to the horizontal and vertical deflection plates.

To avoid the use of high-voltage blocking condensers in the deflection plate circuits and at the same time maintain the deflection plates at the same potential as the second anode (which is necessary to avoid distortion in the picture tube), the positive side of the high-voltage power supply is sometimes grounded and the cathode is then several thousand volts negative with respect to ground. The DuMont Models 180-183 are examples of receivers using this type of circuit. Although high-voltage condensers are not required in the deflection circuits, a high-voltage blocking condenser must be used between the plate of the video output tube and the modulation grid.

Regardless of whether the positive or negative side of the power supply is grounded, the usual precautions against electrical shock must be observed.

SIGNAL TRACING IN FACSIMILE RECEIVERS

Facsimile is similar to television in that both are concerned with the reproduction of pictures at a distance from the source. However, in facsimile the time required for the transmission of a single picture is ordinarily reckoned in terms of minutes whereas in television we have seen that a complete picture or "frame" must be transmitted in approximately one-thirtieth of a second. In facsimile, a permanent record of the picture is made at the receiving point, whereas in television a transient or temporary image is obtained and no record is ordinarily available after the transmission has taken place. Unlike television, which presents a rapid succession of moving pictures to create the illusion of motion, facsimile deals with the reproduction of but a single picture which is permanently recorded by the facsimile receiver. This picture, which may be a reproduction of printed matter, a photograph, drawing, or any combination of these, can be examined after the several minutes required for its transmission have passed, and is available as a permanent record.

Because of the much greater period of time available for the transmission of a facsimile reproduction, it is to be expected that facsimile will use mechanical devices to a much greater extent than television. Present facsimile receivers and transmitters use mechanical scanning devices and synchronizing systems, rather than electronic systems as in television, although electrical impulses are of course used to control the mechanical motions. Thus to a considerable extent, the proper operation of a facsimile system requires that the system be in proper mechanical adjustment as well as in proper electrical adjustment.

At the present time a number of stations in the broadcast band regularly transmit facsimile programs which can be received with a conventional radio receiver in conjunction with a facsimile recorder. Since these stations transmit standard programs during the regular hours, facsimile broadcasts are limited to the early morning hours, generally between one a.m. and six a.m. There are also several stations operating in the ultra-high frequency

range which provide facsimile programs during the day. In all cases standard broadcast or short-wave receivers which tune to these frequencies can be used to receive facsimile programs, since the bandwidth of the average receiver is entirely adequate.

The application of signal tracing to the servicing of facsimile receivers involves a knowledge of the overall operation of the system with special emphasis on the recorder. For this reason we shall devote the following paragraphs to a brief explanation of the Finch facsimile system which is quite typical of facsimile systems. Although other systems have been and are being used, these systems have much in common and the discussion of the Finch system will be of value in understanding other systems as well.

Finch Facsimile Receiver

In one form of the Finch system, the transmitter employs a scanning system which is illustrated in Fig. 10-27. The copy is

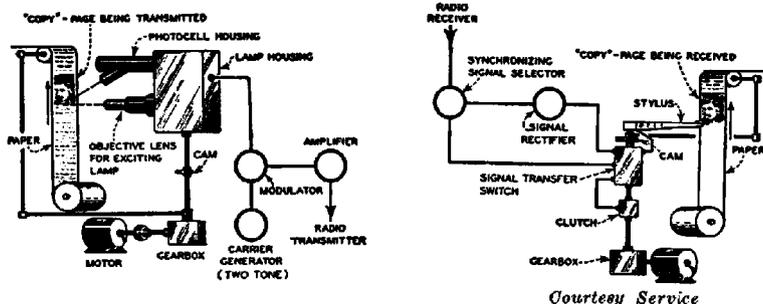


Fig. 10-27. A facsimile transmission system showing the major components used in the transmitter and the receiver.

fed through the scanning mechanism at the rate of 1/100 inch per second and at the same time it is scanned from left to right by a small beam of light about 1/100 inch in diameter. The amount of light which is reflected into the photocell is proportional to the shading of that element of the copy being scanned; a relatively greater amount of light is reflected into the photocell from elements where the copy is white than from darker elements. In

this way the output of the photocell produces a pulsating voltage, the amplitude of which is proportional at every instant to the brightness of the elements being scanned.

The output of the photocell is amplified and is used to control the amplitude of a 2000-cycle signal voltage. This 2000-cycle signal is essentially a carrier which is modulated by the output of the photocell so that its amplitude varies in accordance with the amount of light reflected from the copy. Finally the modulated 2000-cycle signal is fed to the transmitter where it modulates the radio-frequency carrier. Because of the relatively low scanning speeds, as compared with television, this r-f carrier may lie in or below the broadcast band; the bandwidth necessary is even smaller than that required for ordinary sound broadcasting.

As the diagram shows, the transmitted signal is received by a conventional receiver which is connected to the facsimile recorder. After rectification, the 2000-cycle modulated signal is fed to the recording stylus where it traces out the image on the specially treated copy paper. This paper is a white-coated carbon-impregnated paper designed so that it turns various shades of gray or black in proportion to the current which passes from the stylus through the paper.

The required horizontal deflection of the stylus as well as the vertical movement of the copy paper is secured by means of a motor-driven arrangement which is essentially similar to that used at the transmitter. In order to obtain synchronization, the stylus is driven through a friction clutch which makes it possible to hold the stylus at the beginning of each line for whatever small time interval is required to synchronize the stylus with the photocell scanning at the transmitter. The exact moment at which the stylus is released is determined by a 500-cycle synchronizing signal which is transmitted at the beginning of each line. It is for this reason that the carrier generator in the diagram is designated as a two-tone generator since it produces a 2000-cycle tone during the active line scanning, which is changed automatically at the transmitter to a 500-cycle tone at the beginning of each line. In practice the stylus at the recorder is driven about 2% faster than the photocell at the transmitter so that it will be possible to synchronize the scanning. A little reflection will make it clear that this is required since otherwise the stylus

in some cases might not have reached the extreme left position at the instant of arrival of the sync signal.

A more detailed description of the recorder can be obtained with the aid of the diagram in Fig. 10-28 which is a schematic of the Finch Type RB home facsimile recorder. The signal voltage is obtained from the output of the audio amplifier of the receiver used in conjunction with the recorder and is fed to the rectifier circuit. The rectifier employs a full-wave circuit in which a 6A6 is used with the grids and plates tied together.

Circuit Analysis

To analyze the circuit, let us first consider the circuit connections when the recording arm, which carries the stylus, has just returned to the extreme left of the paper. This is the condition shown in Fig. 10-28. For this case, the projection on the clutch

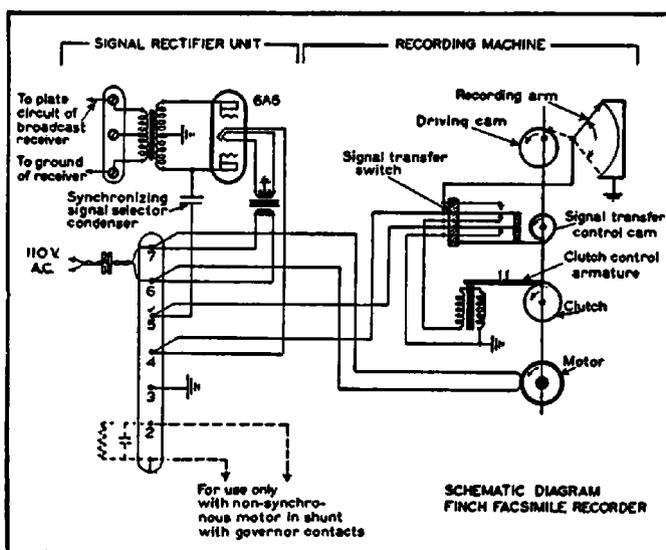


FIG. 10-28. Schematic diagram of the Finch facsimile recorder.

disc holds the stylus in the left position to await the transmission of the 500-cycle sync signal which will release the disc by at-

tracting the clutch control armature. While the stylus is at the left side of the paper, the signal transfer control cam automatically throws the signal transfer switch to the down position so that the following circuits are affected: (a) The stylus is disconnected from the circuit so that no voltage will be fed to the stylus. The shape of the control cam is such that the stylus is also disconnected on the return movement of the stylus to the left side of the paper so that no impression is made on the copy paper during the return trace. (b) The sync signal selecting condenser is shunted across the secondary winding of the rectifier input transformer in order to bypass the 2000-cycle facsimile signal, and thus prevent it from energizing the electromagnet and prematurely releasing the clutch disc before the 500-cycle sync signal is transmitted. (c) The electromagnet winding is connected to the cathode of the rectifier tube so that the rectified 500-cycle sync current will cause the electromagnet to attract the clutch control armature, so as to start the stylus across the copy paper at the proper instant.

At the same time that the clutch control armature permits the clutch to engage, and the stylus starts across the paper, the switch control cam throws the switch to the "up" position, and the following actions take place: (a) The stylus is connected to the cathode of the 6A6 rectifier tube so that the signal voltage is impressed on the stylus, (b) The electromagnet is disconnected from the cathode of the rectifier tube so that no current will flow through the winding, (c) the sync signal selector condenser is disconnected from the secondary winding of the transformer so that it will not bypass the 2000-cycle marking signal.

Servicing the Receiver

From the foregoing description of this typical facsimile system it can be seen that the servicing problems in facsimile will be largely mechanical rather than electrical. So far as the mechanical problems are concerned, these are fully described in the service notes and can hardly be said to fall within the scope of signal tracing. However, insofar as the electrical part of the system is concerned, signal tracing is of definite value in localizing the trouble in facsimile systems.

For our present purposes, we can divide the complete facsimile

receiver into two parts: the radio receiver which includes the audio amplifier, and the recorder which includes the signal rectifier unit and the sync circuits. The servicing of the radio receiver part of the facsimile receiver requires no further discussion here since it is a conventional radio receiver. If the receiver works properly on ordinary broadcast signals, then its operation will be satisfactory for the reception of facsimile signals. However, for proper operation of the recorder, the output of the receiver must be sufficiently high and the output must be properly matched to the recorder input transformer in order to avoid loss of signal amplitude.

To check the operation of the signal rectifier unit, a 2000-cycle signal can be fed to the input transformer and its progress checked through the secondary winding, through the transfer switch, and finally to the stylus. Before this test is made the motor shaft should be rotated by hand so that the stylus is in the middle of the line and the signal transfer switch in the "up" position so as to feed the signal to the stylus. Similarly, to check the operation of the sync circuits, the shaft should be rotated so that the stylus is at the extreme left of the line and a 500-cycle signal should be applied to the input transformer. Using standard practice, this signal can be traced to the secondary winding and should produce a rectified voltage across the electromagnet relay windings of sufficient magnitude to attract the armature. The operation of the recorder can also be checked while a transmitted facsimile signal is being received.

In every case, the manufacturer's service instructions should be referred to before attempting to service facsimile recorders. In general such notes contain the procedure for making the necessary mechanical adjustments as well as hints on characteristic troubles which develop in particular recorders. As a general rule, these data also contain information on the normal voltages required, including the average values of signal voltage required at the stylus, and across the electromagnet windings. This information is of course very helpful in localizing defective conditions.

FREQUENCY MODULATION

Up to the present time all broadcast stations have used amplitude modulation for program transmission. In this method of

transmitter operation the frequency of the carrier is maintained constant, usually by crystal control, while the amplitude of the carrier is varied by the audio modulation impressed upon it. A new system of broadcast transmission by frequency modulation is now being introduced by a few stations in the East. This system was devised by Major E. H. Armstrong and differs from amplitude modulation in that the carrier *frequency* is varied by the impressed audio modulation, while the carrier amplitude is held constant.

Advantages of Frequency Modulation

The principal advantages of frequency modulation over amplitude modulation are an improved signal-to-noise ratio, particularly in poor reception areas where the signal strength of the transmitter is weak, and a reduction in interference when two frequency modulated transmitters are geographically separated but operating on the same frequency. In receiving, better fidelity is usually more easily obtained from frequency-modulated transmissions.

Since the carrier frequency in frequency-modulated broadcasting is varied over a wide band, wide channels are necessary for transmission. Present channels are 200-kc wide and have been allocated in ultra-high frequency bands to avoid interference with other services which would result if channels of such width were assigned within the standard broadcast band. The actual carrier frequency variation is limited to one-half the channel width, as with amplitude modulation, since the frequency of the carrier varies above and below the nominal assigned value when audio modulation is applied. In present frequency-modulated broadcast transmissions, the maximum frequency deviation is held to approximately plus or minus 75 kc during audio modulation.

How Noise is Reduced

The manner in which frequency modulation reduces noise may be understood by remembering that most electrical noises change the amplitude of the signal but not its frequency. Now, in the amplitude modulation method of broadcasting, both noise and audio modulation act to vary the carrier signal voltage so that the two are combined in the signal detected by the receiver. In

frequency modulation, however, the audio modulation varies only the frequency of the carrier signal and not its amplitude. Noise, on the other hand, will cause no change in the carrier frequency, though it will affect its amplitude. If, then, the receiver is designed to detect only variations in signal frequency and not variations in amplitude, noise resulting from amplitude modulation is eliminated. Frequency modulation is not perfect, but a very great reduction in noise is secured by this method.

Special Receivers Necessary

Conventional broadcast receivers are designed only for the reception of amplitude-modulated transmissions and therefore are not suitable for receiving frequency-modulated broadcast signals. The principal differences in the latter are in the design of the detector and in the limiter stage which precedes the detector.

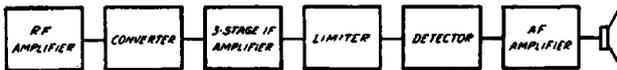


FIG. 10-29. Block diagram of a receiver for the reception of frequency-modulated signals. With the exception of the limiter stage, the lineup is similar to that of a conventional superheterodyne receiver.

A typical stage-by-stage lineup for a frequency modulation receiver is shown in Fig. 10-29. This shows an r-f amplifier, converter, 3-stage i-f amplifier, limiter, detector and a-f amplifier.

Since the transmitted frequency varies about 75 kc above and below the point to which the receiver is tuned and flat amplification is necessary for high-quality reproduction, the carrier-amplifying stages and the converter must be designed to pass a 150-kc band without frequency discrimination. Ordinary tuned circuits are usually far too sharp for this purpose, particularly in i-f circuits, so we find in the frequency modulation receiver that low-Q circuits are necessarily employed to achieve broad tuning.

In the i-f stages, broad-band reception is secured by using a high intermediate frequency, usually of the order of 3 megacycles, and by broadening the i-f transformer response by resistance shunted across one or more windings.

What the Limiter Does

The limiter stage requires detailed consideration. Its purpose is to smooth out any variations in carrier amplitude so that it may pass on to the detector circuit a signal which is constant in voltage but varies in frequency. This is done by designing the circuit and operating the tube so that it overloads even when a weak signal is being received. Then any increase in signal voltage will not cause an increase in the carrier signal voltage which appears across the tuned circuit forming the limiter stage plate load. The high gain in the r-f, converter and i-f stages provides sufficient amplification even for weak signals so that the actual signal voltage at the limiter grid during reception will always be several volts. Any applied signal voltage greater than the overload point causes rectification in the grid circuit. A resistor in series with the grid return of the limiter input circuit is installed so that the grid current resulting from rectification in this circuit causes a voltage drop across the resistor which can be utilized to provide AVC action. This AVC voltage is applied, through appropriate filters, to preceding i-f, converter and r-f stages.

Special Detector Used

Since, in frequency modulation, the a-f modulation causes a variation in carrier frequency, we need a type of detector which will convert these frequency variations into the a-f signal voltages which originally produced these carrier frequency variations, and in this way restore the original modulation. Ordinary detector circuits are not suitable, since they give an output voltage which is proportional to the amplitude of the carrier modulation and not to the carrier frequency. Since the voltage output of the discriminator circuits employed in AFC designs varies with the frequency shift of the applied carrier signal, it serves as an ideal device for the detection of frequency-modulated signals.

A typical AFC discriminator circuit is shown in Fig. 10-30. The primary coil, $L1$, of the discriminator transformer is connected in the plate circuit of the limiter tube and is closely coupled to the center-tapped secondary $L2$, $L3$. When the transformer secondary circuit is tuned to resonance with the alignment frequency of the i-f system, the voltages $E2$ and $E3$ are equal but opposite in phase. Since the d-c voltage across the discriminator

load resistors, $R1$ and $R2$, occurs as the result of rectification of $E2 + E1$ and $E3 + E1$, then, at resonance, the d-c voltage from point B to ground is equal to that from point B to A , as both $R1$ and $R2$ are similar resistors. However, because of the manner in which the diodes are connected, the resulting d-c voltages will be opposite in polarity. Therefore, the voltage across $R1$

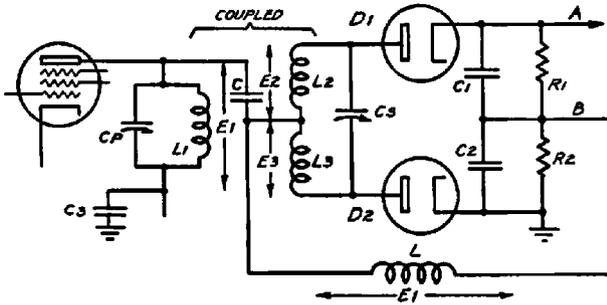


Fig. 10-30. The second detector of a receiver for frequency-modulated signals is similar to the discriminator circuit shown above.

will cancel that across $R2$ and a measurement from point A to ground will show zero voltage between these two points when the circuit is tuned to resonance with the alignment frequency. This is the normal condition for perfect alignment of an afc circuit.

When the signal voltage applied to the discriminator transformer is higher or lower in frequency than that to which it is tuned, the voltages $E2$ and $E3$ will remain equal but their phase relationship with respect to $E1$ will change. As a result, $E2 + E1$ will no longer equal $E3 + E1$. Since this becomes the case, the resulting d-c voltages across $R1$ and $R2$ will no longer be equal and opposite in polarity and a voltage with respect to ground will accordingly appear at point A . As the frequency of the carrier signal becomes higher or lower than that to which the discriminator is tuned, the voltages developed across $R1$ and $R2$ add or subtract. Since point A is at zero voltage at resonance, this signal frequency variation causes point A to assume a potential with respect to ground which varies in a positive or negative direction in accordance with these frequency variations. The

change in voltage of point A with respect to ground as a result of this shifting frequency is represented in the diagram, Fig. 10-31.

How the Discriminator Detects

Now let us see how this characteristic of the afc circuit serves to supply an audio signal to actuate the a-f amplifier of the receiver. We have seen, in frequency-modulated transmissions, that the carrier frequency changes at a rate which is in accordance with the audio modulation impressed upon the carrier. Let

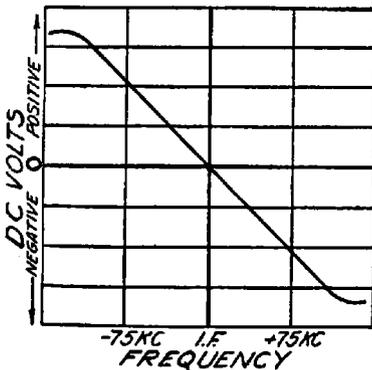


FIG. 10-31. The output voltage of the second detector varies in accordance with the amount by which the signal frequency differs from the intermediate frequency.

us assume that a 400-cycle audio note is being broadcast and the nominal frequency of the transmitter is 42 mc. On the positive half of the 400-cycle modulation, the carrier frequency may be increased while on the negative half it may decrease. If the modulating voltage is sufficient, this may cause a maximum increase of carrier frequency of 75 kc so that the maximum frequency at the peak of the positive half of the wave becomes $42 \text{ mc} + 75 \text{ kc}$ and, at the peak of the negative half of the cycle, to $42 \text{ mc} - 75 \text{ kc}$. Now, referring again to Fig. 10-31, we see that a carrier frequency shift in a negative direction will cause the output voltage of the discriminator to become positive whereas an increase in carrier frequency will cause this output voltage to become negative. Since a 400-cycle note is being broadcast, the carrier frequency increases and decreases and the output voltage of the discriminator becomes positive and negative

at the same rate, 400 cycles per second, as that of the original broadcast note. Now, if we apply this rapidly-varying voltage to the grid of an amplifying tube, the voltage across its output load will vary at the same rate. Since this is precisely what occurs when an a-c signal is applied to a grid, we see that in this manner detection of frequency-modulated signals is effected.

Once the frequency-modulated signal is converted into audio frequencies, any type of conventional audio amplifier is suitable. Since the fidelity of reproduction in a carefully-designed receiver is exceptional, high-grade a-f amplifiers and speakers are usually employed.

The G-E Model GM125 Receiver

The schematic Fig. 10-32 shows the circuit of the G-E model GM125 receiver, which is designed for frequency-modulation reception. This is a 12-tube, single-band receiver which covers a frequency range of from 37 to 44 megacycles. A single r-f stage feeds the 6K8 converter; four i-f stages are employed, the fourth stage acting as the "limiter." The detector is similar to the afc discriminator previously described. The triode section of a 6Q7G is employed as the first a-f amplifier and feeds a 6J5G phase inverter which drives the push-pull 6L6G output tubes.

The r-f and converter stages are similar to those which could be employed in conventional designs for the same frequency band, except that no effort has been made to acquire selectivity in the tuned stages since this would be undesirable in a receiver which is required to pass a wide frequency band without frequency discrimination.

The i-f stages are designed to give a band width of 300 kc. This is done by using a high intermediate frequency (3000 kc) and by shunting each i-f transformer primary winding with a 15,000-ohm resistor.

The last i-f stage operates as a limiter. The limiting effect is secured by using a 6SJ7 tube in this stage and operating it with zero control grid bias and only 65 volts on the plate and screen. Under these operating conditions, the tube overloads with a relatively small applied signal. The high overall gain of the stages preceding the limiter tube provides sufficient amplification so that even a weak signal in the antenna circuit is built up to a voltage sufficient to overload the limiter.

When the signal strength is sufficient to overload the limiter stage, grid current flows through the 330,000-ohm resistor, *R15*, in the grid return circuit of the 6SJ7. The resulting voltage drop across *R15* is used to provide *avc* action and thus prevent overloading of preceding stages. By incorporating *avc* in this stage, there can be no *avc* action until the limiter is overloaded, which is its required operating condition. When such is the case, an increase in signal voltage applied to the limiter grid will cause no increase in the output signal voltage across its plate load but the grid current will increase, thereby assuring an increasing *avc* voltage.

The discriminator-type detector is similar in action to that reproduced in Fig. 10-30. It converts the frequency variations of the i-f signal output to a voltage which varies in amplitude at the audio frequency rate. The essential difference between this type of discriminator and one used solely for *afc* purposes is that the audio component is not filtered out. This must be done when such circuits are used for *afc* applications to avoid modulating the oscillator at the audio frequency. The discriminator load by-pass condensers, *C18*, *C19*, are accordingly only 22 μf each in this circuit, so there is no by-passing of the higher audio frequencies.

The output of the frequency-demodulator is coupled to a tone control network composed of *R11*, *R20*, *R40* and the shunt and series condensers *C39* and *C17*. Operation of *R40* provides attenuation of either high or low frequencies, as desired. The output of this network connects to the volume control, *R21*, which returns to ground through an inverse-feedback network composed of *R37* shunted by *C16* in series with *R22*. The balance of the audio system is conventional.

Alignment Procedure

To align the i-f amplifier, connect an electronic voltmeter (or any other d-c voltmeter which has a high input resistance) across *R15*. Feed a 3-mc signal to the grid of the third i-f tube. Temporarily shunt the secondary winding of *T7* with a 10,000 or 15,000-ohm resistor and adjust *C48* until the voltmeter reading is a maximum. Then remove the secondary shunting resistor and adjust *C49* for maximum reading on the voltmeter. Then

connect the shunting resistor across *T6* secondary, feed the 3-mc signal to the second i-f grid and peak the trimmers of *T6* in the same manner. Repeat this process for each of the i-f transformers in turn until all are aligned.

The frequency demodulator circuit may also be aligned with the voltmeter and signal generator. Feed a 3-mc signal to the input of the i-f amplifier and connect the voltmeter from the cathode connection of *R18* to ground. A small voltage reading usually will be indicated if the circuit is slightly out of adjustment. If not, adjust *C51* until a reading is secured. Then adjust *C50* until the voltage reading is a maximum. After this is done, adjust *C51* until the voltmeter reads zero. The discriminator alignment is then complete.

The r-f and oscillator stages are aligned by feeding a 42.8 mc signal to the antenna terminals and, with the receiver tuned to this point on the dial scale, adjusting the oscillator trimmer *C4* for maximum reading on the voltmeter, which should be connected across *R15*. Then peak the antenna and r-f trimmers (*C2* and *C3*) in the same manner.

The receiver may also be aligned with a special frequency-modulated signal generator.

Chapter XI

SIGNAL TRACING IN RECEIVER DESIGN

BECAUSE of the basic nature of signal tracing, it is to be expected that it should be of value in receiver design as well as in service work. As we have seen, signal tracing provides information on what is taking place in a receiver while the receiver is functioning and this sort of information is valuable to the engineer as well as to the serviceman. In design work, as in servicing, a knowledge of what is taking place in the receiver circuit is essential. In addition, since trouble-shooting is not limited to the service field but must often be carried out in experimental and development work, signal tracing can be used to simplify this phase of design work.

An elaborate explanation of signal tracing insofar as it is related to design work is not required because of the comprehensive treatment in other sections of this book. The technique of signal tracing is essentially the same whether the problem at hand is one of design work or one of trouble-shooting. In both cases, the desired result is to obtain the best possible performance from the circuit, and as such the procedure and measurements are very similar.

As in servicing, the fundamental instrument in signal tracing is the tuned vacuum-tube voltmeter which we have seen must satisfy certain requirements. It must have a low input capacitance, and should preferably employ a probe cable for convenience in getting at various points in the receiver; it should cover a wide range of frequencies, preferably from about 100 kc up through the broadcast band; it should have sufficient sensitivity so that it is possible to pick off the signal in the low-level

stages of the receiver; and it should be provided with a calibrated attenuator.

Essentially the tuned vacuum-tube voltmeter which we have been describing is a further development of the low-capacity untuned type of vacuum-tube voltmeter which employs an acorn tube at the end of a shielded cable. Because of the lower input capacitance and the higher sensitivity of the tuned type, however, the usefulness of the latter is considerably extended over that of the untuned type. Quantitatively, the acorn type of vacuum tube voltmeter has an input capacitance of approximately $6\mu\text{f}$, whereas the tuned type of vacuum-tube voltmeter can be made to have an input capacitance of about 1 or 2 μf . With reference to sensitivity, the untuned vacuum-tube voltmeter has a sensitivity of about 0.1 volt, while the tuned type can be made to have a sensitivity of better than 1 millivolt.

The increased sensitivity made possible through the use of amplification of the signal being measured is often an advantage in design work. In many instances it is desirable to pick off the signal in the low-level stages where its amplitude is not very great. Although it would be impossible to do this with the usual type of vacuum-tube voltmeter, the increased sensitivity available with the tuned vacuum-tube voltmeter makes this possible.

The many uses to which the tuned vacuum-tube voltmeter can be put have been covered in the preceding sections of this book. Measurements made in the course of design work will follow the same general procedure, but in general it will be necessary to use more accurate equipment and to make the measurements to a greater degree of accuracy. Where greater precision is required, it is always possible to calibrate the tuned vacuum-tube voltmeter against a standard signal generator. In this way the greater inherent accuracy of the signal generator can be transferred to the voltmeter.

Signal tracing in design work is especially valuable where it is desired to check the signal voltage at points where it is normally not possible or convenient to check the circuit indirectly, by feeding the signal directly across the point in question. For example, it is sometimes desirable to be able to determine the signal present across tertiary windings, trap circuits, etc., and in cases of this sort the tuned vacuum-tube voltmeter makes it

possible to pick off the signal at the desired point without interfering with the normal operation of the circuit.

The high sensitivity of the tuned vacuum-tube voltmeter used in signal tracing enables measurements to be made of the relative strength of stray r-f fields, and of the effectiveness of shielding. This can be done conveniently by exploring the region with the voltmeter probe and noting the relative readings of pickup at the various points. Generally there will be sufficient pickup from the short exposed section of the probe; however, where the fields being measured are comparatively weak, the pickup can be increased by attaching a short stiff lead to the probe end. With proper attention to grounding of the instrument, approximate measurements can be made of the r-f potential at various points along shielding partitions, chassis, etc.

The use of signal tracing in audio design work is well established because of the greater simplicity of the problem. Thus a vacuum-tube voltmeter of high sensitivity can easily be built to cover the range of audio frequencies. Several commercial instruments which have high sensitivity, good accuracy, and a logarithmic calibration are available. Thus, use of instruments of this type in audio signal tracing is similar to that in servicing and requires no further explanation.

Chapter XII

SIGNAL-TRACING INSTRUMENTS

THROUGHOUT this book we have assumed that the instrument required for making the necessary signal-tracing measurements was available. We were justified in doing this because in the other sections of the book we were concerned primarily with signal tracing as a method, and not with the means or instrument required for tracing the signal. But it goes almost without saying that any system of testing is only as good as the instruments which are employed and so a proper comprehension of signal tracing requires that you understand the instruments used in signal tracing.

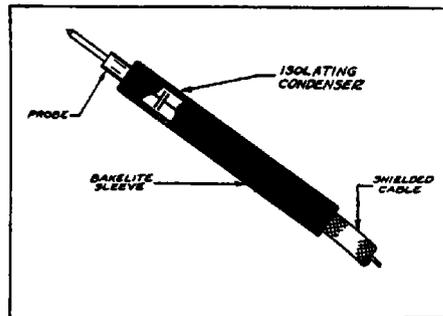
In this chapter we shall from time to time illustrate the points being discussed by references to the Rider Chanalyst. This is not to say that the Rider Chanalyst is the only signal-tracing instrument but rather it is a natural consequence of the fact that the Chanalyst was the pioneer signal-tracing instrument to which other commercial instruments owe their existence. It was not until the Rider Chanalyst had demonstrated conclusively the advantages of signal tracing that other instruments made their appearance. Of course these instruments are not identical with the Chanalyst and it is not our purpose here to show all the variations possible in signal-tracing instruments. For just as there are many receivers ranging all the way from cheap midgets to high-fidelity receivers, so many signal-tracing instruments are possible. With all these variations we are not concerned, but we do want to discuss the fundamental requirements of signal-tracing instruments. And if in so doing we illustrate our points by references to a time-proved signal-tracing instrument, we feel that there is ample justification.

Checking RF-IF Signals

In applying signal-tracing methods we have seen that it must be possible to check the signal at every point in the receiver, starting at the antenna and following right through to the voice coil. Since the natural starting point of the signal is in the r-f section of the receiver, it is logical for you to ask about the instrument used for tracing the signal in this part of the receiver. What type of instrument is required for this purpose?

Essentially of course the radio-frequency part of our signal-tracing instrument, which for convenience we shall call the *rf-if channel*, must be a vacuum-tube voltmeter of some kind. For it must have enough sensitivity to enable picking up the signal right through from the antenna coil, where the signal level is measured in microvolts. But it cannot be a vacuum-tube voltmeter of conventional design because such voltmeters do not have sufficient sensitivity, and in addition place too great a load upon the circuit being checked. Both of these difficulties are eliminated by using a tuned amplifier type of vacuum-tube voltmeter with a special test probe. The rf-if channel in the Rider Chanalyst employs such an arrangement and its advantages will be clear from the description in the following paragraphs.

FIG. 12-1. The special test probe shown at the right makes it possible to measure r-f voltages without detuning the circuit. The cable and input capacity are isolated by means of the air-gap condenser near the probe tip.



Let us start with the input circuit to the channel used for checking r-f signals. Of the greatest importance is the probe which connects the instrument to the receiver under test. As Fig. 12-1 shows, this probe is of special design and construction so as to minimize reaction on the receiver under test. Referring

to the illustration, you will observe that the probe point is not connected directly to the shielded conductor but instead a small air gap isolates the probe point from the conductor. Effectively this means that the probe point is joined to the instrument through a small condenser the value of which is regulated by the size of the air gap. In the Rider Chanalyst this air gap forms a condenser of about 1.5 μf capacity. Now since this air gap is close to the point at which the probe is touched to the receiver under test, it means that the capacity shunted across the test point is less than 2 μf .

In a real sense the entire procedure of signal tracing depends upon the probe arrangement which we have just described. By means of this special probe, we can connect directly across tuned circuits, to the controlled grid and plate of tubes,—in fact to any point where there is an r-f or i-f signal—and measure the signal voltage without any appreciable detuning or loading of the circuit. At the same time it is possible for us to use a shielded flexible cable of convenient dimensions to connect the probe to the input of the instrument. Of course the air gap prevents this cable capacity and the input capacity of the instrument from appearing across the test point.

As we mentioned earlier, a tuned amplifier must be used to obtain the sensitivity required in r-f signal tracing, as well as to supply the selectivity necessary to distinguish among signals of different frequency which are often present at the same point. The input circuit of such an amplifier is shown in Fig. 12-2. The shielded cable is plugged into a jack on the instrument panel which connects through *C5* to the grid of the first amplifier tube. By means of the switch *S1* it is possible to select any one of four values of capacity which shunt the grid to ground.

What is the purpose of these four condensers? As we shall see in a moment, each of these condensers forms a capacity divider in conjunction with the small isolating condenser formed by the air gap in the probe. Thus when the switch is in the *X1* position, one-hundredth of the signal present at the probe point is applied to the input grid. This of course is because the capacity of *C1* is one hundred times as great as the probe capacity of 1.5 μf . *C1* is shown dotted because it is not made up of an actual condenser but consists of the capacity of the shielded cable, the

switch, the tube, and the wiring. In the $X10$ position, a similar action takes place. Here the capacity of $C2$ is made 1,000 times as great as the probe capacity so that only one-thousandth of the signal reaches the input grid. Similarly, $C3$ and $C4$ are made progressively larger to provide additional attenuation so that in all the switch $S1$ supplies multiplier values of 1, 10, 100, and 1000. Thus it provides us with a simple means for determining the relative strength of signals. We might point out that shielding is no problem with this simple but effective type of multiplier because only as much signal as is selected by means of $S1$ enters the instrument through the shielded cable. The rest of the signal voltage drop takes place across the air-gap condenser in the probe sleeve.

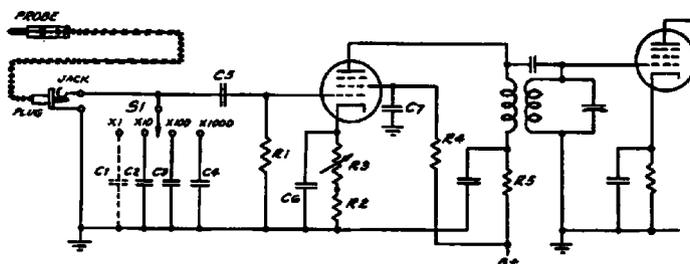


FIG. 12-2. The input circuit of an amplifier suitable for signal tracing measurements. The multiplier switch $S1$ and the control $R3$ make it possible to compare signal levels at different points in the receiver under test.

We have just seen that $S1$ provides us with a means for determining the relative strength of signals in steps of ten. To obtain a continuous attenuation over a range of ten to one, the circuit in Fig. 12-2 is provided with a cathode rheostat $R3$ which varies the gain of the stage over a ten-to-one range. In conjunction with $S1$, $R3$ enables us to obtain continuous attenuation over a range of 10,000. This has been found to be sufficient to handle the problems which occur in the course of signal tracing.

Satisfactory accuracy in the multiplier is secured by using accurate condensers for the capacity divider. As far as the ten-to-one signal level control is concerned, the use of self-bias and series operation of the screen makes the calibration of this control largely independent of variations in tube characteristics.

We need not discuss in detail the three-stage tuned r-f amplifier used following the input circuit. In many respects it is similar to a modern tuned r-f receiver with the exception that special attention is given to securing a flat response over the complete tuning range. In the Rider Chanalyst, special transformers with the primaries resonated below the low-frequency end of the band are used in order to obtain a flat response. To secure stability the components are well shielded and individual filtering is used in the screen and plate-supply leads, as well as individual self-bias resistors. The overall gain is approximately 100,000. Although the tuned r-f amplifier is more expensive than the super-heterodyne type, it has the advantage that for each signal which is present at the test point, only one response is obtained on the signal-tracing instrument. In connection with the frequency range of the amplifier, this important point should be noted: a wide frequency range is not usually required because once the receiver is made to operate properly on the broadcast band and the oscillator has been checked on the inoperative short-wave band, the trouble is already localized. This is explained in detail in Chapter 9.

The detector circuit used following the amplifier is a diode rectifier. The output of this circuit is arranged so that it controls a 6E5 electron-ray indicator tube which is used to supply a reference output level corresponding to the signal required to close the shadow completely. At the same time provision is made in the output for connecting headphones so as to listen to the signal, or an oscillograph so as to be able to view the waveform. For practically all purposes, as we have previously seen, the check of output level provided by the 6E5, or the check of quality made by listening to the signal, is sufficient.

An elaborate meter type of output indicator is not required because we are interested primarily in the *relative values* of the signal in various parts of the receiver. The multiplier and level controls previously described gives us these relative values of signal strengths and thus it is only necessary for the output indicator in the signal-tracing instrument to provide a reference value. A convenient arrangement for this purpose is to use a 6E5 tube and to let the reference indication be the signal output required to close the shadow completely. It is possible to provide a jack

across the diode load so that a meter can be inserted in special cases where the actual value of output signal is desired. This occurs but seldom in the course of practical servicing work.

The quality of the signal, whether noise is present, etc., can conveniently be determined by using a pair of crystal phones across the diode load to listen to the signal. Where a visual check is desired, the waveform can be examined by plugging an oscillograph into the jack to connect its input across the diode load. In this way the r-f amplifier in the signal-tracing instrument supplements the oscillograph by providing the necessary r-f gain. Since the oscillograph amplifiers do not function at radio frequencies, the sensitivity of the oscillograph is of course not great enough to permit connecting it directly to the receiver. In fact even where the oscillograph has a wide-band amplifier, the input capacitance is ordinarily of the order of 30 μf or more so that it cannot be connected directly across a tuned circuit.

A-F Signal Tracing

Signal tracing in a-f circuits is very much simpler than signal tracing in r-f circuits and so also are the instruments which are required. One of the earliest instruments for signal tracing in a-f circuits was a set of headphones. All of you have used this crude form of a-f signal tracing at one time or another and are therefore familiar with its limitations. In the first place, high-impedance circuits are often encountered which are loaded excessively by the phones so that it is difficult to determine just what is taking place in the circuit. A second disadvantage of the headphones is that it is difficult to determine approximately how much step-up in signal is obtained as the signal is traced through successive stages.

Both these disadvantages can be removed by using a single stage of a-f amplification. Because of the high input resistance of the vacuum tube, the loading of the circuit being checked is minimized. It is of course desirable to use a shielded cable and probe, but no special isolating arrangement need be used because the input capacity is not important at audio frequencies. As far as the check of relative signal strengths is concerned, a calibrated potentiometer can be used in the input or cathode circuit of the a-f stage. This in conjunction with a simple multiplier switch

can easily be arranged to check signals ranging from less than 0.1 volt to 200 volts.

In the output circuit of the single-stage amplifier, a diode rectifier circuit feeding a 6E5 can be arranged to serve as a reference indicator. This is similar to the arrangement used in the case of the rf-if channel so that no further discussion is required. Provision for listening to the signal is desirable and a jack across the output should be provided for this purpose. Unlike r-f measurements, a-f signal tracing can be conducted directly with the oscillograph since the internal amplifiers provide sufficient sensitivity for checking the signal even in the low-level stages. However for rapid work, and for tracing noise, it is very convenient to use the headphones in the output jack of the a-f stage.

Checking the Oscillator

In another part of this book we described the manner in which checking the oscillator circuit is related to signal tracing and the localization of trouble in receivers. As we explained there, the r-f voltage generated by the receiver oscillator is no different from any other signal voltage and as such it can be checked in exactly the same manner as other signal voltages. Actually, the problem of checking the oscillator signal is considerably simpler because the voltage available is so much larger than that which we find in the remaining parts of the r-f section of the receiver. Thus the oscillator voltage is almost invariably at least several volts, whereas the other r-f signal voltages are measured in millivolts.

Where the frequency of the oscillator is within the range of the rf-if channel, this section of the signal-tracing instrument can be used to check the oscillator voltage. To avoid reaction or loading of the oscillator circuit, the special test probe containing an isolating condenser is used; this is the same probe illustrated in Fig. 12-1, which we described in connection with r-f signal checking. As is pointed out elsewhere in this book, the reaction on the circuit can be reduced to considerably less than $1 \mu\text{f}$ by holding the probe close to, but not in contact with, the high side of the oscillator section of the tuning condenser; any other appropriate point in the oscillator circuit instead of the condenser can of course be selected.

It is often convenient to use a separate channel for checking the operation of the oscillator. The chief justification for a separate channel for this purpose is its utility in the servicing of intermittent receivers and the simplicity of the circuit. Because of the high signal voltage available, only a single stage using a high gain tube such as the 1852 is adequate. Since only one tuned circuit is required, a greater frequency range can be covered than with the rf-if channel.

An elaborate oscillator channel is not required because it is not important to be able to check the exact value of the oscillator voltage by this means. The chief purpose of the oscillator channel is to be able to check the oscillator frequency and the approximate output. More exact determinations of the oscillator output can be made by means of the electronic or vacuum-tube voltmeter described in a later part of this chapter; this method can be used up to frequencies as high as several hundred megacycles.

Dynamic Voltage Measurements

In our discussion of signal tracing we have assumed that an instrument was available which would measure operating and control voltages without in any way disturbing the receiver. It is now our intention to describe an instrument which makes these dynamic voltage measurements possible.

We have said that the voltmeter must enable voltage measurements to be made without in any way disturbing the circuit. This means that not only must the resistance of the voltmeter be sufficiently high so that a negligibly small current is drawn, but in addition the voltmeter input capacitance must be so small that it does not interfere with the r-f signal voltage which may be present at the test point. To satisfy this last requirement, a special probe is used with the voltmeter. In a way this probe is similar to the r-f probe shown in Fig. 12-1, but instead of a small isolating *condenser*, an isolating *resistor* is used. This resistor, as Fig. 12-3 shows, is mounted directly in the bakelite probe sleeve close to the probe point.

Let us examine the effect of placing this probe in contact with a point at which a signal is present—say the control grid of a

tube at which we wish to measure the avc voltage. To what extent will the probe detune the circuit? We can answer this question easily by keeping in mind that the isolating resistor prevents the capacity of the shielded cable and the capacity of the voltmeter tube from detuning the circuit. Thus the isolating resistor limits the detuning effect to the shunt capacity of the

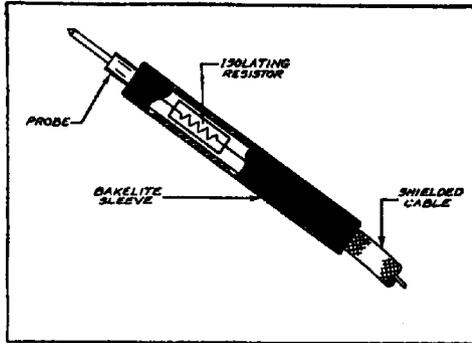


FIG. 12-3. The special test probe makes it possible to measure d-c voltages at any point in the receiver without interfering with the passage of the signal. Isolation of the voltmeter is accomplished by means of the resistor adjacent to the probe tip.

resistor which is entirely negligible. As far as the d-c loading effect on the circuit, the input resistance of the voltmeter is equal to the resistance of the isolating resistor plus the resistance of the voltage divider; this can easily be kept higher than 10 megohms for all ranges so that the d-c loading is negligible. Note that a shielded cable is shown in Fig. 12-3; this is desirable in order to prevent stray voltage pickup. Although stray voltages are not troublesome with low-resistance voltmeters, the shielding eliminates stray voltage pickup which would otherwise be troublesome when using a high-resistance voltmeter.

We have just finished describing a type of isolating probe which makes possible d-c voltage measurements without in any way interfering with the circuit under test, but in order to operate satisfactorily, this probe must be used in conjunction with a voltmeter having a high resistance. Extensive investigation has shown that an electronic or vacuum-tube voltmeter type of instrument is best suited for the purpose. As we shall see, this type of instrument has the advantage of providing high sensitivity

without requiring a delicate ultra-sensitive meter. Although the potentiometer-type and slideback-type instruments both have a high input resistance, the direct-reading type of vacuum-tube voltmeter is superior because no balancing adjustment is required each time a reading is taken.

In the following paragraphs we describe the electronic or vacuum-tube voltmeter used in the Rider Chanalyst. This voltmeter has proved itself to be an extremely convenient instrument for measuring every type of d-c voltage, including control and operating voltages, without in any way disturbing the circuit under test.

The circuit of this voltmeter which is shown in Fig. 12-4 makes use of the high input resistance and amplifying properties which

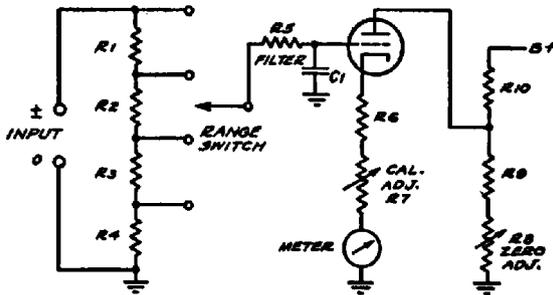


FIG. 12-4. A direct-reading vacuum-tube or electronic voltmeter suitable for the measurement of d-c voltages without loading the circuit under test. The large value of cathode resistance makes the calibration independent of tube variations.

are characteristic of the vacuum tube. The voltage being measured is applied to the control grid of the tube through the multiplier circuit, and its value is interpreted in terms of the plate current indicated by the milliammeter. When the instrument is first turned on, the zero-adjustment control is set so that the meter reads center scale or 0 volts. If a positive voltage is measured, the meter needle will deflect to the right and similarly the needle will deflect to the left for a negative voltage. As the figure shows, the multiplier circuit makes it possible to extend the range of the voltmeter in a simple manner.

So far we have not explained the use of the filter combination *R5-C1* in the grid circuit of the voltmeter. It is the purpose of this resistor and condenser to prevent a-c or signal voltages from interfering with the measurement of the d-c voltage. Thus suppose you wish to measure the d-c voltage at a point where an a-f signal is present. The filter *R5-C1* removes this a-f signal and leaves only the d-c voltage which is indicated by the meter. Actually this filter need not be completely effective because the linearity of the voltmeter circuit prevents rectification of the signal voltage from taking place, and of course without rectification the reading of the meter will not be affected. However it is desirable to include the filter to take care of extreme cases where large values of a-c voltage are present at the points being measured.

The large value of cathode resistance used in this circuit is helpful in providing degeneration so as to minimize the effect of variations in tube characteristics and line voltage on the accuracy of calibration. By this means the accuracy of calibration is made dependent upon the combined value of *R6* and *R7*, rather than upon the tube characteristics. When the instrument is calibrated, the control *R7* is set so that the correct reading is obtained on the meter scale when a standard voltage of known accuracy is applied to the instrument. Once this control has been set, it need not be readjusted unless the tube is replaced. In the latter instance, a slight readjustment of the control may be required.

It is worthwhile emphasizing that the use of this type of voltmeter circuit makes it possible to use a rugged milliammeter rather than a delicate microammeter. In spite of the high input resistance, there is no possibility of overloading the circuit because the voltage is always applied across the complete divider. The only effect of an overload is to cause grid current to flow through the filter resistor *R5* so that the tube is automatically biased by this grid-current flow. The current through the meter can under no circumstances increase above a safe value and, provided the wattage rating of the resistors in the input circuit is not exceeded, no damage will be done. If the instrument is overloaded through the application of a high negative voltage, the tube will be biased beyond cut-off and the meter current will simply drop to zero.

We have already explained that when no voltage is applied to the instrument, the pointer reads center-scale or zero volts. This center-zero arrangement is a very great convenience as has been proved by numerous reports from servicemen who have used this type of instrument. In operation, it is only necessary to clip the ground of the instrument to the chassis of the receiver and *any* voltage—whether positive or negative—can be measured without switching leads. Whether the voltage is positive or negative with respect to the chassis (or any other suitable reference point) will be indicated by whether the deflection is to the right or to the left. This convenience in use has been found to more than outweigh the fact that the use of a conventional left zero provides a longer scale.

There is one precaution which must be observed in using any type of vacuum-tube voltmeter and this precaution is that the instrument ground must always be attached to the chassis or other ground point in the receiver. For example, if the bias at the grid of a type 2A5 tube were being measured, an incorrect reading would be obtained if the ground lead of the voltmeter were connected to the grid and the probe were connected to the chassis. If this were done, leakage between the instrument ground and the receiver chassis, as well as stray a-c voltage pickup resulting from the instrument "floating," would cause a considerable error in the reading. With the center-zero voltmeter this condition is never encountered because the instrument ground is connected to the receiver chassis regardless of whether a positive or negative voltage is being measured. The polarity of the voltage is indicated automatically as we have explained.

In line with the above explanation, it will easily be understood that the test leads cannot be switched when using a vacuum-tube voltmeter. For this reason the "left-zero" type of vacuum-tube voltmeter is not suitable for general service work unless it is provided with a polarity switch so that no switching of the test leads is required. In the latter case, a balanced circuit must be used and the polarity switch must reverse the connection of the meter to the circuit; it should under no circumstances be arranged so as to reverse the test leads.

By way of summary, we can draw the following conclusions:
(1) the center-zero type of voltmeter is best adapted to service

work because of the ease and rapidity with which positive and negative voltages can be measured; (2) the full-scale or left-zero type of instrument is not suitable for the measurement of negative voltages unless it is provided with an *internal* polarity switch; (3) even where a polarity switch is provided so as to make available the full-scale length, the center-zero circuit still has the advantage that no switch need be operated when measuring either a positive or negative voltage.

Throughout this book you undoubtedly have observed the fundamental approach which signal tracing makes to the problem of receiver servicing. And so it is not surprising to find that the instruments which make the tracing of the signal possible are every bit as basic as the method itself—as the signal itself. A well designed signal-tracing instrument has a long and useful life. It will not become outmoded by changes in the system of servicing. As long as the many stations throughout the country remain on the air, as long as intelligence is transmitted by the signals we know today—just so long will this equipment remain useful. Signal tracing is indeed as fundamental to servicing as the signal is to radio communication.