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CONTENTS

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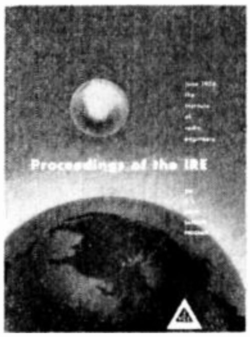

THE COVER—Sometime between July, 1957 and December, 1958, it is anticipated that a 20-inch sphere will start racing through the outer limits of the atmosphere, circling the earth once every 90 minutes at an altitude of more than 200 miles, on an historic journey that will last anywhere from a few weeks to possibly a year. Hundreds of observers all over the world will plot its flight with meticulous accuracy; others will query it by radio and carefully record its responses. The information thus garnered promises to make this event one of the major scientific harvests of our time. The dramatic story of how it is planned to place this man-made satellite in its orbit and to utilize it for gathering scientific data is unfolded in an unique series of seven papers by leading scientists of the U. S. earth satellite program, starting on page 741 of this issue.

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Scanning the Issue

Electrical Engineers Are Going Back to Science! (Terman, p. 738)—The IRE STUDENT QUARTERLY recently printed a brief and very timely article which pointed out that electronics is demanding of our education system engineers who are well grounded in the basic sciences and that our colleges will have to make major changes in their time-honored curricula, and soon, if they are not to be left at the post. A possible inference is that if engineering colleges fail to meet this situation, we may see substantial numbers of engineering students and employers alike turning to non-engineering pastures to get the fundamental scientific sustenance they require. The importance of this message was adjudged sufficiently great to the entire profession to cause the IRE Editorial Board to recommend prompt republication in the PROCEEDINGS and to move a past President of IRE to comment on it in *Poles and Zeros* (see "Evolution," p. 737).

SYMPOSIUM ON THE U. S. EARTH SATELLITE PROGRAM

The IGY Program (Kaplan, p. 741)—On July 29, 1955 the White House announced this country's intention of launching small, unmanned, earth-circling satellites as part of the U.S. participation in the International Geophysical Year, July, 1957 to December, 1958. Few announcements have so captured the interest and stirred the imagination of people everywhere. This was convincingly demonstrated on March 20, 1956 at the IRE National Convention, when one of the largest engineering audiences in history assembled to hear seven leading scientists outline the details of this audacious venture into outer space. The PROCEEDINGS is fortunate to be able to bring to its readers the complete texts of all seven talks, which together make one of the most absorbing accounts to appear in its pages in many years. In the first of these papers, the Chairman of the U.S. National Committee for the IGY describes the origin and nature of the IGY program and how the satellite project fits into it, thus setting the stage for the six papers that follow.

The Exploration of Outer Space with an Earth Satellite (Hagen, p. 744)—The earth is continually subjected to powerful radiations from the sun and from the universe beyond, much of which are absorbed completely, or nearly so, by the earth's atmosphere before reaching the ground. Nevertheless, these radiations are of more than passing interest to us. For example, the ionization of the atmosphere is caused chiefly by ultraviolet radiation from the sun. Without it we would have no long distance radio communications. A small amount of this radiation reaches the earth's surface, where it helps Mother Nature to produce Vitamin D, so essential to health. But we are hindered in our attempts to learn more about ultraviolet rays, partly because they are almost completely absorbed by a layer of ozone lying about 25 miles above the earth, a layer which, incidentally, in keeping us in ignorance, also protects us and all other forms of life on earth from being burned to death. Placing a satellite in the outer reaches of the atmosphere will make it possible to make sustained measurements of this and literally dozens of other important phenomena relating to the earth, the atmosphere and cosmic and solar influences on them. The responsibility of launching the satellite has been assigned to the Naval Research Laboratory, which has established Project VANGUARD to carry it out. In this paper the Director of Project VANGUARD discusses what is now known about the middle and upper atmosphere and relates this information and other important considerations to determining at what height a satellite will have maximum usefulness and which types of experiments are best suited for the satellite.

Placing the Satellite in Its Orbit (Rosen, p. 748)—The highest altitude that has been reached by a large rocket is 250 miles. This was a two-stage rocket which, at the end of the second-stage burning, was traveling about 6000 miles per hour. To place the satellite in its orbit, it is planned to lift it to a height of 300 miles and then to impart to it a velocity of about 18,000 mph to insure that it will orbit. If the launching is successful, it is estimated that the satellite will circle the earth about once every 90 minutes on an elliptical path not closer than 200 nor further than 1400 miles from earth for a period of at least several weeks and possibly a year or more. How this prodigious feat is to be accomplished is described in fascinating detail by the Technical Director of Project VANGUARD, who discusses various possible two- and three-stage launching vehicles and singles out the particular vehicle which has been chosen for the first launching attempt.

Telemetering and Propagation Problems of Placing the Earth Satellite in Its Orbit (Mazur, p. 752)—Telemetering will play an extremely important role in the launching of the satellite. Prior to the actual launching numerous tests will be run during which telemetering will be called upon to tell what is happening during flight and, equally important, why. In the event of an unfortunate occurrence, such as a fire, explosion or erratic rocket maneuver, a clear picture of what is going on in the final fraction of a second before the disaster is essential to the ultimate success of the program. Telemetering will be used also to check the performance of the internal rocket system in the moments just prior to launching, and finally, to transmit vital performance data during the actual flight of the launching vehicle. In this discussion the reader is given a general insight into the requirements which must be met and the problems encountered in telemetering the VANGUARD vehicle.

Tracking the Earth Satellite, and Data Transmission, by Radio (Mengel, p. 755)—Once the satellite has been placed in its orbit, the next big problem is to find it and follow it. The idea of locating an object three hundred miles or more away which measures only twenty inches in diameter and is traveling 18,000 mph staggers the imagination. The problem is met by the specially developed radio tracking system described in this paper, known as the Minitrack system, which utilizes a tiny, 108 mc, 10 to 50 milliwatt transmitter in the satellite and seven receiving antennas laid out in the shape of a cross at each ground station. The direction of the satellite is determined by comparing the phases of the signals received by the seven antennas. The information obtained by Minitrack will be used to forewarn optical ground stations just when and where to look for the satellite so that they may carry out the precise scientific experiments described in the following paper. The Minitrack link will also be used for telemetering scientific data from the satellite and, as mentioned briefly by the author, a simplified version of Minitrack will make it possible for radio amateurs to participate in tracking the satellite.

A Research Program Based on the Optical Tracking of Artificial Earth Satellites (Whipple and Hynek, p. 760)—Radio tracking will give us the position of the satellite with sufficient accuracy to "communicate" with it but not exactly enough to be of scientific value. For this we must turn to highly precise optical instruments which, in combination with photographic or photoelectric recording devices, can tell us the position of the satellite to an accuracy of 30 to 50 feet. Armed with a sufficient number of such measurements made over a period of several weeks from different points on earth, it will be possible to find out accurately the density of the upper atmosphere, the shape of the earth, the distribution of the earth's mass, and irregularities in the gravitational field. This paper discloses how and why these observations will be carried out and describes some of the equipment that will be used.

The Scientific Value of the Earth Satellite Program (Van Allen, p. 764)—The value of the satellite does not stem solely from its tremendous altitude—if it did, it would be far easier to fire a rocket to the same altitude and get the same results—but rather from the fact that it ranges far and wide over the earth at high speed and remains in flight for a protracted period of time. As a result, we can get a good geophysical picture of the earth and its environs from almost every angle and can collect valuable scientific data which can be obtained only by prolonged or repeated measurements. The satellite can be useful to us in two ways: first, as an inert sphere, the position and movement of which can be accurately measured from earth by optical means to yield valuable information about the geodetic figure of the earth and the density of the upper atmosphere; and secondly, as a carrier of instruments and telemetering equipment for obtaining data concerning cosmic and solar radiations, atmospheric phenomena and geophysical conditions. In this final paper on the earth satellite program, the author delves into the various types of measurements which can be conducted with the satellite, the different types of satellites that could be used, and some of the specific experiments which are now under active consideration.

Television Sweep Generation with Resonant Networks and Lines (Schlesinger, p. 768)—Aside from the picture tube itself, one of the points of greatest engineering interest in a television receiver is the sweep circuit. The horizontal-deflection power requirements of modern wide-angle picture tubes run from 30 volt-amperes for black-and-white receivers to as much as 80 volt-amperes for color sets. This represents an important portion of the total power required to operate the receiver. Moreover, the trace linearity and retrace speed must be held to within certain close limits for proper picture presentation. By proposing, as an alternative to the method of sweep generation which has been used almost universally for several years, a new approach that requires less power and gives comparable performance (although at higher cost), this paper makes an extremely interesting contribution to a subject of great practical importance in television receiver design.

IRE Standards on Facsimile: Definitions of Terms (p. 776)—This document, drawn up by the IRE Committee on Facsimile, standardizes the meanings of over one hundred engineering terms used in facsimile work.

Docile Behavior of Feedback Amplifiers (Mason, p. 781)—This paper deals with the effects of loading networks on the stability of feedback amplifiers. Using a simplified geometrical approach, the author examines the various relations which must exist to keep an amplifier stable and develops a useful table which expresses in simple form the stability criteria for three classes of passive loading and ten amplifier types. The deceptive simplicity and ease with which the author treats this important problem (he uses only eight equations) will make this enjoyable and interesting reading to a good many readers, who will find the criteria of particular interest in the design of cascaded amplifiers and, as a matter of fact, even in the design of nondocile amplifiers; *i.e.*, feedback oscillators.

A Note on Bandwidth (Nathan, p. 788)—We normally associate the word "bandwidth" with the range of frequencies over which a network has approximately constant gain. In this brief paper, the concept of bandwidth is extended to networks such as integrators and differentiators which have characteristics of a totally different shape because they are not intended to provide faithful transmission of a signal. The author proposes that the bandwidth of such a network be described by the maximum bandwidth of the input signal which produces an output that does not differ from the output of an ideal network by more than some maximum allowable error. This gives rise to some rather novel ideas concerning our notions of bandwidth and rms error.

Measurement of Microwave Dielectric Constants and Tensor Permeabilities of Ferrite Spheres (Spencer, *et al*, p. 790)—Ferrites, currently one of the most important classes of radio engineering materials, are rapidly being developed and finding widespread use in electronics, most notably in the microwave field. Many microwave applications make use of the property of this material to rotate the polarization of electromagnetic waves. This rotation property is directly related to the dielectric constant and the permeability of the ferrite. In developing new and better ferrites it is, therefore, important to be able to measure these two characteristics, and to do so accurately and with reasonable ease. This can be done, as discussed in this paper, by suspending a spherical sample of the ferrite in a resonant cavity and measuring the changes in frequency and Q that result. When the sample is placed in the maximum E field, these measurements reveal its dielectric properties; when placed in the H field, its permeability characteristics. The improvements in measuring techniques and apparatus presented here, coupled with the fact that it presents a good discussion of what is now an important engineering subject but which heretofore has been largely confined to physics journals, recommends that this paper be given wide distribution among radio engineers.

The Effect of AGC on Radar Tracking Noise (Delano and Pfeffer, p. 801)—It has been found that the compensating action of agc in a radar receiver in trying to maintain the level of a momentarily fading signal is such that it increases the low frequency components of the noise arising from fluctuating properties of the target echo. Theoretically, this increase in noise could be avoided simply by slowing down the response of the agc. However, situations arise, such as when a radar is mounted in a missile which is homing on its target, where fast agc response is necessary to prevent the rapid rise in signal strength from saturating the receiver. The author provides a neat solution to this dilemma by placing a nonlinear filter in the agc feedback path which provides a fast response to rising signals and a slow response to decaying signals, although at some sacrifice in receiver gain, thus making an interesting contribution to a very timely topic.

Theory of Noisy Fourpoles (Rothe and Dahlke, p. 811)—In this paper the author develops equivalent circuits which in addition to providing for the standard internal voltage and current sources of the network also take into account internal noise sources. In so doing, the author puts our knowledge about noise in very concise form and provides useful tools for analyzing a wide variety of noise problems.

John R. Whinnery

DIRECTOR, 1956–1958

John R. Whinnery was born on July 26, 1916 in Read, Colorado. He received the B.S. degree in electrical engineering from the University of California in 1937, and immediately went to work for the General Electric Company in Schenectady, New York.

At the General Electric Company, Mr. Whinnery entered the three-year Advanced Engineering Program, and following that, supervised the High Frequency part of that program for two years. He then worked in the Electronics Laboratory and the Research Laboratory on problems in velocity-modulation tubes, traveling-wave tubes, and disk-seal triodes. In 1945–1946 he was also part-time lecturer in Union College.

In 1946, Mr. Whinnery returned to the University of California to teach electrical engineering and to complete work on his Ph.D. degree. He is now professor of electrical engineering there and vice-chairman of the Electrical Engineering Division in charge of the Electronics Research Laboratory. During summer periods he has worked at Stanford University, the Hughes Aircraft Company, and the Ramo-Wooldridge Corporation, and during an industrial leave in 1951–1952 he was head of the Microwave Section of the Hughes Electron Tube Laboratory.

Mr. Whinnery is co-author with Simon Ramo of the text, *Fields and Waves in Modern Radio*, and is also author of several journal papers on wave guide discontinuities, antenna problems, and microwave tubes.

Mr. Whinnery became an Associate Member of the IRE in 1941, a Senior Member in 1944, and received the Fellow award in 1952. He held offices in the San Francisco Section from 1948 to 1954, becoming chairman in 1953, and has been active in WESCON and on many national IRE committees.

Poles and Zeros

Balance. The IRE membership currently breaks down as follows: Student grade, 16 per cent; Associate, 43 per cent; Member, Senior Member and Fellow combined, 41 per cent. Question: Does the Institute editorial policy recognize this distribution and, if so, how?

Answer: So far as Student grade is concerned, the situation is well in hand. The IRE STUDENT QUARTERLY is published especially for the large and growing student membership. It hits the mark. So far as the other grades are concerned, the Editorial Board is well aware of its responsibility to the heavily-populated grade of Associate Member. It is also aware that the Associates, who pay so large a share of the bills, do not have (and, by and large, do not expect) a proportionate share in determining the content of Institute publications. In consequence, many Associates, as well as many in higher grades, may feel frustrated, particularly if issue after issue of the PROCEEDINGS offers material so specialized in subject or so difficult in treatment as to be beyond interest or comprehension.

The solution to this problem is editorial balance. The objective is that every issue of the PROCEEDINGS shall contain a sufficient variety of material in subject matter and technical difficulty, so that every member will find at least one or two papers of more than passing interest and intelligibility. By the same token, few members indeed, however broad their interests and training, can expect to find *all* the papers of engrossing interest. This is an inevitable conflict, implicit in covering a broad field for a diverse readership. No one can expect a full harvest every issue.

Editorial balance is seldom achieved by allowing nature to take its course. To the unplanned emergence of contributed papers must be added a planned program of solicited papers. Some of these invited papers are "straight technical," intended to fill gaps in the coverage of new developments. Others, of even greater importance in maintaining balanced issues, are sought from authors who have an encyclopedic knowledge of a particular field and who have, in addition, the patience and generosity to prepare a review of that field for the non-specialist.

Such review and tutorial papers have been published occasionally in the PROCEEDINGS for many years. More recently, as a consequence of a program inaugurated by the Editorial Board two years ago, they have been cultivated on a grand scale. No fewer than 9 solicited review and tutorial papers have been published in the PROCEEDINGS in the last 17 months and 21 more are now ready or in preparation. If the authors meet their deadlines (this type of paper takes plenty of persuasion), we can count on publishing at least one an issue from now to the fall of 1957, and by that time there should be a new batch on the fire.

Review papers written to be understood by the nonspecialist are a powerful specific for the editorial disease herein discussed. Why? First, because IRE members are noted for their interest in what the other fellow is doing. Second, because every IRE member qualifies as a nonspecialist, outside his chosen field. The review paper is often of particular interest to the specialist when it covers his own field, since he can read it critically with full appreciation of the fine points of the presentation.

Occasionally such papers appear in other publications and are worthy of republication in these pages. A prime example is the paper on color television by J. M. Barstow, republished here last November from our own STUDENT QUARTERLY. In this issue, the STUDENT QUARTERLY once again provides much solid food for thought, this time a commentary on engineering education, reviewed in the next item by former IRE President J. D. Ryder.—D.G.F.

Evolution. Dean F. E. Terman in "Electrical Engineers are Going Back to Science" (this issue, p. 738) takes a look into the future of electrical engineering education and, in fact, into the future of engineering education in general. What he sees is not a reversal, or a reorientation, but actually a speeding up of the process of evolution which has been going on in engineering education since its beginnings.

This evolution continues away from applied science toward more fundamental science, away from the hardware that differentiates a civil engineer from an electrical, and instead points up the common ground of nature's basic laws. A report issued last year by the American Society for Engineering Education stressed the same trend of our evolution. It calls attention to the apparent fact that, in the past, too much of our educational time had been spent in the art and techniques of engineering, making technicians, and not preparing engineers for the new and challenging creative jobs of the age of electronics, rockets, and the conquest of space.

With electronics in the forefront of this movement, and at the same time supplying much of the explosive driving force, Dean Terman's article becomes of importance to IRE members, as well as to all other engineers. In particular, we wish to emphasize his statement that if the traditional engineering teaching departments do not quickly develop their work further along these fundamental lines, new groups of dynamic, creative, mathematically-trained people will take over the development of the engineering knowledge needed for the new areas of our science-based civilization. This would leave to traditional engineering the dry husk of technician training. Once again, if you do not make a better mousetrap, someone else will do it for you!—J.D.R.

Electrical Engineers Are Going Back to Science!

FREDERICK E. TERMAN†, FELLOW, IRE

In its December, 1955 issue the IRE STUDENT QUARTERLY published an article in which one of our most eminent educators and engineers pointed up the fact that electronics, with its heavy reliance on science, is causing a major change in the educational requirements of today's engineers, and forewarned engineering educators and accrediting bodies to accept and provide for this trend towards science in the engineering curricula of our colleges.

Because of the broad significance of this message, it was felt by the Editorial Board that it should be placed before the entire IRE membership. There is, accordingly, reprinted below, the text as prepared by the author and the illustrations as prepared by the STUDENT QUARTERLY staff.

—*The Editor*

ELECTRONICS is rapidly taking over electrical engineering education. Ten years from now electrical engineering will be synonymous with what today we call electronics. Electrical engineering of the pre-war era which concentrated its attention on phenomena at 60 cycles in general, and rotating machinery in particular, will be regarded as a small part of the broad subject of electronic science.

Whether we will call it electrical engineering or electronics ten years from now I do not know. However, what is certain is that the present trend toward subordinating the very narrow and very special case of 60-cycle power in favor of studying the broad field ranging from dc amplifiers to millimeter waves, and from micro-microwatts to powers of hundreds of megawatts, will continue.

The training that electrical (or electronic) engineers will receive in the future can be expected increasingly to emphasize the basic sciences at the expense of traditional engineering subjects. Differential equations, functions of a complex variable, vector analysis, Laplace transform, matrix theory, theory of random process (*i.e.*, statistics and probability), electromagnetic theory, atomic and nuclear physics, solid state physics, quantum mechanics, etc., are regularly used by many electronic engineers. In contrast these same engineers very seldom find much use for the conventional engineering courses they may have had in statics, dynamics, strength of materials, fluid mechanics, heat engines, surveying, descriptive geometry, etc.

Those electronic engineers engaged in creative work commonly work side by side with physicists, mathematicians, chemists, metallurgists, etc., and their performance is measured by comparison with men having master's and doctor's degrees in these fields. In these circumstances no one cares whether the young man can calculate the deflection of a beam (the formula can be found in a handbook anyway), but he most certainly is expected to have a working knowledge of differential equations, or of Maxwell's equations, or of matrix theory.

Several years ago I made an analysis of the authors who wrote papers for the PROCEEDINGS OF THE IRE and found that during that particular year nearly 40 per cent of all the authors of the papers in the PROCEEDINGS were men whose major subject in college was something other than electrical engineering. The most frequent of these "other majors" were physics and mathematics.

It is thus clear that one can reach the green pastures of electronics through many doors, only one of which is labeled "electrical engineering." Some of the other doors are in fact probably better, because courses in basic science are more valuable to the electronic engineer than the nonelectrical engineering courses (and the 60-cycle courses) included in the typical electrical engineering program of today. This situation is already causing a few farsighted schools to change rather drastically their electrical engineering curricula, and during the next ten years the distance that electrical engineering education will travel in this direction of more basic science at the expense of engineering content of the electrical engineering curriculum will be considerable.

As this inevitable trend toward science develops, the electronic (electrical) engineer is going to look less and less like an engineer as the engineer is defined today. This will cause real trouble in colleges, and particularly in the accrediting of engineering curricula. The engineers in more traditional fields are mistakenly going to feel that while electronics is a useful and important subject, and the men who work in it are fine fellows, they are not really engineers. Whether these men are really engineers or whether they are applied scientists is beside the point, however. The engineering schools are going to be forced to take care of the educational needs of those preparing for a career in electronics, because the pure scientists will not be interested in doing so. Ten years

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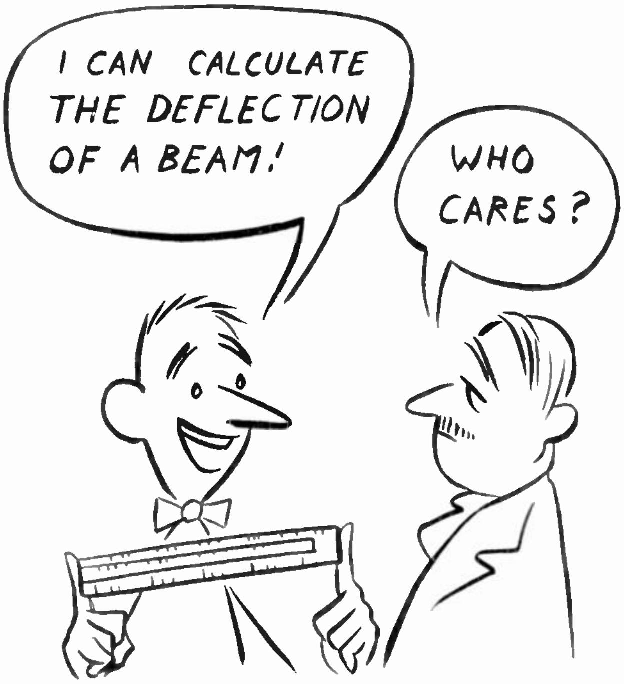
† Stanford University, Stanford, Calif.

from now all the physicists, for example, will be interested in pursuing some new puzzle of nature, say the internal structure of the meson.

Engineering educators will have to accept electronics and the other similar areas of importance that lie between pure science and traditional engineering as being engineering, because otherwise Colleges of Applied Science will develop on the campus and insulate engineering from pure science while taking over the interesting and creative areas. This would leave engineering to concentrate primarily on dull trade school subjects. I cannot see engineers allowing this to happen—too many engineers are ambitious for their profession.



The heavy emphasis on science that is characteristic of electronics arises from several causes. First, problems in electronics usually lend themselves to mathematical analysis. The difficulty of the problems ranges from those that can be handled by simple analysis to those that require very advanced mathematics to handle successfully, so that everyone can make calculations according to the level of his mathematical competence.

Second, electronics is a new field that has grown out of very recent developments in science. It is therefore very close to the frontiers of new knowledge, and each further advance made by the pure scientist in those areas from which electronics originated is of potential importance to electronics.

The present trend in electrical engineering is unique for an engineering field. The first training in electrical engineering in this country was given in physics departments. The early heads of electrical engineering departments were often physicists, and in at least a few instances the same man was simultaneously head of both the physics and the electrical engineering departments of his school. As time went on electrical engineering training became increasingly practical with interest focusing on design and computation procedures and away from the underlying science. Educators and nearly all employers developed the viewpoint that when a man received the B.S. degree in electrical engineering he knew all that was worth knowing about the principles of electrical engineering, and should get out into the world and start getting practical experience. Such an environment did not encourage graduate training and

Enthusiastic young men who worked at all hours.

very little was done. Also very little real research was carried on in the electrical engineering departments of our universities during this era.

In the twenties courses in electronics then called "radio" or "communication" began to appear among the senior year electives, taught by enthusiastic young men who had lots of energy, who worked in the laboratory at all hours with their tubes and circuits, and who appealed to the more adventuresome students. These instructors began to move the center of gravity back toward science, particularly physics and mathematics, and away from handbook design procedures and standardized testing methods. These instructors also stimulated research, and created an interest in graduate work, because they were curious and their students couldn't get a full understanding of these interesting new ideas without coming back to school after the B.S. to learn more.

The result of this evolutionary process is that electrical engineering is now moving away from engineering, and back toward the sciences from which it originally came. It is clear that ten years hence electronics will have brought electrical engineering closer to science than it has been since the latter part of the nineteenth century. This is a unique life cycle for a field of engineering to have traversed.

The field of electronics is steadily becoming more complicated. A television set is an order of magnitude more complex than a home radio, and color television is still more complicated. The technology of microwaves requires more understanding of mathematics and physics than is necessary when dealing with waves below 1,500 kc in frequency. Amplitude modulation is simpler than frequency modulation. Transistors are not only newer than vacuum tubes, they have a higher level of sophistication. And so it goes—always in the direction of requiring *more* knowledge and *higher level* knowledge from the electronics engineer.

The great complexity of electronics and the many areas of science from which it draws sustenance means that the more training an electronic engineer possesses, the more versatile and capable he becomes. There is no such thing as an over-trained electronic engineer. Rather, although there is a shortage of engineers of all categories, the shortage for electronic engineers is greater the higher the level of training. The salaries offered today to men with B.S. training may seem pretty lush, but one should take a look at the salaries being offered to men with Ph.D.'s in electronics from good schools!

Not only is graduate work now very important in electronics, it will be still more so with the passage of time. Even today an able electronic engineer will not achieve his full possibilities in the technical side of electronics unless he acquires considerable formal training beyond his bachelor's degree, either by going to graduate school, evening school, or going through industrial training programs. Unorganized "on the job" experience while valuable is no substitute for formal training in a field where technology is complicated and advancing rapidly.

Electronics is a wonderful field. The opportunities that electronics offers are so many and so varied in their character that everyone can find a place somewhere in the field that suits his personal interests, and utilizes effectively his particular talents. The electronic engineer gains personal satisfaction from the knowledge that his work is important, that his prestige is high, that his advice is widely sought and highly respected. More significant than anything else, however, is the fact that electronics is fun.

* * *

Symposium On

THE U. S. EARTH SATELLITE PROGRAM—VANGUARD OF OUTER SPACE

On the evening of March 20, 1956, two thousand visitors to the IRE National Convention descended on the Waldorf-Astoria Hotel in New York City, filling to capacity a large lecture hall and overflowing into a second and then a third session hall nearby. The cause of this huge turnout was a special symposium on the U. S. earth satellite program, organized and presented under the joint auspices of the IRE Professional Groups on Military Electronics, on Telemetry and Remote Control, and on Antennas and Propagation.

This unprecedented display of interest, coupled with the fact that many attendees could not see the slide presentations that accompanied the talks, led to the decision to publish the entire symposium in the PROCEEDINGS at the earliest possible date.

Accordingly, there is presented in the following pages the complete texts of seven papers prepared by leading scientists engaged in the earth satellite program outlining the objectives of the program, the scientific gains it is hoped will result, and the tremendous scope of the problems associated with placing a satellite in its orbit, tracking it, and gathering scientific data from it.

It is worthy of note that this presentation anticipates by more than one year the first attempt to launch a satellite. In effect, the authors candidly place themselves on record "before the fact" concerning one of the boldest and most imaginative scientific experiments ever attempted by man. A report in these pages on the "after-the-fact" results will be eagerly awaited to see how well their expectations are borne out.

—*The Editor*

The IGY Program[*]

JOSEPH KAPLAN[†]

Summary—**This paper presents very briefly the nature and origin of the International Geophysical Year, and in more detail two areas of special interest: rocket studies of the upper atmosphere, and satellite studies. It brings out the scientific basis for the satellite program and the development of U. S. interest in launching a satellite for scientific observations. The present status of the program is commented on briefly.**

THE GEOPHYSICAL sciences embrace the study of the earth, its atmosphere and oceans, and those solar and cosmic phenomena whose effects are felt on the earth. These sciences offer many opportunities for the increase of our fundamental knowledge of the physical universe. For instance, cosmic rays provide the scientist with nuclear particles having energies millions of times greater than can be produced by a man-made accelerator such as a cyclotron. At the same time, the geophysical sciences provide us with information of a very practical kind. For example, meteorology furnishes weather data important in every field of human activity; ionospheric physics provides communication data important in long-range radio communication and navigation.

The surge of interest in the earth satellite program had its basis in the assemblies of some forty nations, meeting to plan and integrate the unprecedented study of man's physical environment known as the Inter-

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national Geophysical Year, 1957–1958. This worldwide study primarily embraces those fields of geophysics in which observations must be conducted simultaneously over the earth if we are to achieve significant progress in our understanding of the earth and its atmosphere. Problems to be studied include aurora and airglow, cosmic rays, geomagnetism, glaciology, gravity, measurements, ionospheric physics, longitude and latitude determinations, meteorology, oceanography, seismology, and solar activity. Two additional areas of activity are of special interest: rocket studies of the upper atmosphere, and the recently announced satellite studies, which represent a logical extension, technically and conceptually, of the rocket program.

When scientists first began to discuss the desirability of an International Geophysical Year, they naturally turned to the International Council of Scientific Unions (ICSU) as the organization best qualified to secure the cooperation of scientists from all countries and to undertake the complex task of international technical planning. Accordingly, the ICSU established a special committee for international development of the IGY program, the Comité Spécial pour l'Année Géophysique Internationale (CSAGI). This committee then called upon appropriate bodies in various countries for the planning of national programs.

In the United States, the National Academy of Sciences, which is this country's representative in the ICSU, established the U. S. National Committee for the International Geophysical Year, composed of a number of the nation's leading geophysicists, and delegated to it the responsibility for planning, directing, and executing the U. S. program. To secure funds for this program, the Academy turned to the National Science Foundation, the Government agency responsible for federally supported basic research.

Earlier in this paper I mentioned two additional areas of activity of special interest: rocket studies of the upper atmosphere and satellite studies. In the rocket program, the United States will fire hundreds of research vehicles during the IGY, ranging from the relatively small balloon or aircraft-launched vehicles through multiple-stage, solid-propellant combinations to high performance Aerobees capable of reaching 200 miles. These will be fired from locations that range from the Arctic to the Antarctic. Other countries will also contribute to the rocket sounding field during the IGY, thereby extending the geographical coverage.

Time will not permit me to go into any of the many and complex problems in the high atmosphere to whose solutions rocket studies will contribute greatly. However, I would like to list the experiments which will be performed by rockets.

1) *Atmospheric Structure*

Basic upper atmosphere meteorological data will be obtained at new locations and at various times by the employment of established rocket techniques. The quantities measured will be pressure, temperature, density, and winds.

2) *Atmospheric Composition*

The chemical and ionic composition of the high atmosphere will be determined by spectrographic and mass spectrometric means. Special emphasis will be placed on the nature of the ions at the various ionospheric levels, since this is vital to further development of ionospheric theory. The vertical distribution of ozone, and the question of the pressure of nitric oxide and water vapor in the high atmosphere will also receive attention. Much of this work will be done within the auroral zone where our knowledge of the high atmosphere is meager.

3) *Radiation Studies*

There will be measurements of auroral Lyman-alpha and air fluorescence, determination of the heights and intensities of dayglow radiations. Rocket spectrograms will be made of the solar ultraviolet spectrum to wavelengths shorter than the Lyman-beta line of hydrogen. The solar spectrum in the ultraviolet and X-ray regions will also be studied by means of photon counters, with special attention to its behavior during solar flares.

4) *Particle Studies*

The nature and intensities of auroral particles and the directional characteristics of auroral particle streams will be studied. Low energy cosmic rays will be measured as a function of geomagnetic latitude, and an effort will be made to correlate fluctuations in cosmic ray intensity with solar and magnetic phenomena.

5) *Ionospheric and Geomagnetic Measurements*

The variation of charge density with altitude in the ionosphere will be determined in the auroral zone by a number of techniques. An effort will be made to distinguish between electrons and ions. Measurements will be made of the earth's magnetic field at various latitudes to provide information on the position and magnitude of electrical currents flowing in the lower ionosphere and on auroral particle streams.

Rockets make possible direct measurements of quantities which are either not observable, or are only indirectly observable from the ground. They can also be used for measuring the altitude dependence of geophysical parameters. But they have a marked disadvantage in that they spend only a short time at any one altitude during their flight, and that their total flight time in itself is extremely short. Thus, particularly in the case of the large rockets used for extreme altitude studies, they are not easily adapted to synoptic type or long term studies. This is an unfortunate shortcoming, since fluctuations in such solar effects as ultraviolet and X-ray radiations, cosmic ray intensities, current rings encircling the earth, and particle streams impinging upon the high atmosphere are among the most important and interesting problems connected with the physics of the upper atmosphere and with solar-terrestrial relationships.

Clearly an earth satellite would provide synoptic data over the earth, at high altitudes, over appreciable periods of time, and the satellite thus constitutes a valuable addition to the International Geophysical Year program, permitting measurements that would otherwise have been impossible.

As plans for the International Geophysical Year progressed, several international scientific bodies called attention to the value of an earth satellite in advancing scientific knowledge of phenomena that lie beyond the reach of observers on the earth, and even beyond instruments contained in balloons or rockets. In October, 1954, the Special Committee for the International Geophysical Year adopted a resolution asking the participating nations to give thought to the possibility of a satellite.

In response to the CSAGI resolution, the U. S. National Committee for the International Geophysical Year (USNC-IGY) began its initial studies in October, 1954. These studies related to the value of the program and to the technical feasibility of launching satellites. By March 19, 1955, the Committee had satisfied itself on both points and transmitted its findings to the President of the National Academy of Sciences and the Director of the National Science Foundation for establishment of a Government position.

Studies of the nature of the satellite and the experiments which might be undertaken were continued. On May 6, 1955, the Committee submitted its initial program proposal to the Government for federal support, via the National Science Foundation.

Late in July, the Government's favorable response to the Committee's proposal permitted the Chairman of the USNC-IGY to inform the President of CSAGI, Dr. Sydney Chapman, that the U. S. IGY program would include satellite studies.

The CSAGI made public this decision on July 29, 1955, in Brussels, at about the same time that the White House announced that "the President has approved plans by this country for going ahead with the launching of small, unmanned, earth-circling satellites as part of the United States participation in the International Geophysical Year which takes place between July, 1957 and December, 1958."

The satellite will be observable by the scientists of many nations, who will be able to gather data by tracking the object's course through the skies. In addition, its design and instrumentation will be made known. After the satellite's flight, the results of the observations will be published. Thus it will constitute a research instrument for the scientists of every nation.

Two months after the President's announcement, the representatives of participating nations met at Brussels to continue the work of planning and coordinating their programs. The inspiring character of the President's announcement was clearly revealed. The assembled scientists of more than forty nations received the news of the plans for the satellite enthusiastically. This reception was based in part on the great admiration in which the scientists of other countries hold the past achievements and prospective future accomplishments of American rocket scientists. More important, however, was the knowledge that the value of the scientific observations made during the International Geophysical Year would be greatly enhanced by the addition of data obtainable only from research satellites.

Shortly after the President's announcement, the Technical Panel on the Earth Satellite Program was formally established, with functions corresponding to those of the twelve other panels of the U. S. National Committee, each of which is in charge of the program in one discipline or technical problem area. This panel, with such additional membership and consultants as are necessary, will have fundamental responsibilities, acting on behalf of the U. S. National Committee, in further developing, coordinating, and directing the over-all scientific satellite effort. The Panel expects to utilize the contributions of many scientists and institutions, a feature that has characterized the planning of all of the programs of the U. S. National Committee.

The Department of Defense, which is making substantial and indispensable contributions to two other programs of the U. S. National Committee (in the Antarctic and in making rocket observations), is providing the facilities and experienced personnel without which a launching could not realistically or economically be attempted. The Committee's May 6, 1955 proposal to the Government recognized the need for such assistance and called for Defense logistical and operational support, system design and construction of propulsion units, launching, facilities, and technical personnel.

The Department's participation in the satellite program is being accomplished under the code name of Project VANGUARD as a Joint Army-Navy-Air Force program under Navy management. A group has been established, under the direction of Dr. John P. Hagen of the Naval Research Laboratory, to carry out the Department's responsibilities.

It is expected that a number of universities, observatories, and other nongovernmental organizations will participate in the satellite program by proposing experiments and observations for which the satellite could be used, in locating it and keeping it under observation during its flight, and in analyzing and interpreting the data obtained.

Once the President's approval of the project was announced, it was desirable to begin certain technical phases of the effort immediately, so that launchings could be begun as early as possible during the 1957–1958 period of the International Geophysical Year. The group in charge of Project VANGUARD went to work at the Naval Research Laboratory almost immediately, and certain necessary propulsion equipment is already being procured. Three contracts have been awarded for the manufacture of the units which will propel the satellite into its orbit.

In the meantime, work on the scientific and engineering problems involved in providing the satellite with the proper instrumentation, launching it, and observing it, is being carried on jointly by the National Academy of Sciences and the Department of Defense. The papers following will tell you of the progress that is being made.

The Exploration of Outer Space with an Earth Satellite*

JOHN P. HAGEN†, FELLOW, IRE

Summary—**Sometime during the coming geophysical year (July, 1957 to December, 1958) an attempt will be made to launch an artificial satellite in an orbit around the earth. The Office of Naval Research has been assigned the responsibility to perform this task and has established Project VANGUARD in the Naval Research Laboratory to carry it out. The Department of Defense turned to the Navy to manage this triservice project because of its extensive experience in upper-atmosphere research with rockets.**

The satellite which Project VANGUARD intends to launch in an orbit is a small one, yet must be a research vehicle. The National Committee for the IGY of the National Academy of Sciences has established a panel which is concerned with the nature of the scientific experiments to be done in the vehicle. Work is in progress not only on the vehicles, but on the experiments to be done in the satellite.

Experiments conducted in an artificial earth satellite circling the earth in the outer tenuous region of our atmosphere can greatly increase our knowledge of the atmosphere—its structure, its constituents, and the powerful radiations both electromagnetic and corpuscular that impinge upon it and help determine its state.

FOR CENTURIES man was limited in his exploration of outer space to observations he could make from the surface of the earth in the visible part of the spectrum. The nature of the outer atmosphere, parts of the solar system, and the universe beyond were deduced from the partial knowledge gained from observation of a limited part of the spectrum. Within the last century he became aware of the extension of the electromagnetic spectrum to the ultraviolet and X-ray regions on the one hand and to the infrared and radio region on the other. However when the light of a star, the sun for example, was examined with the then new techniques it was found that the light was effectively cut off at both the infrared and ultraviolet ends. The cause of the cutoff was soon deduced to be the atmosphere. It was found that the infrared absorption could be materially reduced by making observations from high mountains but this was not so for the ultraviolet absorption. Much later it was found that the ultraviolet absorption was due to a region in the atmosphere about 20 miles above the earth where there is a proportionally large amount of ozone. Ultraviolet light of still shorter wavelengths is absorbed by other components of the atmosphere such as oxygen and nitrogen. There is thus a window in our atmosphere which through no accident of nature corresponds in wavelength range to the sensitivity of the human eye. Recently a second window has been found in the radio region of the spectrum. This window extends from a few millimeters wavelength to several meters wavelength where the ionosphere becomes effective. It is through this window that workers in the new field of radio astronomy have discovered many new facts about the universe in which we live.

We thus have a twofold interest in putting a research vehicle in the region of outer space beyond the confines of our atmosphere. The first interest is in making astronomical observations in that part of the spectrum now denied to us. The second interest is to determine the nature of the atmosphere itself; to study the incoming electromagnetic and corpuscular radiations and relate them to the affected regions of the atmosphere such as the ozonosphere and the ionosphere and to the unusual phenomena in the atmosphere such as the aurora.

I will not attempt to record the history of the struggle to go beyond the atmosphere but will refer in passing to the climbing of high mountains, the flying of kites to heights of 6 miles; the flying of airplanes and manned balloons to 13 miles and the observation of pilot balloons to 24 miles. With these early attempts the mysteries of the lower parts of the atmosphere were revealed. We know that both the density and temperature decrease with height up to a height of 12 miles. Above this height the density continues to decrease but the temperature strangely begins to increase. We now know that the absorption of solar ultraviolet radiation in the ozone layer just above the stratosphere causes the marked increase in temperature. Balloon measurements gave the first indication of the extension of the sun's spectrum toward the ultraviolet and gave us the measurements of temperature that determined the existence of the stratosphere.

After the war the availability of V-2 rockets, and the subsequent design and manufacture of more suitable and better rockets such as the Aerobee and the Viking, made possible for the first time the extension of scientific experimentation into the middle region of the atmosphere—that region where the ionosphere is formed, where auroras exist, where X rays and ultraviolet rays from the sun are still present in measurable quantities. The rockets in their flight passed through the denser lower parts of the atmosphere and stayed for minutes at a time in the rarified middle atmosphere. In the few hours of total time at these heights available since the inception of the rocket sounding program much has been done in the way of spot measurements of solar ultraviolet, cosmic rays, ionosphere, magnetic fields, and air composition and density. Now that rocket techniques

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have advanced to the state where we can consider placing a small research vehicle in an orbit about the earth high above the atmosphere, we can plan to make these measurements over longer periods of time.

Therefore let us first consider what we presently know about our atmosphere so that we may better judge at what height a satellite will have maximum usefulness and which types of experiments are best suited for the satellite.

The atmosphere (Fig. 1) supports itself in the earth's gravitational field and except for local effects of winds one would expect the pressure to decrease in an exponential fashion with height. Rocket pressure measurements show this to be so. In the lower (60 miles) part of the atmosphere the pressure decreases by a factor of 10 for each 10-mile increase in height. By the time heights considered for the satellite orbit are reached, the pressure is estimated to be that corresponding to a hard vacuum.

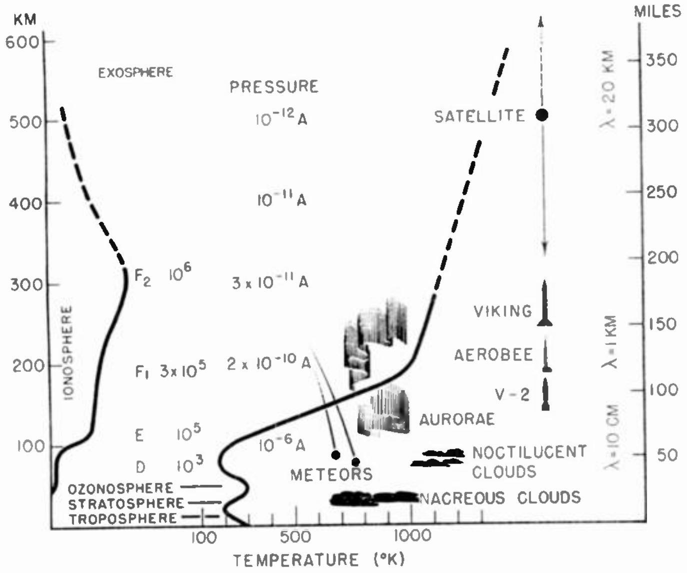

Fig. 1—The earth's atmosphere extends far beyond the stratosphere. It is in the rarified outer atmosphere that the ionosphere, auroras and other effects of solar emission are found.

The change in temperature with height is not so simple as that of pressure. At first the temperature decreases with height, falling 80°C in 12 to 15 miles. At this height the temperature reaches a minimum. The region of this minimum in temperature is called the stratosphere. Between the stratosphere and the earth's surface, in the region called the troposphere, more than 90 per cent of the atmosphere is found. Incidentally, if one should take all the air below a height of 130 miles and reduce it to normal pressure and temperature, it would form a layer five miles thick; the remainder of the atmosphere above 130 miles if reduced the same way would form a layer 1/1,000 of an inch thick. Just above the stratosphere there is a region containing ozone, formed by a photochemical reaction of solar ultraviolet radiation with molecular oxygen and ozone molecules. The ozone layer, so called even though the percentage composition is only a few thousandths of one per cent, gives rise to the name ozonosphere. Ozone strongly absorbs the sun's ultraviolet radiation and the consequent heating causes the temperature to rise with height in this region. The rise persists to a height of 30 miles where the temperature reaches a value of about 0°C. At this height the concentration of ozone falls off and with it the heating, and the temperature once more falls. The fall persists to a height of about 50 miles where there is a second broad minimum. Between 50 and 100 miles there is a rapid and steady rise in temperature until at 100 miles the temperature reaches a value of about 1,000°C. Above 100 miles the rate of rise tapers off. Theory shows that the temperature in the outer atmosphere, or exosphere, is in the range 1,500 to 2,000°C. It is in this region that the planned satellite orbit lies. One must remember that in rarified gases temperature begins to lose its meaning. The mean free paths of the gas molecules are great and collisions infrequent. Furthermore, the specific heat and thermal conductivity of the gas are low due to the very low pressure. A body the size of the satellite will find its own temperature in this rare gas; the controlling factors being the absorption of solar radiation and of infrared radiation from the earth balancing the self-radiation of the satellite itself. We can then control to some extent the temperature of the satellite by choosing the surface coating to have selected characteristics of absorption and reflection of visible and infrared radiation.

In the exosphere the mean free paths of the air molecules can be many kilometers long. It is thought that molecules come into the region from the denser regions below due to their thermal velocities and then due to the long mean free paths, continue to a height determined by the initial velocity and fall back into the atmosphere.

It is upon this atmosphere that the radiation from the sun over its broad spectrum, extending from X rays to long radio waves, falls. Our problem with the satellite is to extend the rocket-gained knowledge of this radiation and to determine its effect upon the atmosphere.

The spectrum regions on the short wavelength side of the visible window, on the long wavelength side of the radio window through the atmosphere, and all the region between the two windows are blocked off by absorption of one kind or another. The absorption is due to atomic and molecular processes in the infrared and ultraviolet parts of the spectrum and to electron collisions in the ionosphere in the long wave radio end. Each of the processes occurs at a different height and each, through its absorption of powerful sunlight, has an effect on the nature or the composition of the atmosphere: for example, consider the ozonosphere and the ionosphere both caused in large part by the absorption of ultraviolet radiation, one resulting in a strong ultraviolet absorber and the other well known to us as a source of absorption and refraction of radio waves.

As the rocket art developed and sounding rockets reached even further into the upper atmosphere, spectra of the sun (Fig. 2) were made, chiefly by Tousey and coworkers at NRL for the ultraviolet, and with counting techniques, by Friedman and his group for the X-ray region. These rocket measurements, lasting for only a few minutes have greatly extended our knowledge of the solar spectrum and our understanding of the processes governing the physical conditions in our atmosphere.

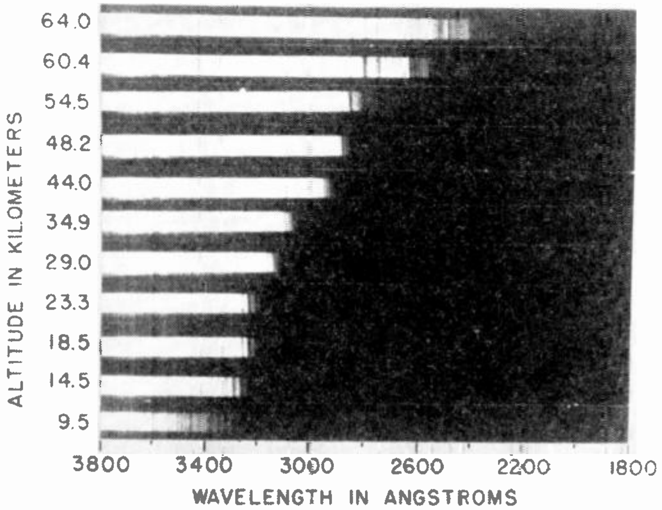

Fig. 2—The absorption of ultraviolet radiation by the atmosphere is graphically demonstrated. Succeeding spectra are taken at greater heights during a rocket flight. At the greater height much more of the ultraviolet spectrum of the sun is seen.

The measurements confirm our picture of the absorption of solar radiation by the atmosphere and make the satellite measurement which may extend over days and weeks duration even more desirable. These studies have in the past been limited to the few minutes during which a rocket is sufficiently high in the atmosphere to be outside the absorbing layers. The X radiation and ultraviolet radiation from the sun will be associated very closely with the corona and with activities in the corona. It is highly important during the time of the Geophysical Year, which coincides with the period of maximum solar activity, to be able to put in that outer region of the atmosphere experiments which will monitor the ultraviolet radiation from the sun and observe its variations with the changing solar activity. It is only by measurements such as these that we will obtain a more complete understanding of such fundamental processes on the sun as the occurrence of the solar flare.

We want then to put the satellite in such an orbit that we may obtain an unobstructed view of space to study solar and stellar spectra in their full spectrum; to study cosmic rays before they are absorbed and modified by our atmosphere; to study other corpuscular radiation originating in the sun; to study the magnetic field of the earth at these heights with emphasis on modifications by currents in the conducting ionosphere; to study the ionosphere itself and its outer limits; to study the density of atoms and ions in interplanetary space; and to study the density of dust and micrometeors in space. Our first attempts necessarily will be crude for there is a severe weight limitation on instrumentation; yet all results must be telemetered to the earth. There is no room in the present design to consider the use of photographic film, its ejection and recovery.

To perform these studies of outer space one would desire the satellite to be in an orbit as high above the earth as possible. However there is another aspect of the problem that requires that the orbit be such that the satellite will remain just within the atmosphere. Some of the experiments to be done with the satellite do not require instrumentation in the vehicle but do require that it be visible and bright enough to make accurate measurements of position possible. Out of these observations can come a measurement of the drag and hence, of the air density at this height. Also out of these measurements can come new and better information on the shape of the geoid, new and better information on the relative position of islands and continents—geodetic and mapping problems with which we have struggled for centuries. These geodetic and upper air density measurements are of such importance that it is now planned to so locate the orbit that their measurement will be favored.

The chosen orbit is a nominal circle 300 miles above the surface of the earth. If one could control perfectly the angle and velocity of firing, the orbit could indeed be circular. In fact the intended height of launching is 300 miles but errors in this height, in angle and in velocity, as Rosen[1] will explain, will result in an elliptical orbit. In the elliptical orbit it is intended that the nearest approach be not less than 200 miles and the furthest extension not greater than 1,500. While the atmosphere at these heights is extremely tenuous, drag is sufficient to take energy out of the orbit and cause the satellite to spiral to earth. Based on our present estimate of densities, it is calculated that the satellite would exist in a circular orbit of 300 miles height about one year (Fig. 3). If the height were 200 miles the lifetime would be only 15 days, and were it 100 miles then the lifetime would be less than one hour.

The satellite will be launched from Patrick Air Force Base in Florida (Fig. 4) and so the inclination of the orbit to the equator will be at least the latitude of Cocoa, Florida. Actually the inclination will be somewhat greater than this and will be in the range 35 to 45°. It is desired to have the inclination as large as possible so that the satellite will be observable in the temperate latitudes where the density of scientific population and equipment is high.

Once the satellite leaves the stand it becomes a separate entity and exists in space with an orbit of its own, freed of the rotation of the earth about its axis. The orbit is however a part of the earth system in its

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[1] M. W. Rosen, "Placing the satellite in its orbit," Proc. IRE, p. 748; this issue.

revolution around the sun. The period of the satellite in its orbit will be about 90 minutes. As the earth rotates on its axis (Fig. 5) the satellite will be overhead some twenty odd degrees to the west each revolution. In this way, in time, it covers a latitude band equal to twice the inclination of the orbit and even spaced about the equator.

The satellite attempt will be made during the period of the International Geophysical Year. After the first successful flight I am sure we will have a resurgence of talk of manned space flight. Let us remember that the practical problems involved indicate that these things are for the future. We have much to learn not only about conditions in outer space but also about the means for establishing even simple payloads in a useful orbit.

The benefits we stand to gain in this venture excite the imagination. A successful experiment in solar ultraviolet radiation alone would adequately repay us for all the heartaches and the tremendous effort necessary to put this satellite in outer space.

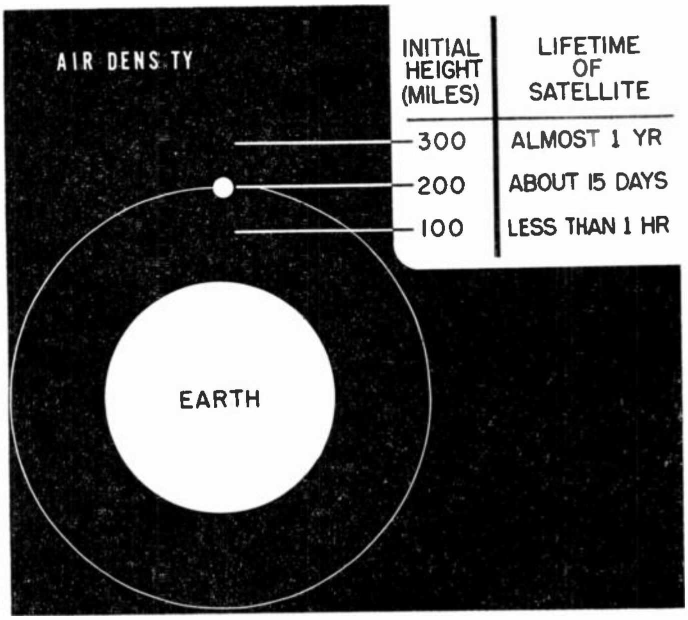

Fig. 3—The rarified upper atmosphere causes drag upon the satellite. Estimated lifetimes for a twenty (20) inch twenty-one (21) pound sphere are shown.

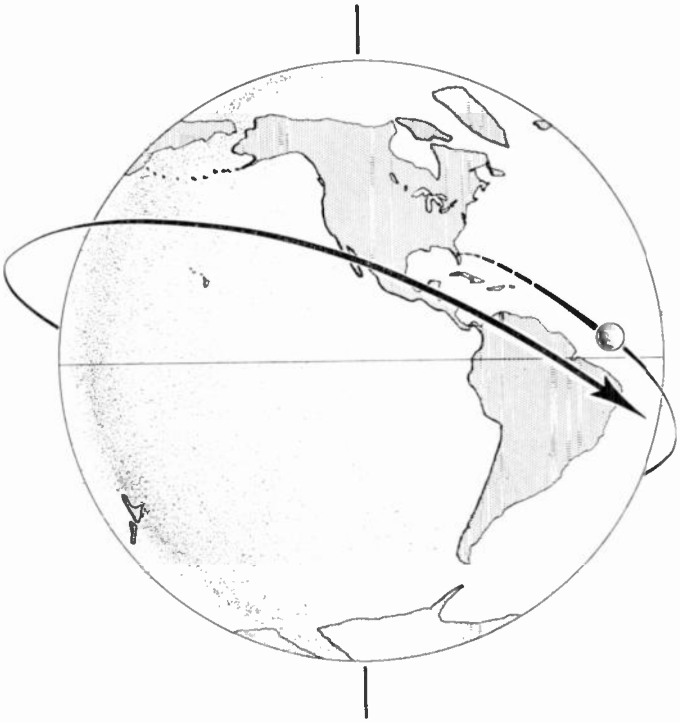

Fig. 4—The planned orbit for the satellite is shown; during the ninety (90) minutes of the first circuit of the earth by the satellite, the earth will have turned on its axis and the satellite will pass over a more westerly point.

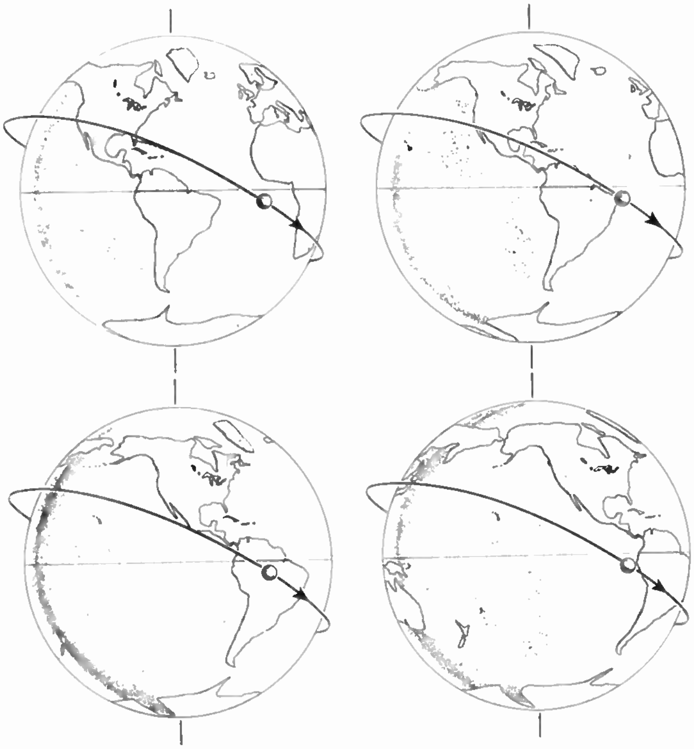

Fig. 5—The earth turns under the satellite orbit. Relative positions of the earth and the satellite are shown for four successive orbits.

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Placing the Satellite in Its Orbit*

MILTON W. ROSEN†

Summary—**The VANGUARD satellite launching vehicle is a three-stage rocket of which the first two stages are guided and the third stage is maintained in a fixed orientation while it is firing. The first stage, an improved Viking, serves primarily to raise the remaining stages to altitude. The second stage, another liquid-propellant rocket, contains the guidance for the three-stage vehicle and, in addition, supplies some of the propulsive energy. The third stage, a solid-propellant rocket, is ejected from the second stage at orbital altitude and provides about half of the required orbital velocity.**

The VANGUARD launching vehicle system was chosen from a number of possible two- and three-stage vehicle combinations. It represents the smallest satellite launching vehicle consistent with the present state of rocket development.

INTRODUCTION

THE MISSION of Project VANGUARD is to place an object in an orbit around the earth, to determine the orbit, and to obtain useful scientific information from the object. The first part of the mission is to be achieved through the development and use of a satellite-launching vehicle incorporating sufficient propulsive energy and the necessary flight path control. The second part is achieved by tracking the object using radio and optical instruments. Scientific information can be obtained in two ways, first by observation of the satellite from the earth and second by telemetering information from the satellite itself. This paper is concerned with the first part of the mission, more particularly, with the choice and development of the satellite-launching vehicle.

DESCRIPTION OF THE LAUNCHING VEHICLE

The VANGUARD launching vehicle (Fig. 1) is a three-stage rocket of which the first two stages are guided and the third stage is maintained in a fixed orientation while it is firing. The composite vehicle is cylindrical and without fins. It is about 72 feet long and 45 inches at its greatest diameter, giving a fineness ratio of 19 to 1. The gross weight with propellants is about 11 tons. From an energy standpoint the launching vehicle may be thought of as providing both potential and kinetic. It must raise the satellite to its initial orbital altitude, about 300 miles. In doing so it must also raise itself, in several stages, to various altitudes. If the launching vehicle did no more, the satellite would immediately fall back to earth. In order to achieve an orbit, it must have sufficient kinetic energy to balance the earth's centripetal (gravitational) pull. The velocity corresponding to the required kinetic energy is roughly 25,000 feet per second. All three stages of the launching vehicle contribute to this circular (or orbital) velocity.

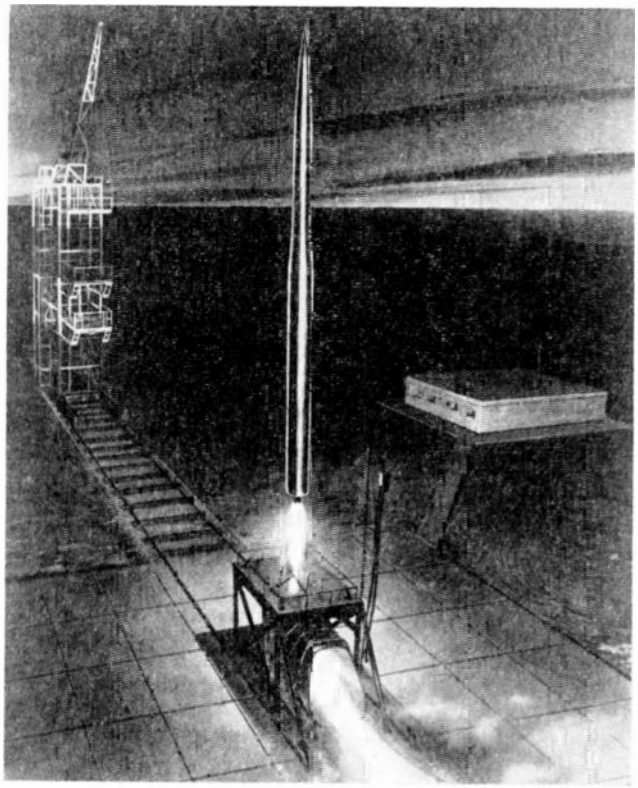

Fig. 1—Artist's conception of take-off.

The first stage (see Fig. 2) is a liquid propellant rocket similar to the Viking, but with substantial improvements. The major propellants, liquid oxygen and gasoline, are fed to the rocket motor by turbine-driven pumps. The motor can be tilted, as in Viking, to control the vehicle's orientation and flight path. The electrohydraulic controls that position the motor have the necessary response to stabilize a finless airframe in pitch and yaw. Roll control is provided by small auxiliary jet reactors. The two main propellant tanks are integral with the airframe's skin. The pressurizing gas is helium. Guidance information is obtained from an inertial reference system carried in the second stage that separates and ignites at the end of first-stage burning.

In summary, the first stage is essentially a guided liquid-propellant booster that provides most of the energy to raise the remaining stages to orbital height and about 15 per cent of the required orbital velocity.

The second stage is a liquid-propellant rocket that attaches to the forward end of the first stage and also carries in its nose the third stage and the satellite payload. The propellants, nitric acid, and unsymmetrical dimethyl-hydrazine are fed directly to the motor from high pressure tanks integral with the airframe's skin. Again, the pressurizing gas is helium. The motor is gimbal-mounted, as in the first stage, and positioned in

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pitch and yaw by electro-hydraulic controls. An array of jet reactors provides complete control of orientation during second-stage coasting flight. The reference system located wholly within the second stage consists of three gyroscopes, a pitch programmer, appropriate error sensors, and, if necessary, integrating devices to provide in-flight information on velocities. This reference system provides the necessary guidance during three periods of flight: first-stage powered flight, second-stage powered flight, and second-stage coasting flight.

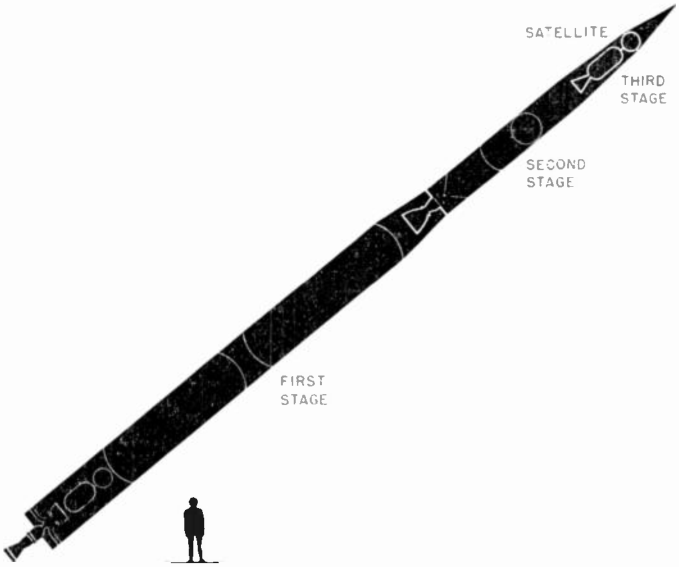

Fig. 2—VANGUARD launching vehicle.

The second stage also carries the master sequence controller that times the major in-flight operations such as ignition and cutoff of the various stages, stage separation, etc. The sequence of operations will be described more fully in connection with the launching vehicle's trajectory.

The second stage houses within its nose, which is the nose of the entire vehicle, the third stage and the satellite. The nose cone protects the more delicate satellite sphere from the aerodynamic heating it would encounter, if exposed, during the first- and second-stage ascent through the atmosphere. The cone is jettisoned early during second-stage burning, after which time exposure of the satellite would not be detrimental. The mechanism for spinning the third stage is also carried by the second stage.

This all-important second stage is indeed the brain of the launching vehicle. In addition, it supplies the remaining energy required to reach orbital height and about 32 per cent of the orbital velocity.

The third stage is a solid-propellant rocket that is unguided and is maintained during burning in a stable orientation roughly paralleled to the earth's surface, by spinning it about its longitudinal axis. Several propellant formulations are being tested—the final choice has not yet been made. The third stage is spun while in the the second stage, and then, is separated and ignited. This last stage is fired at orbital height and it provides about 50 per cent of the required orbital velocity. The satellite payload, presently viewed as a 20 inch sphere, is attached to the front end of the third stage and may be separated when orbital velocity has been attained. It is apparent then that the third stage must reach orbital velocity and, if separated from the payload, will itself become a satellite.

THE ASCENT TRAJECTORY

The earth, by virtue of its rotation, imparts to the launching vehicle an initial velocity relative to free space. For the chosen launching site, Cape Canaveral on the east coast of Florida, (latitude 28° 28′ N) the earth's rotational velocity is 1,340 feet per second. The full rotational velocity is gained if the vehicle is aimed due east; the gain is reduced if the vehicle is aimed north or south of east so as to produce an orbit of greater than 28° 28′ inclination to the equator.

The three-stage vehicle takes off vertically under first-stage power (see Fig. 3). It ascends in a smooth curve tilting gradually from the vertical in the direction (to the east) of the intended orbit. At first-stage burnout the vehicle is about 36 miles above the earth and is traveling at an angle of roughly 45° to the vertical. The first stage separates and coasts to an impact about 230 miles from the launching point.

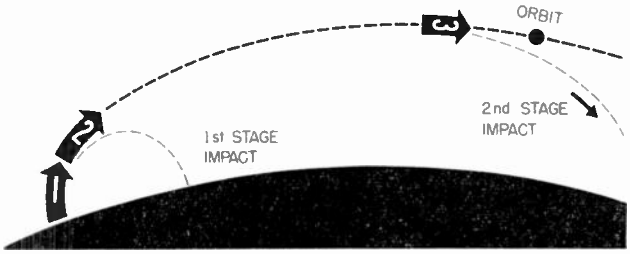

Fig. 3—VANGUARD launching vehicle trajectory.

The second stage ignites immediately upon separation and proceeds under power on a progressively more inclined trajectory to an altitude of about 140 miles. At burnout it has a vertical velocity sufficient for ascent to 300 miles altitude and a horizontal velocity that is about half the required orbital velocity. As noted previously, the nose cone will have been jettisoned early in second-stage powered flight. No separation occurs at second-stage burnout; the second-third-stage combination coasts forward a distance of about 700 miles in ascending to the 300 mile third-stage projection altitude.

During the coasting period several important functions are performed. The two-stage vehicle is brought to the correct orientation (roughly parallel to the earth's surface) for projection of the third stage. Then the third stage is imparted at the rotation necessary for stable flight. When second-stage zenith is reached the third stage is separated and fired. At this point the vehicle is, so to speak, fully committed—no further control can be exercised. Separation of the payload, if desired, will have been previously armed and timed to occur after third-stage burnout.

At burning's end the third stage will have a velocity vector of some direction and magnitude. Owing to the accumulation of errors in second-stage orientation, in sensing second-stage zenith, and in third-stage stability during firing, the final velocity vector can hardly be expected to be truly tangential to a circle. Moreover, the vehicle is being designed to have a final velocity in excess of that required for a circular orbit—this excess represents an essential margin for error. If the resulting satellite orbit lies within a perigee of 200 miles and an apogee of 1,400 miles (Fig. 4), then the launching vehicle will have accomplished its mission.

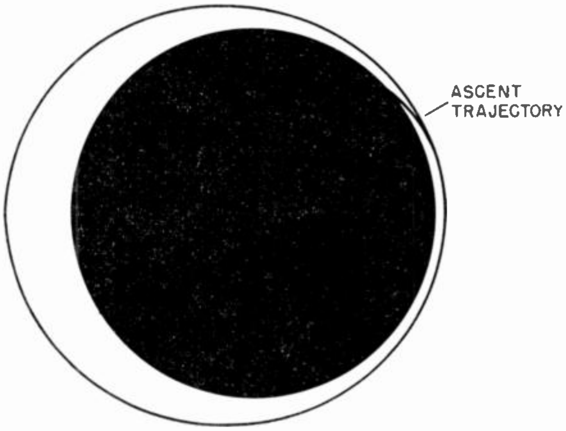

Fig. 4—Plan view of orbit with {200 mile perigree / 1400 mile apogee.

Choice of Vehicle Combination

The discussion thus far has been concerned with how the VANGUARD launching mission is being accomplished. Now we consider why one particular configuration was chosen from a number of possible launching-vehicle combinations.

The first and basic choice is the number of stages. A theoretical analysis (Fig. 5) of staging shows that, for the same gross weight and payload, two stages give a 33 per cent velocity gain over one, the gain for three stages is 45 per cent, and is only 70 per cent for an infinity of stages. When the added complexity of multistaging is considered, it would appear that any more than three or four stages is difficult to justify.

A one-stage rocket that flew all the way into the orbit would be the simplest configuration. Such a rocket is not realizable with propulsion that can be obtained now or in the foreseeable future through chemical combustion. Any attempt to estimate the gross weight of such a rocket would rest upon fantastically impractical assumptions as to weights of power plant, structure, controls, and other essential rocket-borne equipment. Therefore, the ensuing discussion considers only two- and three-stage combinations, with the reservation that a four-stage rocket would be admissible and would fall into one of the general categories that will be described.

The second basic decision is the extent to which active guidance must be employed or, more simply, the number of stages that need be guided. This decision can and does influence the character of each stage, its size and complexity, and whether it should employ liquid or solid propellants.

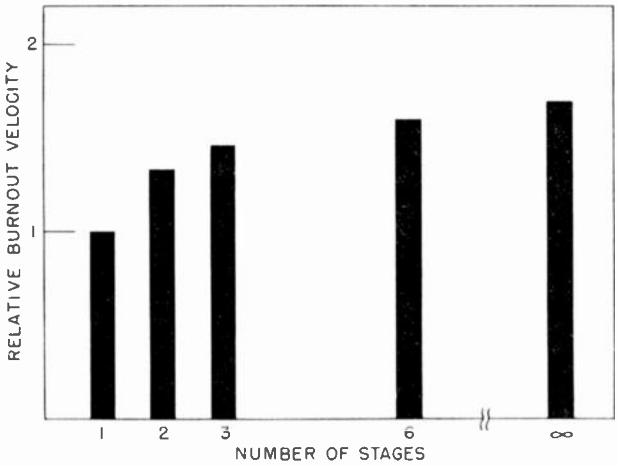

Fig. 5

Three-Stage Combinations

The three-stage combinations fall into three categories, depending upon the method of guidance, which also has a profound influence upon the ascent trajectory.

In the first system (Fig. 6) only the first stage is guided and it provides all of the potential energy to the system. Its coasting zenith is at orbital altitude and it may furnish a small part of the orbital velocity if its ascent path is somewhat inclined from the vertical. It must achieve the correct orientation prior to release of the subsequent stages. The remaining two stages (three or more could be used) are unguided—they would probably be solid propellant rockets, would fire in sequence, and provide the major share of orbital velocity. The trajectory is less efficient than that of VANGUARD and as a result the first stage would tend to be larger. Moreover, the system sets a high premium on guidance precision in the first stage since any error in

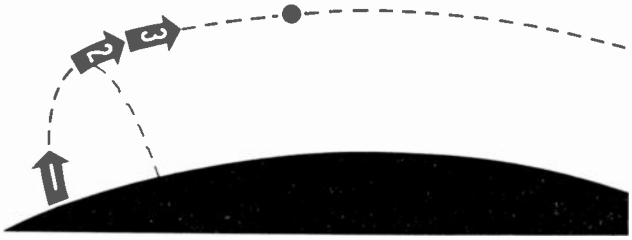

Fig. 6—Three-stage combination; first stage guided.

pointing is magnified by the high velocity component contributed by the unguided stages. Nevertheless, this system offers much in the simplicity of all stages subsequent to the first one.

In the second system the first two stages are guided; the third stage is unguided and fires at second stage zenith. This is the VANGUARD combination (Fig. 3) and its characteristics have been described previously.

The third system (Fig. 7) contemplates guidance in all three stages in a gradual powered ascent to the orbit.

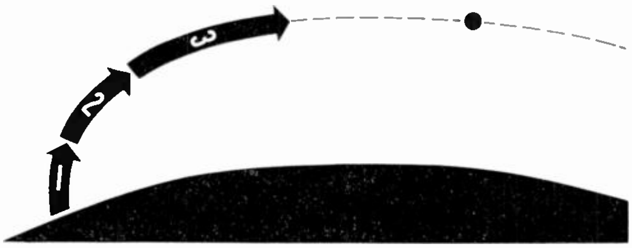

Fig. 7—Three-stage combination; all stages guided.

The difficulty here is that guidance components must be carried in the third stage where weight penalties are ten times as great as in the second stage and two orders of magnitude greater than for the first stage. In order to provide third-stage guidance the total vehicle gross weight would have to be at least several times that of the VANGUARD vehicle.

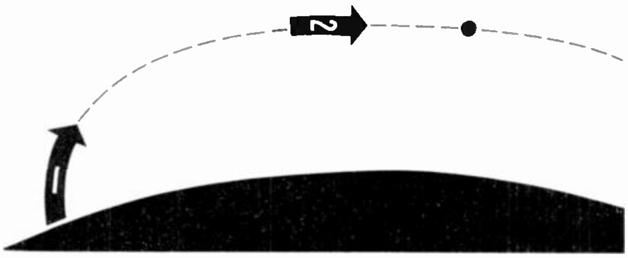

Fig. 8—Two-stage combination; first stage guided.

TWO-STAGE COMBINATIONS

Two-stage combinations are derived readily from the three-stage systems described previously. Two categories are considered. In the first (Fig. 8), the first stage is guided, it coasts to altitude, orients, and ejects a second stage that makes up the deficit in orbital velocity. This system by virtue of its simplicity would be preferred above all others, if it could be achieved. It makes great demands upon the propulsive efficiency of the first stage which must supply all of the potential energy and in addition, a sizeable portion, probably half, of the orbital velocity. Launching vehicles of this type are to be anticipated as successors to VANGUARD.

The second system (Fig. 9) is now obvious—both stages guided. For reasons given earlier (under three-stage combinations) it would be larger than the first system but would make less demands upon guidance precision.

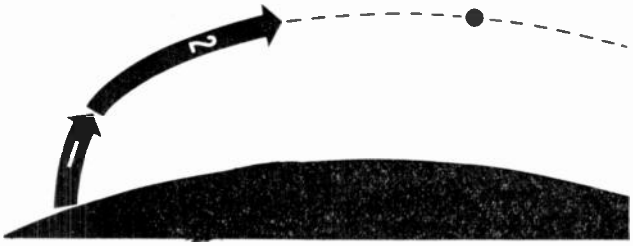

Fig. 9—Two-stage combination; both stages guided.

CONCLUSION

In summary, the VANGUARD launching system is believed to represent the smallest vehicle combination consistent with the present state of rocket development. The need to use existing techniques and components, wherever possible, made necessary many practical concessions that would not be necessary if the time scale were less critical. High levels of performance and a high degree of reliability will be required of all VANGUARD components and systems.

It is significant at this point to remember that the highest velocity and the altitude record for a large rocket was established in 1949 by the two-stage Bumper-Wac. The altitude was 250 miles and the maximum velocity, attained at the end of second-stage burning, was only 9,000 feet per second. The Bumper-Wac's payload weight was very close to that contemplated for VANGUARD. That we now attempt to raise the same payload to 300 miles and, in addition, impart to it the more than 25,000 feet per second of velocity necessary to insure an orbit, is a tribute to our engineering progress in rocketry and its many allied fields.

Telemetering and Propagation Problems of Placing the Earth Satellite in Its Orbit*

DANIEL G. MAZUR†, SENIOR MEMBER, IRE

Summary—**The earth satellite vehicle telemetering requirements are briefly presented. Primary problems are propagation over extended ranges utilizing light weight transmitters, diversity of equipment needs during the testing phase, reliability, and complexity of operations. Some of the general considerations and planning are given.**

INTRODUCTION

THE ROLE that telemetering will play in the launching of an earth satellite is a challenging one. At every step of the way, telemetering will be employed as a basic tool in the achievement of a successful combination of rockets. Its duty will be to monitor the complete performance of each rocket throughout a varied testing phase and to provide, with minimum weight penalty, the essential and significant vehicle data during the actual satellite attempts. The requirements for telemetering during the test and mission phases are somewhat dissimilar. During the test portion of the program there is a need for the most complete rocket evaluation possible, while during mission, the transmission of only significant vehicle parameter data is possible. The telemetering discussed here pertains only to the vehicles since the problem of satellite package is the responsibility of another group. Because of its special nature, this project will place unusual demands on equipment for reliability and for the necessity of operating under harsh environmental conditions.

BACKGROUND

The active role of telemetering from large scale rockets began in this country in 1946. The establishment of a V-2 Upper Atmosphere Research program gave impetus to extensive development and refinement of both frequency and time division telemetering systems which had been employed during the war. The increase of rocket firings led to the need for increased accuracy, increased channel frequency response, reduction in cross-talk, better stability, better decoding methods, and gradually the extensive use of subminiaturization techniques. Improvements in components and vacuum tubes were seized on eagerly to solve the ever-growing problem of providing more channels in less space.

STATE OF THE ART

Today it is not unusual to have for a requirement the telemetering of hundreds of pieces of information from rockets fired to altitudes in excess of 150 miles. Frequently these pieces of data are required to accuracy unknowns of one or two per cent and the frequency response desired may vary from dc to several thousand cycles per second. In addition, the satisfactory operation of telemetering during the major portion of flight is considered essential. Although these are the present day requirements this is not to say that they are always met; however, most of them are well within the state of the art. For example, of historical interest is the firing of a single stage Viking rocket in May, 1954 to an altitude of 158 miles. This rocket was completely instrumented with telemetering equipment and signals were successfully transmitted and recorded throughout the flight.

REQUIREMENTS

With this background in mind, the problems of telemetering the launching vehicle performance can be examined. The ultimate requirements are set by the trajectory of the vehicle and the geographic location of the launching site. As described by others, the launching vehicle will be a three-stage rocket combination in which the second stage will coast up to an altitude of approximately 300 miles where the satellite carrying stage will be fired. The launching will take place at the Air Force Missile Test Center, Cocoa, Florida. This firing range is comprised of the launching point, Cape Canaveral, and a chain of island stations extending from the Bahama Islands to beyond Puerto Rico.[1] Safety limitations will preclude flying the rocket directly over these islands and, therefore, the slant range between the rocket transmitting equipment and closest ground receiving points will be well in excess of 300 miles during certain phases of the trajectory.

Since the test program will consist of firing varied combinations of first and successive stages, diverse needs exist for channel capacity, frequency response, accuracy, and form factor. Each new propulsion unit will require extensive measurement both as to its performance and as to the vibrations set up. Gyro operation data and stage ignition and shut-down characteristics are desired with as high accuracy as possible, that is to say, at least one per cent. As the progressive stages of the vehicle diminish in size, so does the space that is allocated for telemetering. With the advent of the first satellite attempt, an abrupt transition must take place in the equipment provided as the emphasis is suddenly shifted to providing the barest essential operational information using one or two light weight transmitters.

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* Presented at the IRE National Convention, New York, N. Y., March 20, 1956. To appear in the 1956 IRE CONVENTION RECORD, Part I.

† Naval Research Laboratory, Washington, D. C.

[1] M. S. Friedland, "Guided Missile Range Instrumentation, a New Electronic Art," 1954 IRE CONVENTION RECORD, Part 5, "Aeronautical electronics and telemetry," pp. 48–57.

One must keep in mind that for every pound of weight added to each stage above the first there is a nonlinear increase in velocity penalty of the ultimate payload. Telemetering has established for itself an important place in the prelaunching ground checkout operations, whereby the performance of internal rocket systems can be analyzed using the same equipment as will be employed during actual flight. The demands for this service will increase with the ground checkout of combinations of various stages.

IMPLEMENTATION

To meet these requirements, a program embracing the use of time division and frequency division multiplexing has been planned. The equipment includes pulse position modulation, frequency modulation, and pulse width modulation commutation devices. Each of the systems, whose use is being contemplated, has seen active service in other rocket programs and has had its reliability proven under fire, so to speak. Of extreme importance in the application of any of these systems is the transmission and reliable reception of signals at long ranges. The power required in the rocket is dependent upon a number of parameters and these can be discussed briefly. The bandwidths expected are in the order of 500, 300, and 100 kilocycles. The noise figures of the various receivers contemplated are approximately 6 db. Use of insertion preamplifiers may better this figure by 2 or 3 db. Required carrier over threshold for minimum usable signal is assumed as 12 db for fm transmission and 15 db for AM transmissions. Useful recording might be expected down to one or two microvolts of input should background electrical noise not be restrictive. It is desirable to have a safety factor of at least 20 db to take care of unknown propagation losses, rocket antenna nulls, poor aspect, or tracking errors.

Under these conditions, to achieve a safety factor of 20 db or more at the anticipated ranges, one would have to use radiating powers that might be prohibitive from the point of size and weight of the equipment involved. The additional weight could seriously penalize mission performance. Therefore, to maintain adequate safety factors at the expected ranges, it is planned to take advantage of decrease in bandwidth and improvements in ground antenna gain. The use of crystal controlled transmitters is considered a necessity in extended range operations. Their use will allow tune-up procedures to be minimized, and thus will permit some time saving in the acquisition of radiating carriers which are not detectable until the rocket rises. Multiple ground stations will be employed to afford back-up protection in case of any ground equipment malfunction. Permanent recording of data will be made in some instances on photographic film and in others on magnetic tape. Real time presentation, that is visual display on meters and pen recorders, will be available at selected locations during the flights. It is presumed that a vast amount of data will be collected from each rocket firing and, if so, the requirement for fast data reduction will be troublesome. Some data will be of the form that mere visual inspection will suffice. Other data will require normalization and will be reduced semi-automatically. Use of automatic data reduction methods will be made insofar as it is practical.

DEVELOPMENT

In an effort of this nature where time and equipment reliability play the most important roles, it is not possible to undertake extensive research to design the perfect telemetering equipment for each application. Rather one must make use of existing equipment whose reliability has been substantiated, while phasing in as many fully engineered new developments as appears prudent. The desirability of reduction in receiver bandwidths to help minimize necessary transmitting power has been cited. An example of a new equipment whose use can be significant is the development of a crystal controlled frequency modulation receiver, instituted by the Ballistic Research Laboratory, Aberdeen, Maryland and being carried out by the NEMS-Clarke Company, Silver Spring, Maryland.[2] This receiver permits use of either 500 kc or 100 kc IF amplifiers, and, the use of this 100 kc amplifier in conjunction with a pulse width modulation transmitter will permit some power saving. Frequency deviation will be reduced to an optimum value, taking in account the minimum input for reliable, accurate recording. Variation in transmitter crystal frequencies and heating effects will have to be considered so as to prevent the possibility of exceeding the pass band of the narrow IF amplifier.

It is hoped that a larger reduction in required transmitting power may be obtained by use of new ground receiving antennas, which have been developed specifically for this program by the Physical Science Laboratory, New Mexico College of Agriculture and Mechanic Arts. These consist of three element helix arrays mounted on a single ground plane. Measured gains vary from 18 to 20 db ± 0.5 db over a circularly polarized isotropic source from the low end to the high end of the standard telemetering band (216 to 235 mc). The gain of this type antenna may be compared to that of the conventional single element helix which averages 10 to 12 db over the same frequency range.[3]

The problem of rocket antennas might be touched on briefly. Since the test program requires a multiplicity of radio transmitting equipment, sincere effort must be made to keep the number of antennas to a practical minimum. Moreover, the configuration will limit to some extent what is feasible in the way of antenna design. Of primary importance will be the problems associated with aerodynamic heating, and, in some cases,

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[2] M. S. Redden, Jr., and H. W. Zancanata, "A new crystal-controlled ground station telemetering receiver," National Telemetering Conference; 1955.

[3] J. B. Wynn, Jr., "High Gain Antenna System for Multiple Operation," 1954 IRE CONVENTION RECORD, Part 5, "Aeronautical electronics and telemetry," pp. 116–122.

ionization at reduced atmospheres. In general, antennas with patterns as omnidirectional as possible will be used. Consequences of poor rocket aspect are too severe to permit antennas with patterns having deep, wide nulls. Throughout most of the flights the ground stations will view the rocket from the side and underneath.

ROUTINE SERVICES

As in most rocket programs, telemetering has routine service aspects which form an integral part of the prelaunching checkout phase in addition to its being the primary means of obtaining in-flight data. From previous experience, routines have been established for the step-by-step use of the flight telemetering equipment in each major operation of ground check-out of the rocket. For example, in a captive or static firing, propulsion performance is monitored and recorded just as it would be during the flight. This series of ground tests is culminated in a final interference check in which all electronic equipment in the rocket is operated in conjunction with its associated ground equipment. Under flight conditions total reliance is placed on telemetering inasmuch as it is often the sole means of obtaining flight performance. This leads to a rather peculiar situation where the utmost is expected of the telemetering equipment during any flight occurrence, either fortunate or unfortunate. Under unfortunate occurrences might be listed fires, explosions, and erratic rocket maneuvers. It is expected even then that the telemetering equipment will provide a routine service long enough to tell what happened and why. No one is interested in further operation once the major cause of a malfunction has been ascertained. Interestingly enough, the margin of success by which the telemetering equipment achieves this may often be only a fraction of a second, in case of an explosion. A telemetering record which lasts only a few seconds, under such conditions, but provides the complete story may be considered perfect. From a practical point of view, providing such a routine service can well become harrowing at times.

COMPLEXITY

Perhaps one of the major problems in a program of this nature is the necessity for coordination of manpower rather than of equipment. To fire a rocket, scores of people may be involved in a complicated, rigidly prescribed sequence where a new step cannot be taken until the previous one has been accomplished. To adhere to such a schedule and successfully meet a preset firing date on time sometimes requires minor miracles. To illustrate the problem solely from the telemetering point of view, one can gauge the complexity of this operation by realizing that in some vehicle combinations four transmitters will be employed. In addition, approximately twenty or so ground stations spread out literally over a thousand miles will be operated simultaneously and must provide dual or overlapping coverage with each an important link in the chain.

SUPPORT

To effectively prosecute such a program takes the close cooperation of many groups including the rocket manufacturer, The Glenn L. Martin Company; the firing range, the Air Force Missile Test Center; its range contractor, Pan American; and its instrumentation contractor, the RCA Service Company. This cooperation is being achieved. In addition, facilities of the Army such as the Ballistic Research Laboratory, the White Sands Proving Ground, and the Redstone Arsenal, are providing either equipment or technical background. Such Naval activities as the Bureau of Aeronautics, the Bureau of Ordnance and their field establishments are contributing in similar fashion. Many contractors are involved in the manufacture of equipment and are giving every consideration in an effort to spur a program of mutual interest. Particularly generous in this respect has been the Applied Science Corporation of Princeton.

CONCLUSION

Some of the problems and general planning in connection with telemetering of the earth satellite launching vehicles have been briefly presented. Of major importance is the propagation of signals over extended ranges, the diversity of requirements for both the test and mission phases, and the necessity for the use of reliable light-weight equipment. In treating these problems an attempt has been made to outline their general scope rather than give a detailed technical exposition. Some sidelights on the role that telemetering plays in a rocket program have been mentioned as appropriate background.

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Tracking the Earth Satellite, and Data Transmission, by Radio*

JOHN T. MENGEL†, SENIOR MEMBER, IRE

Summary—**The next round of problems created by an earth satellite after it is placed in its orbit are those associated with proving that the satellite is in fact orbiting, and the measurement of its orbit. The magnitude of these problems for optical methods is discussed, and the Minitrack system developed by the Naval Research Laboratory for acquisition and tracking of the satellite by radio techniques is described. A sub-miniature radio transmitter operating continuously for at least two weeks will be provided within the satellite to illuminate antennas at ground tracking stations. By phase-comparison techniques, these ground stations will measure the angular position of the satellite as it passes through the antenna beam, recording its "signature" automatically without the need for initial tracking information. Analysis of this signature will provide the complete angular history of the satellite passage in the form of direction cosines and time. These data will be transmitted immediately to a central computing facility for the computation and publication of ephemerides. Specific ephemerides will be transmitted to each principal optical tracking station to provide acquisition data to them. The probable tracking accuracies and the major problems associated with the Minitrack System are described.**

THE FINAL realization of man's efforts to place a satellite in an orbit about the earth will immediately pose a new series of problems: how to prove that the satellite is in fact orbiting; how to determine the precise orbit that it is following; and how to measure what is happening within the satellite from the vantage point of a ground station.

The immensity of the first of these problems, how to prove that the satellite is in fact orbiting—the acquisition phase—can be realized by considering an analogy to the satellite. Let a jet plane pass overhead at 60,000 feet at the speed of sound, let the pilot eject a golf ball, and now let the plane vanish. The apparent size and speed of this golf ball will closely approximate the size and speed of a satellite 3 feet in diameter, at a height of 300 miles. In the case of an actual satellite, the initial launching information such as time of launch, direction of launch, and first and second stage tracking data, could localize the time of arrival of such a sphere over any given ground location to within six minutes and its position to within several hundred miles, during the initial orbit. The acquisition problem is to locate the object under these conditions, and the tracking problem is to measure its angular position and angular rate with sufficient accuracy to alert nonacquiring tracking stations as to the time and position of expected passage of the object.

The solution to these two problems is met in the Minitrack System of radio angle tracking developed by the Naval Research Laboratory. This system utilizes an oscillator of minimum size and weight within the satellite to illuminate pairs of antennas at a ground station which measures the angular positions of the satellite using phase-comparison techniques. Employing radio methods, it is independent of essentially all weather conditions, visibility conditions, and time of day, so that operation is assured whenever the satellite is within the ground station antenna beam. An operating frequency in the vhf band permits good efficiency with minimum weight components in the satellite, while at the same time providing reasonable antenna beam widths at the ground station with large collecting areas.

Let us look initially at radio-phase-comparison techniques. These work on the interferometer principle, whereby the path length from a signal source to one receiving antenna is compared with the path length from this same source to a second receiving antenna. Referring to Fig. 1, let S be the signal source, and A_1 and A_2 the two receiving antennas a distance of A_1A_2 apart. Baseline A_1A_2 is actually n wavelengths or $360n$ radio phase degrees long at the radio frequency being used. The signal from S arrives at antenna A_1 at the same time it arrives at point P on the way to antenna A_2, and thus arrives at antenna A_2 a time later dependent on the time it takes a radio signal to traverse distance PA_1. If the phase of the radio signal arriving at antenna A_1 is compared to the phase of the radio signal arriving at antenna A_2, the phase difference measured will be a

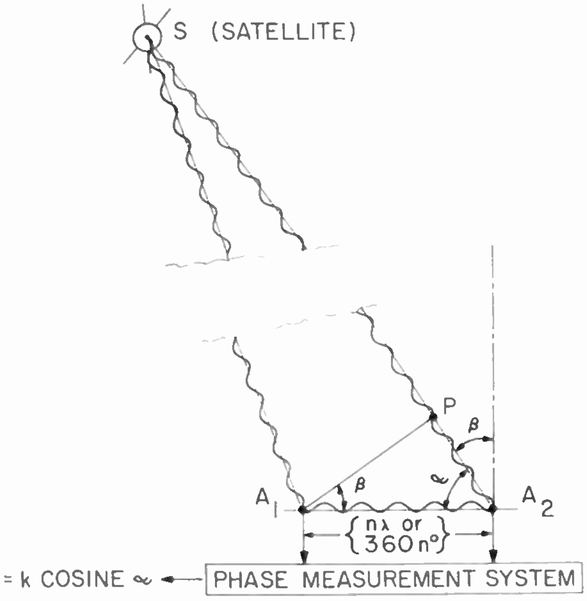

Fig. 1.—Phase-comparison technique.

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* Presented at the IRE National Convention, New York, N. Y., March 20, 1956. To appear in the 1956 IRE CONVENTION RECORD, Part I.

† Naval Research Laboratory, Washington 25, D. C.

direct measure of radio path PA_2. Further, radio path PA_2 and radio path length A_1A_2 are related as follows, for a radio source at a great distance compared to radio path length A_1A_2:

$$PA_2 = A_1A_2 \sin \beta.$$

Thus, a measurement of the phase difference in the two radio path lengths is actually a measurement of the sine of the angle between the radio path and the antenna baseline. In more common usage, this phase difference is a measure of the cosine of the angle between the radio path and the normal to the antenna baseline, and hence measures one of the direction cosines of the signal source.

By the addition of another set of antennas, as shown on Fig. 2, orthogonal to the original set, two direction cosines are measured, giving the complete angular position determination of the source.

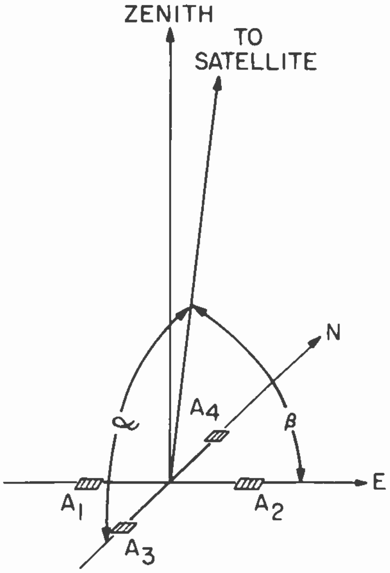

Fig. 2—Two axis system.

In this system the direction cosine is measured to an accuracy dependent on the capability of the phase-measuring components to resolve small phase differences, as well as on the length of the baseline between the pair of antennas. In this sense, the baseline length is analogous to the diameter of the aperture in a normal antenna system, except that a normal antenna system has a beam width that is inversely proportional to the size of the aperture. In the phase-comparison system, the two antennas in a pair can be any size or beamwidth, provided they are identical in phase contour across the antenna pattern.

Unlike the normal antenna, however, a phase-comparison system is ambiguous in the angle it measures, because the phase angle repeats itself every 360°. Thus, if the phase comparison circuit measures the phase difference as 95°, it could actually be 95°, 455°, or $360n° + 95°$, each of which corresponds to a different space angle. Resolution of these ambiguities is accomplished by using more than one pair of antennas to measure each direction cosine of the source. For example, as shown on Fig. 3, if antennas A_1 and A_2 operate as a pair for fine angle information, they would produce an ambiguous angle at points S_1, S_2, S_3, S_4, S_5, etc. If now antenna A_3 is added to operate as a pair with A_1, with a baseline length equal to one fifth of baseline A_1A_2, then this pair will provide ambiguous angles only at point S_5, S_{10}, etc. If the beamwidth of the antennas used is restricted to angles less than that corresponding to S_5, then these two antenna pairs will provide nonambiguous direction cosine information over the total antenna beamwidth. In a similar manner, additional antenna pairs could be used to eliminate ambiguities if a wider antenna beam pattern is used.

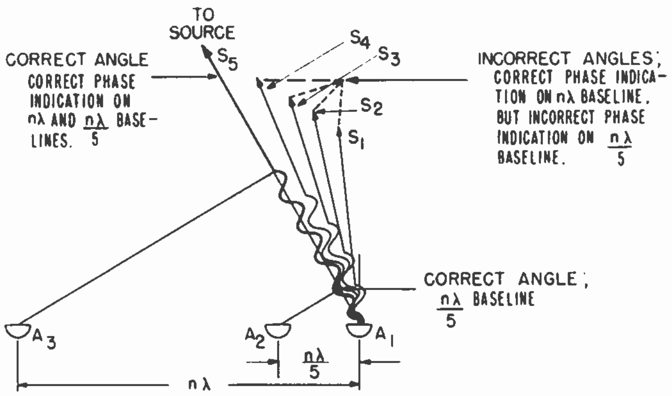

Fig. 3—Three-antenna ambiguity resolution.

In the Minitrack system, an operating frequency of 108 mc is used. In order to provide the maximum coverage for acquiring the satellite in its passage, a fan beam is required for the ground antenna pattern, with its major axis in the north-south direction. Using a ground antenna array of approximately 5 feet by 50 feet ($\frac{1}{2}$ wavelength by $2\frac{1}{2}$ wavelengths), a fan beam approximately 90°×12° is obtained, with a gain of about 40 (16 db) above isotropic. This pattern will provide a north-south coverage of about 600 miles per station for a satellite at an altitude of 300 miles, and about 60 miles in the east-west direction.

An actual Minitrack ground station layout will include seven of these antennas in the form of a cross, Fig. 4. Antennas A_1 and A_2 will provide fine angle measurement in the east-west direction, with antennas A_3 and A_1 providing ambiguity resolution out to ±10°, compared to the ±6° east-west beamwidth. In the north-south direction, with a ±45° beamwidth, four antennas are used, $A_4 - A_5$ for fine measurement, $A_4 - A_6$ for medium ambiguity resolution to ±10°, and $A_6 - A_7$ for coarse ambiguity resolution to ±60°. Baselines $A_1 - A_2$ and $A_4 - A_5$ (the fine baselines) are 500 feet, baselines A_1A_3 and $A_4 - A_6$ (the medium baselines) are 50 feet, and $A_6 - A_7$, the coarse baseline, is 7.5 feet.

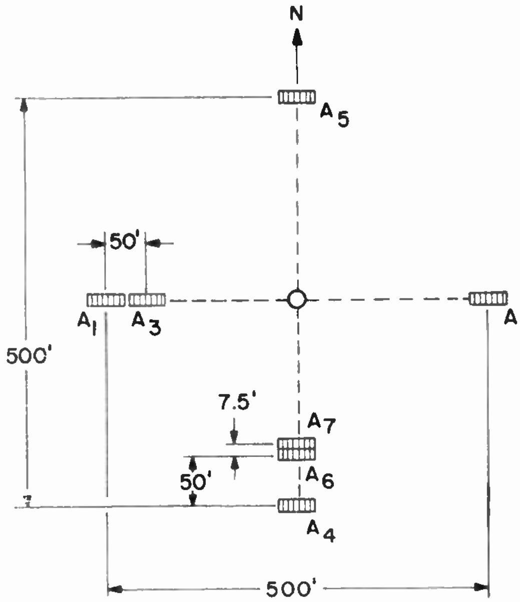

Fig. 4—Minitrack station antenna layout.

The system analysis for the Minitrack angle tracking system is based on the parameters indicated in Table I.

TABLE I

F: operating frequency: operating wavelength	108.00 mc 10 feet 3.05 meters
G_r: Ground antenna gain (based on a 90°×12° beamwidth at the 6 db points, above isotropic)	40
G_t: Satellite antenna gain (based on a planar turnstile array of 4λ/4 elements, above isotropic)	0.5
R: Maximum range required	1500 miles 8.5×10^6 feet
B: Predetection bandwidth	10,000 cps
B_d: Postdetection bandwidth	5 cps

The ratio of received signal power to the transmitted signal power is

$$\frac{P_r}{P_t} = \frac{G_t G_r \lambda^2}{(4\pi R)^2} = 1.75.10^{-13}.$$

The received power level needed is based on an analysis by J. J. Freeman of this Laboratory of phase-comparison detector systems. According to his analysis for the ratio of predetection and postdetection bandwidths given, a received power level of 3.10^{-16} watts is required. On this basis, a transmitter power of

$$\frac{3.10^{-16}}{1.75.10^{-13}},$$

or approximately 2 milliwatts is required in the satellite for a 30 db postdetection signal-to-noise ratio.

The Minitrack transmitter within the satellite will be a simple, minimum weight oscillator with a power output at 108.0 megacycles of between 10 and 50 milliwatts. Two developments for this application are currently being conducted, one using subminiature low-filament drain vacuum tubes and the other using transistors. These two developments will be brought to completion for comparison tests, at which time the type most suitable for actual satellite use will be chosen. Both units will use crystal control for frequency stability and will have a minimum operating life of 350 hours, or slightly over two weeks. The transistor unit will provide the lighter and smaller package, an estimated two pounds complete, including antenna, antenna phasing system, oscillator, and batteries for 20 milliwatts output, although at the possible expense of an additional temperature requirement. In addition, the problem of statistical evaluation of the transistor unit cannot be done so completely as for the case of subminiature tubes, because of the few units that have as yet been produced for operation at these frequencies. The subminiature tube development, on the other hand, can be made today to a weight of three pounds complete, including antenna, antenna phasing system, oscillator, and batteries, for between 15 and 20 milliwatts output. Reliability and general utility of this unit is very high, although at the cost of a considerable increase in size and weight over the transistor unit.

Battery power for the Minitrack transmitter may be of several types, depending on the outcome of comparison environmental tests. Because of the vacuum ambient in which the satellite moves, all batteries will probably require pressurization. Of the common battery types that are being considered, the zinc-silver-oxide cell, the zinc-mercury cell, and the indium-mercuric-oxide cell appear to be able to meet the satellite requirements for temperatures, pressurization, weight and size. Of the nonstandard types, the so-called solar cells appear to hold some interest but are to be considered only after intensive tests to determine their reliability under the severe surface conditions to be met by the satellite. Samples of these units may be flown in the initial satellites on dummy loads, to measure their capabilities.

The method of phase-comparison being used in the Minitrack system for angle measurement is shown in Fig. 5, for a single antenna pair. It should be remembered that the complete Minitrack station will include seven antennas, including five complete antenna pairs, requiring five phase comparison units similar to the one shown here.

In the phase-comparison system, a prime objective is to minimize differential phase-shift errors introduced by the system. For this reason separate amplification of the signals from the two antennas is kept to a minimum and then is accomplished only in low gain, wide-bandwidth stabilized amplifiers. The main system amplification is accomplished in a single combined amplifier which amplifies both signals simultaneously with a bandwidth that is large compared to the frequency difference between the signals being amplified.

Referring to Fig. 5, the two antennas feed preamplifiers at the antenna mount. These preamplifiers are required to increase the received signal level sufficiently to be fed over nearly 300 feet of air-filled coaxial line to the Minitrack trailer. These preamps utilize two GL-6299 planar triode stages to give a noise figure of 2.5 db, a gain of 23 db, and an over-all bandwidth of 16 mc.

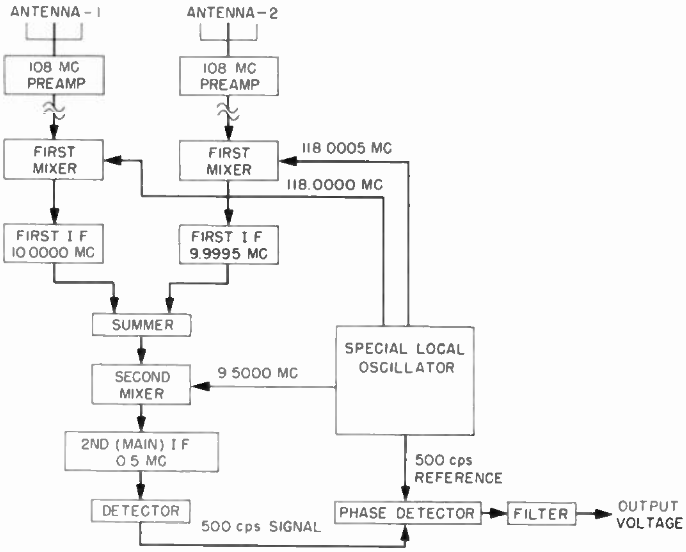

Fig. 5—Basic Minitrack comparison system.

The differential phase shift between pairs of these amplifiers is less than a fraction of a degree. At the Minitrack trailer, the signals from the two preamplifiers are fed to the first mixers, which utilize two outputs from a special local oscillator unit to convert the two antenna signals into two first IF signals separated in frequency by 500 cycles. This is accomplished by phase-locking the output frequencies of 118.000 mc and 118.0005 mc from the special local oscillator unit 500 cycles apart. After this mixer, the two IF signals at 10.000 mc and 9.9995 mc are combined in a simple adding circuit, and amplified in a low gain 10 mc IF amplifier stage. The combined signal is then converted a second time to a combined 0.5000 mc and 0.4995 mc signal in a second mixer stage, after which it is amplified in the primary amplifier of the system, a 0.5 mc IF amplifier with high gain and agc, which is specifically designed to introduce the least possible amount of differential phase error. This amplifier has a bandwidth of 10 kc, and determines the predetection bandwidth of the system. The combined output of this amplifier feeds a square law detector, which reconstitutes a 500 cycle signal. The phase difference between this signal and the 500 cycle difference frequency signal from the special local oscillator unit is identical to the phase difference that existed between the two signals received at the two antennas initially.

Phase-comparison is accomplished between the 500 cycle signal from this diode detector after filtering and the 500 cycle reference frequency from the special local oscillator unit. Several methods for accomplishing this phase comparison have been used: direct comparison to give an analog voltage output whose amplitude is directly proportional to the phase; digital comparison whereby a pulse whose length is proportional to the phase is used to gate an oscillator output, thereby providing a series of pulses whose number is proportional to the phase; or a servo comparison whereby an angle resolver is inserted in the reference channel prior to feeding a null phase detector, the output of which controls a servo amplifier so as to rotate the resolver to maintain a zero phase difference into the null phase detector. The position of the resolver shaft in this latter case is proportional to the phase, and can be read off by any of a number of analog or digital readout units. In the Minitrack system, two of these methods will be used—the direct comparison method for backup data on all channels and for primary direct writing data on the ambiguity resolving channels, and the digital comparison method for primary presentation of the fine channels. The digital output will be read 100 times a second for photo-recording backup of the fine data, and 10 times a second for direct-writing recording for the primary record of the fine data. Timing will be accomplished from a Western Electric 0-76A/U rf oscillator and associated count-down circuits referenced to radio station WWV with an accuracy of approximately 1 millisecond.

Primary data presentation will thus be by three direct writing records of the analog, voltage of the ambiguity resolving antenna phases, and two direct writing records in digital form of the fine antenna phases, all as a function of time. Visual comparison with the ambiguity resolving channel records should suffice to provide ambiguity-free data from the fine channels. In actual operations, bore-sighting techniques will be used to determine the phase in the east-west fine antenna pair corresponding to a space angle of 4° to the west of zenith, the zenith, and 4° to the east of zenith. These phases will be utilized as reference points and the actual phase pattern of the satellite passage transcribed from the digital record to an actual plot vs time for both the east-west angle and the north-south angle. The time of passage in the east-west direction over the reference points for the $-4°$, $0°$, and $+4°$ zenith angles will be read, as well as the north-south angles corresponding to these times. These six pieces of data, the times of crossing the $-4°$, $0°$, and $+4°$ zenith angles, and the north-south angles that were measured at these times, will be sent to a central computing facility within 20 minutes of a tracking event, to be used in determining the orbit of the satellite.

The central computing facility will receive data in this form from as many as nine of these ground stations. These stations may each receive as many as four readings per day from the satellite, with two being a probable minimum. An orbital determination sufficient for course direction of an optical tracking station can be obtained from six such readings, and subsequent readings will improve the calculations further. In the course of a two week period it is felt that an orbital determination will be possible to an accuracy suitable for geodetic use in determining the shape and size of the earth to a better value than presently available.

With regard to the computing facility that will be established for processing the tracking data from the Minitrack stations, complete ephemerides will provide tracking angle and time information for the principal locations at which optical tracking stations are located, to permit the tracking equipment to acquire the satellite, as well as for most of the major cities from which the satellite could be visible. It is not too unrealistic to predict that during a satellite event the evening newspapers will publish on their front pages three boxes, one for the baseball scores, one for the horse race results, and one for the evening time and angles at which the satellite can be picked up!

Two major problems face us with respect to the use of the Minitrack system as a precision angle tracking system. The first is the determination and application of a simple method of calibration of the system in terms of actual space angle referred to the zenith. The second is the determination of the effect of the ionosphere on a system of this type, which must transmit through virtually the complete depth of the ionosphere.

With respect to the first of these problems, the calibration of the system, tests using airplanes, tethered balloons, free balloons, and helicopters are now being conducted. This problem involves not only the matter of placing a test transmitter at a particular point in space by one of the methods just suggested and the measurement of its position precisely with an optical theodolite or other radio tracking equipment, but also the determination of the phase-center and the far-field phase contour of the ground antenna arrays. This application of multi-element arrays as components of a phase comparison system may be the first application on such arrays other than for radio astronomy which include the requirement for the control of the phase contours of the array. Because the size of the array precludes normal pattern measurements on antenna test ranges, tests for this property of the antenna must be done by measuring the phase, amplitude, and spacing of the individual elements.

The second problem, that of the effect of the ionosphere, is considered the most serious. The ionosphere will be the ultimate limitation on the accuracy of the angle measurements made by the Minitrack system, and its effect can be reduced only by increasing the operating frequency. Unfortunately this cannot be done at this stage of the program, although steps are being taken to do just this at later stages. The operating frequency of 108.00 mc was chosen on the basis of satellite weight and adequate ground antenna beam width, and as such is fixed. During the IGY, the sun spot activity cycle is at or near maximum, so that ionosphere activity will also be a maximum. Electron densities as high as 3 million electrons per cc are to be expected during daytime operations, which will cause an apparent shift in the angular position of the satellite at a 45° zenith angle of about 4.0 milliradians of space angle. Assuming that the ionosphere is predictable to at least ±25 per cent, this angular error should reduce to 1.0 milliradian which, at the present time, is considered to be a fairly good estimate of the system accuracy for large zenith angles. Transit time errors will be smaller than the apparent size indicated from these errors, because the maximum angle possible in the east-west direction is only about 6°. For small zenith angles, or night-time operation, system accuracy should approach, or exceed, 0.1 milliradian of space angle. This corresponds to 20 seconds of arc. Investigations of the exact magnitude of the ionosphere errors, based both on the predictable and the variable factors of the ionosphere, is being undertaken by using the Minitrack system in conjunction with rocket flights that will approach or exceed 200 mile altitudes. These measurements will be started in May of this year and will continue during the Vanguard Test Vehicle Program.

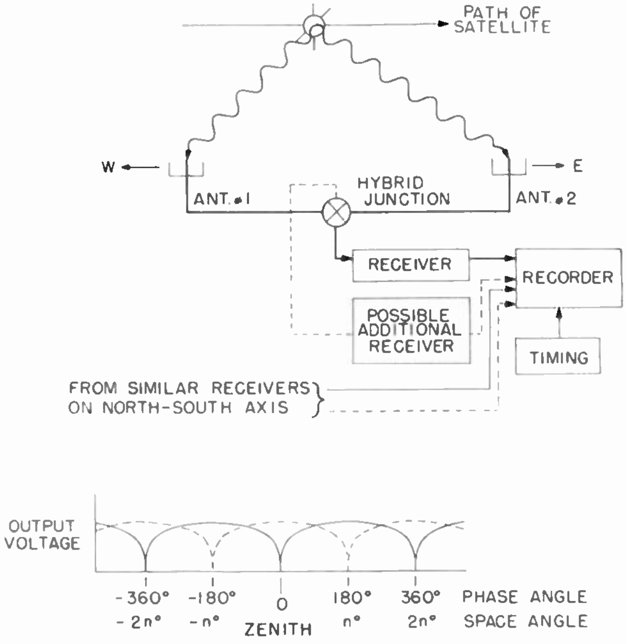

Fig. 6—Mark II Minitrack system.

A second version of the Minitrack system, called the "Mark II Minitrack" system has also been developed for use primarily in obtaining additional times of transit at locations other than the prime Minitrack sites, (Fig. 6). Radio amateurs will be encouraged to establish such stations. This system would use only four antennas, eliminating ambiguity resolving antennas, and would utilize hybrid junctions to compare the phrase relationship between the signals received at each antenna of a pair. Standard AM techniques rather than phase comparison techniques would be used to amplify the signal to a recording level. The system operation would use the fact that the satellite is moving across the antenna field, thereby causing the path length difference in the two radio paths to scan in multiples of a wavelength, causing a null in the output of the hybrid at every multiple. Precise angle measurements are thus made at each null. This system will be proposed in detail at a later date.

Data transmission from the satellite (telemetering) will be accomplished by utilizing the Minitrack rf links. To provide telemetering only when the satellite is over a ground recording station in order to minimize battery requirements within the satellite, a method of ground command turn-on is required. This is accomplished by means of a ground transmitter that will be energized as the satellite approaches a ground station site. Upon reception of this signal on a miniature super-heterodyne receiver within the satellite, the scientific experiments will be energized, a telemetering premodulator, or coder, will be energized, and the Minitrack antenna will be switched from the low power Minitrack oscillator to a $\frac{1}{2}$ watt transmitter modulated up to 60 per cent by the telemetering signal from the coder.

Fig. 7 shows a block diagram of the complete Minitrack installation within the satellite to provide for satellite acquisition, satellite tracking and transmission of data from the satellite. The receiver for the command-turn-on signal consists of a crystal mixer to combine the continuously running low power Minitrack oscillator signal and any signals received in the antenna, plus an IF amplifier-detector unit feeding a tuned audio amplifier-relay circuit. Activation of this relay circuit applies battery voltage to the scientific instrumentation circuitry, the telemetering premodulator, and the modulated telemetry transmitter, and at the same time removes the low power Minitrack oscillator from the antenna and connects the modulated telemetry transmitter to the antenna. A time delay unit in the relay circuit holds the relay on for a fixed period, probably of about 30 seconds, after which the relay opens, the three circuits are de-energized, and the low power Minitrack oscillator is reconneced to the antenna. In this package, the low power Minitrack oscillator and the command turn-on receiver operate continuously for a period of two weeks, while the other three circuits have power capacity for about two turn-ons per orbit, of about 30 seconds each, or about 3.5 hours total.

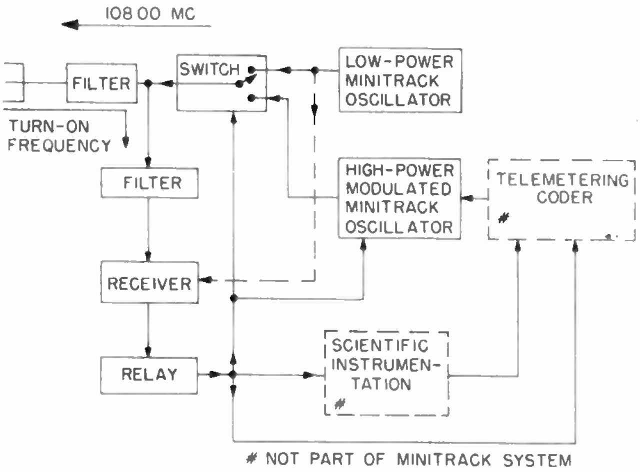

Fig. 7—Block diagram of Minitrack satellite components.

I have described a radio system for the acquisition and tracking of an earth satellite that should be independent of weather, cloud, seeing conditions, or of the time of day. As to whether or not it is, let us wait for the third box on your evening newspaper under the banner headline "First Earth Satellite In Orbit."

A Research Program Based on the Optical Tracking of Artificial Earth Satellites[*]

F. L. WHIPPLE[†] AND J. A. HYNEK[†]

Summary—The tracking of artificial earth satellites is here viewed as an integrated research program. The physical and orbital specifications of the first U. S. satellites are assumed in the tracking program planned under an assignment made to the Smithsonian Astrophysical Observatory by the IGY Satellite Committee of the National Academy of Sciences. The optical program involves early acquisition tracking by (radio or) visual means, frequent orbit calculations, ephemeris predictions for the precise photographic tracking, the establishment and operation of 12 to 15 precision photographic stations over the earth, operation of a communication net, and both current and final analysis of the positional data for important geophysical results. Such results include density determinations in the high atmosphere, geodetic system calibrations over the earth, shape of the geoid, isostasy investigations, and other geodetic studies to a precision an order of magnitude greater than presently possible.

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On July 29, 1955, the President announced that the United States would launch a small instrumented earth-circling satellite as part of our effort for the International Geophysical Year. This program was developed by the United States National Committee for the International Geophysical Year of the National Academy of Sciences, and it was submitted to the Government by the Academy in the Spring of 1955, through the National Science Foundation. The United States National Committee recognized that construction, logistics, and technical assistance could be provided only by the Department of Defense, with its extensive rocket research experience. In response to the President's endorsement of the program, the Department of Defense has begun procuring equipment under Project VANGUARD of the Naval Research Laboratory.

The Artificial Satellite Program opens a new era in scientific research. The first satellite is expected to have a spherical shape, 20 inches in diameter, and to travel in an orbit inclined at less than 40° to the equator, having a perigee altitude of some 200 miles and an apogee altitude of about 800 miles. The consequent period of revolution will be 90 to 100 minutes.

The Smithsonian Astrophysical Observatory has been assigned the task of planning the program for optical observation of the satellite and of analyzing the optical data. This program is now being organized; its general outline and the principal problems to be solved are described here. The techniques as planned, however, should not be regarded as the only possible methods or necessarily the best; but rather as those apparently most feasible when we consider the probable physical characteristics of the satellites and their orbits, along with the real budgetary and operational problems. We are indebted to L. Spitzer, Jr. who helped in the early planning of the general program.

Problems and Goals of Satellite Tracking

The success of artificial earth satellites as scientific vehicles will depend largely on the ease and accuracy with which they can be tracked. Various research goals demand different orders of orbital accuracy. Acquisition for recording by telemeter requires that we be able to predict the orbit with only a low order of accuracy, of several degrees in position and a number of seconds in time. For geodetic purposes, on the other hand, we must be able to deduce a final instantaneous orbit to within seconds of arc, and a few thousandths of a second of time. Ephemeris predictions to obtain accurate photographs should be exact to a degree or two and to a very few seconds of time.

The first of these problems, rough ephemerides to locate the satellite on its successive orbital returns, can best be solved by receiving radio signals originating in the satellite, the NRL Minitrack system. If the radio equipment fails, however, visual observation through wide-angle optical aids of low power will be an indispensable alternative. Ordinary binoculars or wide-angle, elbow-type prism monoculars will be the most useful in meeting this problem. According to plan, several visual observing stations should be located in the United States and, we hope, in other countries as well, with a corps of experienced visual observers at each station. Each person would be assigned to an instrument fixed in position, probably along the meridian, and would be responsible for observing only a relatively small section of the meridianal sky. Passage of the satellite through the field of one, or possibly two, of the binoculars could be timed by stop-watch methods or by the auditory reception of radio time signals to an accuracy of a second of time, or perhaps somewhat greater.

Plans are well advanced to organize a number of such groups throughout the country under the direction of a National Committee of Visual Observers, whose members will be responsible in their respective geographical areas for the screening of observers and observations. The computing center will accept only the observations screened and codified by these appointed observers. Radio amateur relays and telephone, telegraph, and cable services will probably all be required for communication.

The visual observing corps will be extremely useful, and indeed essential, in both the early and late stages of the existence of each satellite. In the early stages they could substitute for the minitrack system if, for any reason, this radio device should fail to operate, and they will be invaluable during the last several revolutions of the satellite just prior to its disintegration as it spirals into the denser atmosphere. In these last stages the radio-signals system is not expected to operate because of short battery life, and the data obtained by visual observers will be our only source of information about the satellite in an orbit with rapidly changing elements. In the last few revolutions of the satellite, the orbital changes are expected to be so great that the more elaborate and precise observational techniques cannot be depended upon.

The rate of spiralling produced by the atmospheric drag provides an extremely sensitive measure of atmospheric density (and pressure) as a function of height. The sensitivity exceeds 10^{-16} grams per centimeter^3 (10^{-13} atmos). The measurements apply at altitudes perhaps 30 to 60 miles above the initial perigee distance down to the present level of rocket measures for upper-atmospheric density. Temperature determinations would be linearly related to known or assumed values of the atmospheric mean molecular weight.

Precise photographic measurements of the satellite's position made during favorable twilight passages will lead to geodetic positions in three dimensions with respect to the center of the earth, to an accuracy of the order of 30 to 50 feet. A net of highly precise points at 12 to 15 sites on the earth's surface will establish the shape of the earth to a precision about an order of magnitude greater than that attainable at present, will interlace the continental geodetic systems with a correspondingly increased accuracy, and reduce the errors of present systems. Furthermore, the motions observed will greatly increase our knowledge of the distribution of mass within the earth, thus illuminating problems of isostasy, of density of material near the surface of the earth, and of geophysical data concerning the earth's solid body.

PRECISE OPTICAL TRACKING

By precise optical tracking we shall mean here observing the satellite with optical instruments of relatively high precision, the observations being recorded photographically or photoelectrically. The goal of such optical tracking is to obtain with comparable accuracy the *position* on the celestial sphere (during evening and morning twilight periods) and the *time* the position is occupied. The apparent angular rate of the object, and the accuracy to which time can be measured in the field, control the positional accuracy obtainable. Table I gives the apparent angular motion of an object moving 4.79 miles per second normal to the line of sight at various distances from the observer.

TABLE I

APPARENT ANGULAR MOTION OF SATELLITE

Distance (miles)	Time					
	1.0 s	0.1 s	0.03 s	0.01 s	0.003 s	0.001 s
200	1.37°	8.2′	148″	49.4″	14.8″	4.9″
300	0.91	5.5	99	32.9	9.9	3.3
400	0.69	4.1	74	24.7	7.4	2.5
500	0.55	3.3	59	19.8	5.9	2.0
600	0.46	2.7	49	16.5	4.9	1.6
800	0.34	2.1	37	12.4	3.7	1.2

One second of arc normal to the line of sight corresponds to the following number of feet at the distances listed:

Distance (miles)	200	300	400	500	600	800
1″ (in feet)	5.12	7.68	10.24	12.80	15.36	20.48

The satellite will thus move at apparent angular rates of approximately 1,000 to 5,000 seconds of arc per second of time. Since time can be measured, in practice, to the order of 1 millisecond, the use of a precision crystal clock implies a possible accuracy of 1 to 5 seconds of arc along the path of the satellite.

It is customary in typical astronomical problems to use instruments of long focal length and consequently of large scale, but it is obvious that the customary methods of obtaining positions of astronomical objects on the celestial sphere, with the accuracy expected of astronomical observations, cannot be applied to the satellite problem. The satellite imposes unique conditions: it will cross the United States in about ten minutes, and because of its relatively low altitude it will be within good observing range at any one location for only one or two minutes. To illustrate, the Yerkes 40-inch refractor, famed for its accurate stellar parallax measurements to less than a few hundredths of a second of arc, is rendered totally useless in this problem since the satellite would have a linear speed in the focal plane of this instrument of the order of one foot per second. Short focal lengths are therefore called for; yet the focal length must suffice to render one second of arc, which may be adopted as an ideal accuracy goal in this problem, equivalent to a few microns in the focal plane. A focal length of two or three feet satisfies these conditions, with one second of arc extending over about 3 microns in the focal plane, a measurable distance on film. The satellite, at minimum distance and maximum rate, will move at about 1 centimeter per second in the focal plane.

In designing equipment for satellite observation, it must be kept in mind that as the art progresses and the scientific needs of the Satellite Program change, the size and nature of the vehicles launched may also change. It would be short-sighted to design an observing program for one specific type of satellite, not only because IGY satellites may differ one from another as the program progresses, but because other agencies and other countries may put similar, yet different, vehicles into orbits around the earth at various altitudes and inclinations to the equator.

POSSIBLE PHOTOGRAPHIC TECHNIQUES FOR OBSERVING A SATELLITE

Calculations show that at a zenithal distance of about 200 miles in twilight a 20-inch sphere with albedo 0.6 would have a photographic magnitude of 6.3 and a visual magnitude of 5.7. A similar 30-inch sphere would be of photographic magnitude 5.4 and visual magnitude 4.9. The Baker Super-Schmidt meteor camera of aperture 12 inches, focal length 8.0 inches and effective focal ratio of f/0.85 will, with ordinary fast emulsions, reach 6.3 photographic magnitude with an image trailed at 1 degree per second. At 200 miles zenithal altitude the angular speed of a satellite would be 1.3 degree per second. These are practical working limits determined in the field.

The speeds of photographic emulsions are now being greatly increased. Recent emulsions on the market are several times faster than those of a few years ago and the manufacturers indicate that we may expect further increases in speed. There has also been considerable improvement in developers to bring up sensitivity near the toe of the photographic characteristic curve.

It is important to note the effect of distance on the photographic limit for a body moving with a constant linear speed. The sensitivity of a fixed camera falls off proportionally only to the inverse distance, not to the inverse distance squared. Hence the loss in magnitude by an increase in distance from 200 miles up to 1,300 miles is effectively only two magnitudes, not four.

As an alternative to the photographic technique there are also the image converter and image-tube techniques. These both promise speeds of the order of 50 times those of fast emulsions. On the other hand, the image tubes are not particularly well adapted to the

Schmidt-type cameras anticipated, because image-tube surfaces are normally flat instead of spherical, and because the surface areas are small. The relatively great expense and the time required for engineering development to meet the specific problems at hand are additional difficulties which, with the lower positional accuracy obtainable at present by electron optics, make it essentially mandatory that primary emphasis at the moment be placed on photographic methods. It is clear, however, that electron optics methods show great promise and we have therefore instituted research in the present program to develop these techniques for adaptation to this specific problem, preferably using the same optics as are to be employed in the photographic method.

A practical consideration applies to both photographic and photoelectric methods, whichever tracking system may be chosen; the system must be reliable, and operable by well-trained personnel who will not usually be specialists. These observers cannot be expected to use tracking systems that depend on extreme operating skill or on good luck. A number of such tracking systems that have been suggested to the authors might give excellent results in the hands of professional astronomers in large observatories. For field operation, however, they do not appear to provide practical observing routines.

It is therefore anticipated at present that a photographic Schmidt system of about 20-inch aperture and of f/1 or f/1.5 speed, of relatively simple design, will be used as the basic optics of the photographic tracking system. We are indebted to James G. Baker for critical advice in these matters. The stringent condition imposed on the tracking problem, that we can observe the satellite only during the morning and evening twilight periods, demands a rapid means of plate or film changing. In the bright twilight periods exposures longer than 2/10 of one second will cause serious fogging. To meet this problem, a camera system has been designed which uses continuous film, probably of cinemascope size (55.625 millimeters) which can be transported in discrete steps at varying rates, determined by the depth of twilight. It is planned to employ two types of shutters, synchronized with these rates: one a *gross* shutter which operates once during each film transport cycle and is open for 20 per cent of the cycle. Thus in a 1-second film transport cycle the exposure would be 0.2 second, and in the longest cycle of approximately 5 seconds, the gross shutter would allow a full second's exposure. During the time the gross shutter is open, a rotating barrel-type shutter with period of 5 per cent of the total film transport cycle will interrupt the exposure for periods of about 1/100 of a second. Such an interruption will provide time marks with a separation of the order of 100 microns in the satellite trail. The rapid shutter will be synchronized with a stroboscopic presentation of a crystal clock face which will be photographed directly onto the film strip.

In those passages in which the satellite is considerably fainter than maximum, it will be necessary to abandon the fixed-telescope system and to adopt a sytem of partial following. Continuous following, whether the satellite is bright or faint, is undesirable because the stars would be reduced to long trails with a consequent loss both of faint stars and of measurability of bright star images. Furthermore, continuous following demands more precise ephemerides than partial following. It is expected that under dark twilight conditions a star field can be photographed with the telescope fixed, then with the telescope moving, the exposures being superposed on the same film strip. Under brighter twilight conditions it may be necessary to photograph the star field and the satellite separately with appropriate fiducial and time marks on the two film strips. Whether the motion will be oscillatory or discontinuous in the forward direction is not yet decided.

A fast wide-angled Schmidt system of the type described above is desirable because it can be used in fixed position in an alt-azimuth mounting or moved in the direction of the satellite's motion. Such a system can be expected to photograph satellites as faint as the 10th magnitude, a 15-inch sphere at a distance of one thousand miles. Accuracy of position determination, however, will be sacrificed at fainter magnitudes. The optical axis of the telescope will be allowed 3 motions: two from the alt-azimuth type of mounting and a third, along the direction of the satellite's motion, from the fact that the telescope is mounted in a gimbel ring.

THE TRACKING SYSTEM

Because the nodes of a satellite orbit will move westwardly about the equator with a period of some 50 days, the latitudes at which the satellite will cross the twilight zones will oscillate through their full range, from maximum north to south and back again, with this same period. Stations near the northern and southern limits will have the greatest opportunity to observe the satellite, and equatorial stations the least, the ratio being roughly three to one. The average station will probably have an opportunity to observe the satellite during a morning or an evening twilight period approximately once a week, or somewhat more frequently. The observing stations should be located in regions of optimum sky transparency and freedom from clouds, to avoid reducing this rate below approximately one observation per week per station. The best observing conditions in terms of sky transparency are generally at latitudes approximately plus or minus 30°. Hence it will be desirable to have chains of stations located around the earth at these two latitudes, insofar as land masses and practical considerations permit, in order to search for a possible third axis of the earth. On the other hand, it is highly desirable that a *wall* of the stations be erected approximately along the seventy-fifth meridian, a meridian so important in the observational planning for the International Geophysical Year. The construction of twelve to fifteen stations is now anticipated, the number depending upon the exact cost of the stations and the manner in which they are operated. We are particularly indebted to W. A. Heiskanen for advice with regard to station location and indications of the type of geophysical data that may result from satellite observations.

Since the great-circle motion of the satellite across the sky must be predicted at each twilight crossing for each station, with an accuracy of roughly one degree and with a time precision of a few seconds, an orbit calculation and prediction center must be maintained in conjunction with the observing program. This center is planned for Cambridge, Massachusetts at the Smithsonian Astrophysical Observatory (and the Harvard College Observatory). The rapid communication of approximate photographic positions from the various stations, and ephemeris predictions to the various stations as well as to all serious observers, are planned for this computing center. The computing problem is suggested by the fact that one ephemeris position every minute represents points spaced some 300 miles apart along the trajectory of the satellite. Since fairly accurate directions from individual stations must be predicted when the satellite is within possible range, the magnitude of the simple ephemeris calculation becomes considerable.

The computing center will also be an analysis center, in which the geophysical data obtained from the satellite observations will be analyzed in detail. It is planned to carry out this analysis as soon as possible after the photographic observations are measured in order that plans for later satellites may be altered to ensure their best scientific utilization.

Much depends upon the length of time during which the satellites can remain in their orbits. With an anticipated orbit of perigee 200 miles and apogee 800 miles from the earth's surface, the best estimates of upper atmospheric densities suggest that a satellite will remain in its orbit for approximately one year. The uncertainties in the upper-atmospheric densities are the order of a factor of 5 and permit the possibility that the lifetime may amount to several years or be as short as two or three months. If, however, the perigee distance is not attained, the lifetime of a satellite will be reduced markedly. Geophysical observations requiring the highest precision of observation will not be particularly useful unless a number of observations are obtained at each station. A lifetime, therefore, of less than six months will probably not lead to results of the highest possible significance. A lifetime of several years is highly desirable, but increases the operational cost of the station by a serious factor.

The problems of the basic theory to be used in the calculations are being investigated by L. E. Cunningham, who has kindly given up his work at Berkeley for a few months to assist in the Satellite Tracking Program. Of particular importance is the effect that gravitational anomalies will have on the general motion and predictability of any satellite. Much will depend upon the extent to which these anomalies act as *noise* in orbital calculations or to the extent to which the observations will enable us to determine characteristics of the gravitational anomalies and to check the conclusions obtained by other geodetic and gravity methods. A total of from 200 to 1,000 precise observations of an artificial satellite can be used to determine simultaneously a number of geophysical quantities including coordinates of the stations, gravitational effects, isostatic factors, triaxial characteristics of the earth, interrelationship among geodetic systems, and corrections to individual geodetic systems. In addition, detailed measurements of atmospheric resistance in the spiralling satellite orbit can be analyzed to show latitudinal and seasonal effects in upper atmospheric densities, as well as to provide a mean altitude density profile, which can be connected to the highest altitudes reached in direct rocketry measures.

A host of physical, geophysical and astronomical research possibilities will be opened up by the first artificial earth satellite, and it will be only the beginning. . .

The Scientific Value of the Earth Satellite Program*

JAMES A. VAN ALLEN†

Summary—**Planning for the fullest possible scientific utilization of the initial group of U. S. satellites is proceeding actively under the supervision of the National Academy of Sciences and its appropriate Panels and Working Groups. An inert satellite, tracked from an array of ground stations, will provide a means of unprecedented precision for the determination of the geodetic figure of the earth, for the transoceanic linkage of mapping networks, and for the measurement of atmospheric density at very high altitudes. A variety of physical observations with active, on-board instrumentation has been considered. The highest "flight-priority" has been assigned to the following: a) the monitoring of the intensity of the solar ultraviolet; b) the monitoring of cosmic ray intensity and the measurement of its latitude, longitude, and altitude dependence; c) the measurement of the size spectrum and the number density of interplanetary dust; and d) the measurement of the earth's optical albedo over large areas. A concerted attack on the technical problems of successful on-board observations is being made.**

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INTRODUCTION

TO MY BEST knowledge Thomas Mann has thus far had no connection with the earth satellite program. But he has written a single sentence which summarizes it exquisitely: "What perplexes the world is the disparity between the swiftness of the spirit and the immense unwieldiness, sluggishness, inertia, permanence of matter."

Thus it is that there is nothing new about the principles of establishing artificial satellites of the earth. These have been understood for years. The element that is new is that a specific program of work is now under way to actually do the job.

Similarly, there is very little that is essentially new about the scientific value of satellites. This subject has been voluminously discussed in recent years. It must be confessed that much of this discussion has been vague, general, and even grandiose. Yet such is the nature of the early stages of human endeavor! During the past year, as the technical feasibility of producing satellites has become progressively more tangible, plans for their scientific use have become much more sharp and specific.

In January of this year our Upper Atmosphere Rocket Research Panel held its tenth anniversary meeting in Ann Arbor, Michigan. The two-day meeting was devoted exclusively to specific, detailed scientific proposals for the use of small satellites. There were 38 papers, prepared and presented by authors from universities and other research institutions throughout the United States. The proceedings of this conference will go to press in early April and will be published in book form by late summer. This compilation is recommended as a far more definitive treatment of the subject than is undertaken here.

ORGANIZATION OF THE SATELLITE PROGRAM OF THE UNITED STATES

The satellite program of the United States is a portion of our national contribution to the world wide program of scientific investigations which are planned for the International Geophysical Year 1957–1958. A counterpart satellite program has been undertaken by Russia. It is expected that there will be full exchange of information between the two countries except insofar as specific missile characteristics may be classified by the respective national authorities.

As with other aspects of our IGY work, the U.S. satellite program is under the aegis of the National Academy of Sciences. Detailed supervision has been vested in an appointed group of scientists and engineers known as the Technical Panel on the Earth Satellite Program (TPESP). The President has directed the Department of Defense to develop the necessary vehicles and to provide appropriate logistic support for the conduct of the firings. Management of these aspects of the program has been assigned to the Office of Naval Research and by it to its Naval Research Laboratory (Project VANGUARD).

Two working groups of the TPESP are now in operation: a Working Group on Internal Instrumentation and a Working Group on Tracking and Computation. These working groups are specifically concerned with scientific utilization of satellites.

TECHNICAL BOUNDARY CONDITIONS

It is very difficult to think fruitfully of performing an experiment with a satellite without having a rather clear idea of the technical boundary conditions, or limitations. Of the various limitations which might be discussed, the maximum permissible weight of the apparatus is the most important single one. From this point on I shall be as specific as possible and shall refer to the immediate IGY program only.

It is the *intention* of the VANGUARD group to provide us with a vehicle which will place a twenty-one pound object (along with the combustion bottle of the third stage) in a reasonably durable orbit.

But since cases are on record of missile systems not coming up to full expectations—at least not in their early stages—it is only prudent to plan on a variety of lesser weight payloads as well. This our Technical Panel has done.

The *price* of payload is succinctly expressed by a single number, the velocity penalty per pound of payload. Mr. Rosen estimates this number as 80 (ft/sec) per pound. In the case of many missile systems a performance less than that expected may merely reduce the capabilities of the system in a noncrucial way. But only a slender margin of performance separates the propulsion system which sends a payload two-thirds of a revolution about the earth from one which sends it for 1,000 revolutions. Thus we must be prepared to trade payload weight for final velocity, if necessary. The payload of IGY satellites may therefore be expected to lie in the range zero to twenty-one pounds. It is to be understood that *zero payload* means that only the third stage propulsion bottle is delivered into an orbit. Such a satellite will have important scientific value, as pointed out by Professor Whipple, in spite of the absence of on-board instrumentation.

The physical configuration of the payload is a matter of active discussion among persons concerned and it is not likely that any single choice of configuration will be made. It is more probable that a variety of payloads will be developed and flown during the IGY program. The three leading possibilities may be typified, though perhaps not accurately represented, by the following:

1) A rigid sphere of diameter 20 inches. Such a body would be separated from the third stage bottle after burnout. It should have good optical visibility and it is of the best shape for the accurate deduction of atmospheric density from the observed rate of loss of energy due to drag. In addition, a small active instrument might be carried.

2) A physically compact payload having the maximum content of on-board scientific apparatus, a minimum of inert structural weight, and poor to negligible optical visibility. Such a payload might or might not be separated from the third stage bottle, the decision being dependent upon thermal and antenna considerations and perhaps upon technical considerations having to do with the scientific apparatus. A payload of this type might be visualized as being a cylinder 18 inches in length and 6 inches in diameter.

3) An inflatable sphere whose inflated diameter might be some five feet. Such an object would have splendid optical visibility and would be well suited to the determination of atmospheric density. But there might be little or no weight available for active instrumentation.

On the basis of the foregoing it is evidently a mistake of oversimplification to think any one of the following: that the payload will be spherical; that the payload will weigh twenty-one pounds; that successive payloads will be identical; or indeed, that there will, with certainty, be any payload at all.

SCIENTIFIC UTILIZATION OF SATELLITES

There are two broad classes of scientific utilization of satellites. The first class contemplates an inert body only (though the inclusion of active instrumentation is in no way prejudicial, except for the additional weight involved) and a system of ground-based observing stations adequate to determine, with high precision, the elements (or parameters) of the orbit and the time rate of change of these elements. Computational interpretation of such observations should yield results of unprecedented precision on the geodetic figure of the earth, on the transoceanic linkage of mapping networks, and on the atmospheric density at very high altitudes; *e.g.*, 150 to 400 miles. It is conceivable that a single successful satellite whose lifetime was at least several weeks would yield a sufficiently great body of observations to satisfy these three objectives, though synoptic observation of atmospheric density may prove to be of interest. And it will eventually be desirable to recheck the mapping networks with orbits of different inclination. Knowledge of the air density at great altitudes is of trivial importance in the flight of "short range" missiles (*i.e.*, ones of several thousand miles range) but it is of crucial importance in determining the lifetime of artificial satellites and it has a fundamental role in understanding the physical-chemical processes in the high atmosphere. Indeed, the atmospheric density enters to the second power in the reaction rates of binary processes in the atmosphere; hence, large uncertainties in atmospheric density result in enormous uncertainties in the rates of certain chemical reactions which are of basic importance.

The second class of scientific utilization of satellites depends essentially on the inclusion of active instrumentation in the satellite and on the transmission of observed data by radio telemetering. The tangible foundation for the work of this class which will be undertaken is the work with high altitude rockets which has been done, almost exclusively by American scientists, during the past ten years. The vehicles used in this work have been successively reworked V-2's, Aerobees, Vikings, rockoons, and two-stage solid fueled rockets. A distinctive field of research and a new type of scientist have evolved. Major contributions have been made to the knowledge of upper atmospheric physics, of the primary cosmic radiation, and of the radiations from the sun. This work is being continued and advanced at a rapid rate by the efforts of a number of very able and dedicated scientists and engineers in the United States. And research workers in other countries—notably France, Australia, England, and Germany—are following our lead and are attacking a number of problems in a novel way. The International Geophysical Year should be a particularly fruitful period.

Satellites possess a number of essential advantages over conventional rockets. The altitude achieved is not in itself one of these, since it is technically far easier to fire a rocket more-or-less vertically to any specified altitude than it is to place an object in a durable orbit at that altitude. The unique scientific applications of an inert satellite have been described in previous paragraphs. The special advantages of satellites as vehicles for active instrumentation are as follows:

1) The long time duration of the flight at very high altitude makes possible the attack on phenomena which, though scientifically important, are of very low intensity or magnitude so that cumulative observation is necessary. An example is the intensity, if any, of the light nuclei, lithium, beryllium, and boron, in the primary cosmic radiation. Another example is the determination of atmospheric density by internal methods. Another is the determination of the size spectrum and number density of interplanetary dust particles.

2) The long time duration of a successful satellite flight above the absorbing layers of the atmosphere makes it possible to undertake continuous monitoring of the intensities of arriving radiations and to examine the cause-and-effect correlation of these observations with the independently observed consequences within the atmosphere and at ground stations. Important examples of such arriving radiations are the short wavelength electromagnetic radiations from the sun, the primary cosmic radiation, the primary auroral radiations, and the light from intergalactic space.

3) The widespread and rapid geographical coverage of the orbit of a satellite makes possible a variety of spatial (and temporal) surveys of geophysical conditions in the vicinity of the earth, in its atmosphere, and on its surface. The following studies exemplify this possibility: survey of the geomagnetic field, survey of the albedo (or cloud cover) of the earth, survey of the latitude, longitude, and altitude dependence of cosmic ray intensity, etc.

SPECIFIC SCIENTIFIC INSTRUMENTATION FOR THE IGY SATELLITES

• During the past few weeks, I have been serving as chairman of the Working Group on Internal Instrumentation of the U. S. Technical Panel on the Earth Satellite Program. The principal jobs of this Working Group are the review of scientific proposals, and the laying of plans concerning joint development of components and telemetering systems, layout of telemetering receiving stations, and other matters affecting the successful conduct of on-board observations.

It is, of course, desired that the observations undertaken be of the most fundamental and far-reaching nature. And, in view of the stringent technical limitations of weight, power, data storage, and transmission, etc., it is necessary that the apparatus in the satellite be quite simple in nature, mechanically and thermally rugged, and proved-in as to reliability and capability to a very high degree.

We have now sifted over a considerable number of proposals for *on-board* instrumentation and have assessed them on the following four aspects.

Scientific Importance

This aspect was taken to be measured by the extent to which the proposed observations, if successful, would contribute to the clarification and understanding of large bodies of phenomena and/or by the extent to which the proposed observations would be likely to lead to the discovery of new phenomena.

Technical Feasibility

This criterion encompassed evidence for previous successful use of the proposed technique in rockets (or otherwise), apparent adaptability of the instrumentation to the physical conditions and data transmission potentialities of presently planned satellites, nature of data to be expected, and feasibility of interpretation of observations into fundamental data.

Competence

An assessment of competence of persons and agencies making proposals was attempted. The principal foundation for such assessment was previous record of achievement in work of the general nature proposed.

Importance of a Satellite Vehicle to Proposed Work

The nature of each proposal was analyzed with respect to the questions: Is a satellite essential or very strongly desirable as a vehicle for the observing equipment proposed? Or could the observations be made nearly as well or better with balloons or conventional rockets as vehicles?

A tentative Flight Priority List, containing, as of March 9, 1956, nine types of scientific apparatus, has been established by the TPESP. Official "letters of intent" to support these developments have gone out to the six different laboratories involved. Full activation must await Congressional action on current askings.

Thus, a good first approximation to what is actually intended to be done can be had by examination of the current Flight Priority List. In this list the official project designation, the title of the investigation, the name of the principal investigator, and the name of his institution are given.

ESP-1: "A Proposal for Meterological Observations from an Earth Satellite," W. G. Stroud, Signal Corps Engineering Laboratories.

ESP-2: "Proposal for IGY Satellite Experiment to Detect Extreme Ultraviolet Solar Radiation by Photoelectric Techniques," H. E. Hinteregger, Air Force Cambridge Research Center.

ESP-4: "Proposal for the Measurement of Interplanetary Matter from the Earth Satellite," Maurice Dubin, Air Force Cambridge Research Center.

ESP-6: "Ionospheric Structure as Determined by a Minimal Artificial Satellite," Warren W. Berning, Ballistic Research Laboratories, Aberdeen Proving Ground, Md.

ESP-7: "Proposal for Measurement of Meteroic Dust Erosion of the Satellite Skin," S. F. Singer, University of Maryland.

ESP-8: "Satellite Environmental Measurements," H. E. La Gow, Naval Research Laboratory.

ESP-9: "Solar Lyman-Alpha Intensity," H. Friedman, Naval Research Laboratory.

ESP-10: "Cosmic Ray Experiment," L. H. Meredith, Naval Research Laboratory.

ESP-11: "Proposal for Cosmic Ray Observations in Earth Satellites," J. A. Van Allen, State University of Iowa.

Other proposals are arriving from time to time and it is likely that the list will be extended. The final decision as to which specific piece of apparatus is flown on a specific satellite vehicle must await the results of a variety of developments, both technical and scientific, and cannot be made sensibly until a date near the actual firing date.

* * *

Television Sweep Generation with Resonant Networks and Lines[*]

KURT SCHLESINGER[†], FELLOW, IRE

Summary—**The synthesis of a current sawtooth from a limited number of first harmonics has been studied. It was found that good linearity is easier to obtain than a fast retrace. Scan distortion may be held below 5 per cent over 80 per cent of scan, by adding only 4 harmonics in a "least square" proportion. Fast flyback, on the other hand, requires 8 harmonics to be usable for commercial television.**

Several practical systems for resonant sweep have been tested. All circuits used shock excitation of multiresonant networks by pulses of current. Both pentodes and small hydrogen thyratrons were used successfully.

The best multiresonator for synthetic sweep is a delay-line, 3 per cent shorter than a halfwave long and shorted at the far end. To minimize dispersion, a "slanting wafer" type of construction has been developed which permits control of mutual without effect on self-inductance.

INTRODUCTION

THE VOLT-AMPERE demand for magnetic television sweep increases with the first power of the ultor voltage, and with the third power of the deflection design angle.[1] As a result, reactive power for sweep has doubled at each step in the development of TV picture tubes from 54° through 72° to the modern 90° bulbs. Since the screen area was also greatly enlarged in the process, more ultor voltage had to be supplied to insure adequate light output.

As a result of this evolution, modern TV receivers use about 30 volt-amperes for horizontal sweep which is about five times more than early sets in the postwar era. In recent color receivers, deflection requires between 45 and 80 volt-amperes input to the yoke, depending on the type of color tube employed.[2,3]

To supply that amount of reactive power economically, a sweep output circuit of the "power-feedback" type has been adopted almost universally.[4] Physically speaking, this circuit belongs to the class of systems with time-varying parameters. It employs two synchronous electronic switches, the sweep pentode and diode, to change the load circuit from an LR network during trace, into an LC network during retrace.

The ac-dc conversion efficiency of this type of sweep generator is, on the average, about 67 per cent, measured in terms of reactive power delivered to the yoke $[\frac{1}{8}LI^2f]$ over power drained from the B supply.[1] This is the equivalent of an over-all circuit Q of about 4. ($Q=2\pi\times$reactive power/power lost). Only recently, a somewhat better efficiency has been achieved in an advanced deflection system for color[3] (75 sweep volt-amperes, 77 watts input, $Q=6.3$). However, the amount of power needed for sweep is still an important portion of the total power required for TV receiver operation.

It is therefore justified to investigate other possible means for the generation of high-power television sweep. Since the deflection yoke is basically a low-loss inductance[5] and since the scanning process is a periodic function, it seems feasible to establish high-field energy in the yoke by the cumulative action of resonance. To this end, the yoke should be included in a network, presenting the correct amount of capacitance at the sweep frequency and at a number of consecutive harmonics thereof. This attractive approach has found some attention in the patent literature,[6] but it does not seem to have been successfully reduced to practice. Some of the inherent difficulties become apparent from a study of the basic properties of harmonic synthesis.

MATHEMATICAL CONSIDERATIONS

To be practical, any method for TV-sweep generation has to meet certain standards of trace linearity and retrace speed.[7] In present receivers, horizontal scan distortion averages around 10 per cent, and any further reduction while desirable, seems to be difficult to achieve.[8]

As to sweep retrace, it has to be complete within the line-blanking interval, for which NTSC color standards specify 16.5 per cent of the line period.[9] With due allowance for delay in synchronization, a retrace percentage of 15 per cent is usually considered adequate.

If the sweep is to be composed from a limited number of harmonics, the resulting sweep linearity and flyback speed can be predicted analytically.

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[*] Original manuscript received by the IRE, October 21, 1955; revised manuscript received December 23, 1955. This paper was presented at the 1955 Fall Meeting of the RTMA in Syracuse, N. Y.

[†] TV-Research Dept., Motorola Inc., Chicago, Ill.

[1] K. Schlesinger, "Television sweep and scanning techniques," in "Handbook of Television Engineering," D. G. Fink, ed., McGraw-Hill Book Co., Inc., New York, N. Y.; (to be published in 1956), Section 6.

[2] Low figure used for CBS 19 inch Colortron 205.

[3] M. J. Obert, "Deflection and convergence of the 21 inch color kinescope," *RCA Review*, vol. 16, pp. 140–169; March, 1955.

[4] O. H. Schade, "Magnetic deflection circuit for cathode ray tubes," *RCA Review*, vol. 8, pp. 506–538; September, 1947.

[5] A. W. Friend, "Television deflection circuits," *RCA Review*, vol. 8, pp. 98–138; March, 1947.

[6] R. B. Dome, U. S. Patent 2-299-571; October 20, 1942; C. J. Miller, U. S. Patent 2-608-672; August 26, 1952. Dome shows the use of a shorted line for the transmission of sweep, but does not disclose the use of resonance to obtain high circulating power.

[7] "IRE standards on television: methods of measurement of aspect ratio and geometric distortion, 1954," PROC. IRE, vol. 42, pp. 1098–1103; July, 1954.

[8] John Tosberg and Monte Burgett, "What Price—Horizontal Linearity," 1955 IRE CONVENTION RECORD, Part 7, p. 148.

[9] "NTSC signal specifications," PROC., IRE, vol. 42, p. 18; January, 1954.

Specifically, it can be stated how many harmonics, *i.e.*, how much bandwidth, is required to meet each of the above specifications.

Retrace Time

Fig. 1 shows an ideal sawtooth wave with 11 per cent retrace. Its Fourier expansion is given by:

$$i = I\cdot\frac{1}{\pi}\cdot\frac{1}{1-p}\sum_{n=1}^{\infty} a_n\cdot\sin n\omega t \qquad (1)$$

where:

$$a_n = \frac{1}{n}\cdot\frac{\sin n\omega p}{n\pi p}.$$

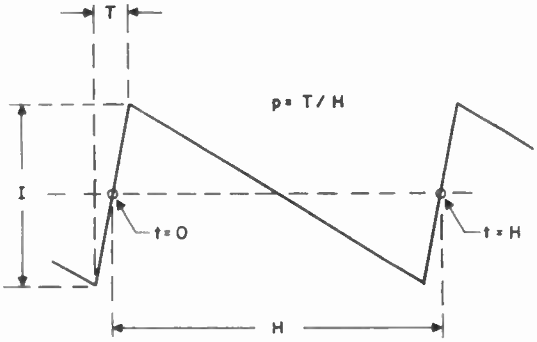


Fig. 1—Ideal sawtooth wave.

Since this spectrum goes through zero at $n=1/p$, it is customary to limit the system bandwidth to only the first N harmonics, where:

$$N = \frac{1}{p} - 1. \qquad (2)$$

The flyback time T_N of the resulting "short" Fourier series is considerably longer than $T=pH$. The retrace percentage $p_N=T_N/H$ of the bandwidth-limited signal may be found by differentiating (1) and solving the resulting equation (3):

$$0 = \sum_{n=1}^{N}\frac{\sin n\pi p}{n\pi p}\cdot\cos\,(n\omega T_N) \qquad (3)$$

for T_N by interpolation. This has been done for various values of N and the results are shown in the graph Fig. 2. Specifically, it is found that to obtain a retrace percentage of 15 per cent, one has to include all harmonics up to $N=8$. This requires a system bandwidth of 126 kilocycles. If there were no bandwidth retriction, the retrace percentage would be $(1/N+1)=11.1$ per cent.

Quite generally, it is found, that a sweep wave composed of only the first N positive Fourier terms requires 37 per cent more retrace time, and has only 73 per cent of the flyback speed, than if all harmonics were used. This may be formulated as follows:

$$p_N = 1.37\cdot p = \frac{137}{N+1}\text{ per cent} \qquad (4a)$$

$$N = \frac{137}{p_N} - 1. \qquad (4b)$$

It is this retrace condition (4b), rather than sweep linearity requirements which makes it necessary to use more than just a few harmonics for use in synthetic sweep.

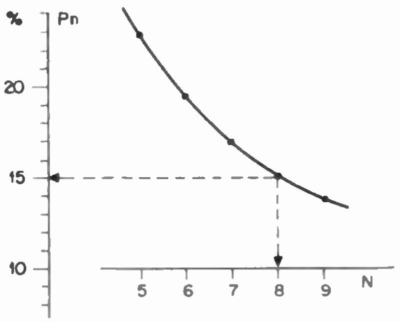


Fig. 2—Retrace percentage of synthetic sweep using N harmonics.

Sweep Linearity

It is of interest to note, that the conventional Fourier coefficients have the property of a "least squares" approximation, taken over the full period of the function. This synthesis is not the best possible for our purposes. It can be shown, that better sweep linearity may be achieved, with the same number of harmonics, if the relative harmonic amplitudes are slightly modified, to meet a "least-squares" condition for the trace-interval only, rather than for the full sweep period (see appendix).

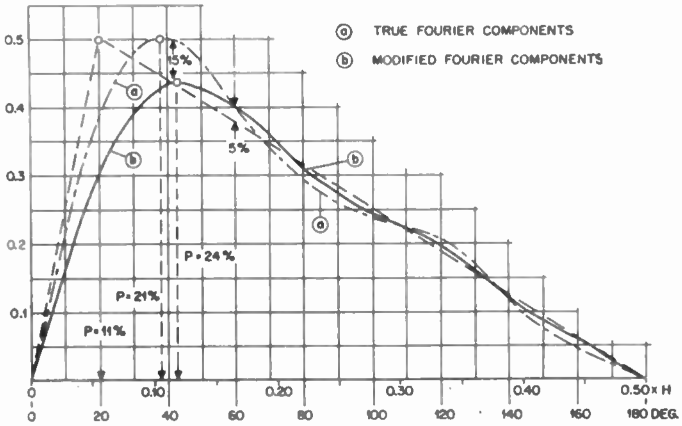


Fig. 3—Synthetic sweep from 4 harmonics.

Fig. 3 shows synthetic sweep waves composed of only four harmonics of an "ideal" sawtooth (retrace, 11.1 per cent; amplitude, 1 ampere peak to peak).

Curve (*a*) of Fig. 3 is the sum of the first 4 Fourier components. Curve (*b*) of Fig. 3 is composed of the first 4 modified Fourier coefficients. The relative amplitudes used for each curve are given below in Table I.

TABLE I

	a_1	a_2	a_3	a_4	Fig. #
True Fourier Coefficients	0.31	0.145	0.088	0.056	(3a)
Modified Fourier Coefficients	0.342	0.145	0.068	0.025	(3b)

It is seen, that sweep distortion is reduced, by the modified series, from 15 per cent to 5 per cent in the trace interval, while the deviation during retrace has almost doubled.

The above shows that good linearity may be readily obtained over a limited range and with a relatively small number of harmonics, by deviating from the amplitude distribution of the Fourier spectrum. This fact is borne out by experience as will be shown further on in the text.

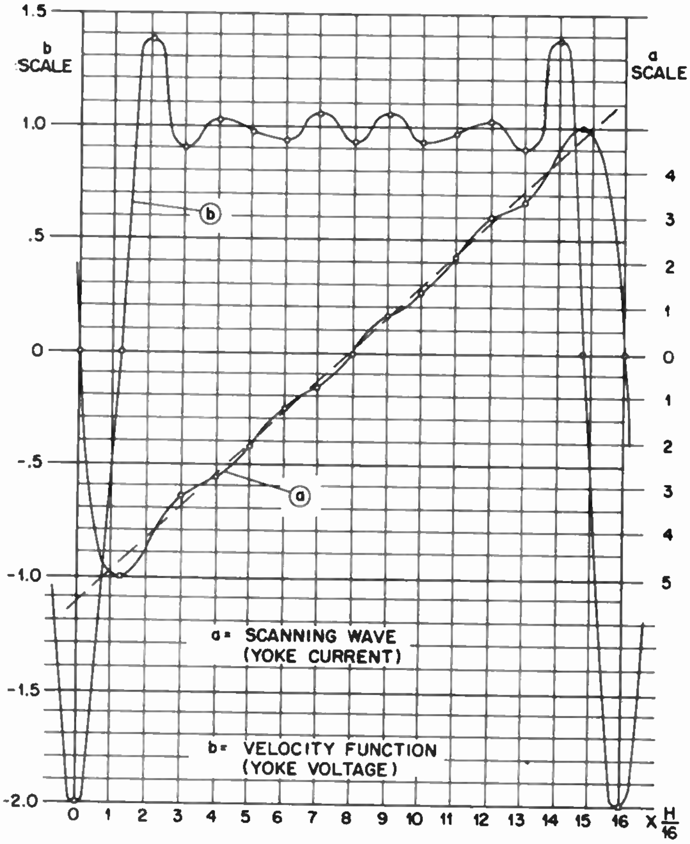


Fig. 4—Synthetic sweep: 8 Fourier components.

Fig. 4(a) shows the appearance of synthetic sweep, if 8 harmonics are used. This curve combines good linearity with adequate retrace time ($p=15$ per cent). Fig. 4(b) shows the sweep velocity as a function of time. This is also the waveform of voltage across the yoke. While there is as much as ±10 per cent change of scanning speed, it should be borne in mind that the visibility of such speed variations in the picture is reduced by a factor of $1/2\pi$, and that it is more noticeable on objects in motion than at rest.

Again, experience confirmed the retrace prediction, but did somewhat better on waveform, than the Fourier expansion leads one to expect [see Fig. 13(a)].

Physical Principles of Resonant Sweep

Resonant sweep may be realized in an arrangement as in Fig. 5(a). This shows a deflection yoke L_y, shunted by capacitance C_y, and terminated by a ladder network with 4 series resonant arms. Fig. 5(b) shows the reactance diagram of this structure. If the arms resonate close to the zero frequencies midway between sweep harmonics, the yoke may be resonated, simultaneously, at 4+1 poles; *i.e.*, at 5 harmonics of the line frequency.

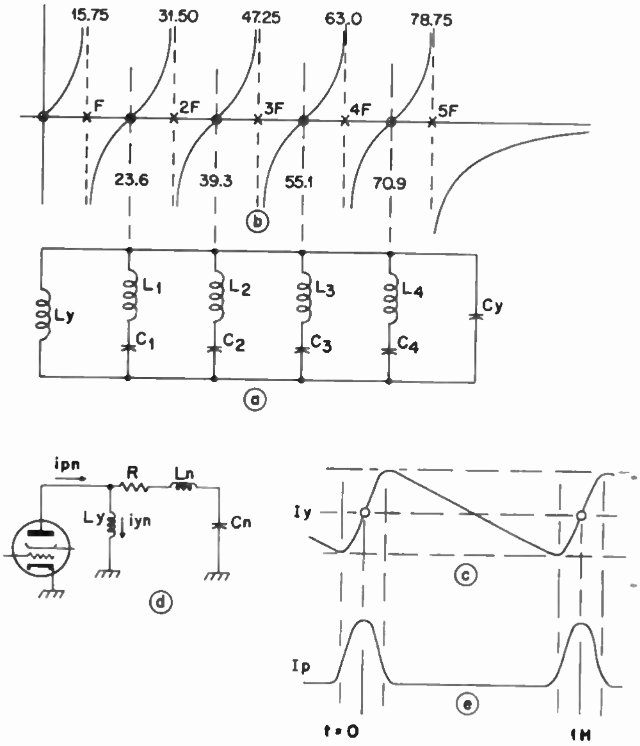


Fig. 5—Sweep forming network.

To obtain, in the yoke, a sawtooth current of the waveform shown in Fig. 5(c) the harmonics should all be in phase, and they should have amplitudes as given by the Fourier-expansion, (1).

These harmonics i_n may be shock-excited by a constant current generator, feeding a suitable, nonsinusoidal, current-wave I_p into the yoke at line frequency. To find the waveform of I_p, we consider each mesh of the network separately [Fig. 5(d)]. In a high-Q system of this type, the nth harmonic of the yoke current i_{yn}, bears the following relation to the plate-current harmonic i_{pn}:

$$i_{yn} = i_{pn}'\left(-jQ_n\cdot\frac{L_y}{L_n}\right). \qquad (5)$$

Evidently, each resonant arm has, in this connection, an effective Q_n', which is smaller than its actual Q_n by the decoupling factor L_y/L_n:

$$Q_n' = Q_n' \cdot \frac{L_y}{L_n} \cdot \tag{6}$$

The actual exciter current I_p is the sum of all i_{pn} or, with (6), (5) and (1):

$$I_p = \frac{I_y}{\pi(1-p)} \sum \frac{\sin n\pi p}{n\pi p} \cdot \frac{1}{n \cdot Q_n'} \cdot \cos n\Omega t. \tag{7}$$

Now, if it so happens that $nQ_n' = \text{const}$; *i.e.*, if:

$$Q_n/L_n = \frac{\text{const}}{n} \tag{8}$$

the exciter current is a pulse train as shown in Fig. 5(e). In a ladder network such as shown, the branch inductances increase with n, in order to meet the tightening selectivity requirements for the higher sidebands. Thus, (8) may be satisfied, even with branches of constant Q. But even if (8) is not met, the final output waveform may be adjusted by changing the waveform of the current input, rather than by controlling the Q's of the individual circuits. In general, the exciter current I_p will resemble a train of pulses, or else, a periodic interruption in a dc current.

RESONANT SWEEP WITH LADDER NETWORK

Fig. 6 shows a system, which gave enough output to sweep a 72° tube at 15 kv. The multiresonant ladder network is shunted across a pulse transformer whose output inductance is larger than the yoke inductance.

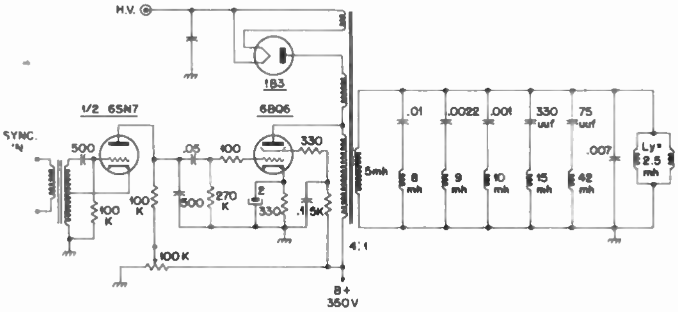


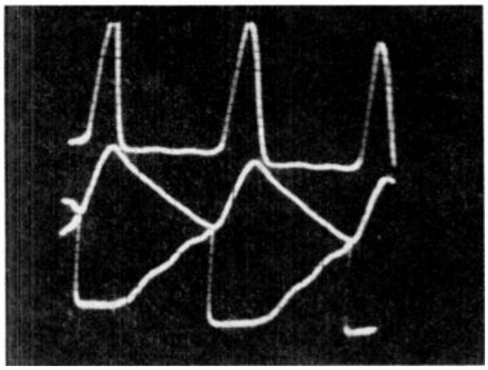
Fig. 6—Circuit with sweep forming network.

The primary is connected to a 6BQ6 type pentode at a turns ratio of 4 to 1. The plate current is allowed to rise linearly during the second half of the sweep cycle, and is then cut off for about fifty per cent of the time. Fig. 7(a) shows the yoke voltage, yoke current, and cathode current in their time relationship. Fig. 7(b) shows an enlarged view of yoke voltage and current. Performance data for the ladder resonator were:

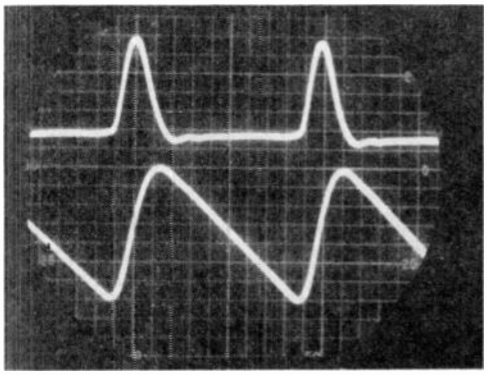
DC plate supply		360 volts
DC plate current		50 ma
DC screen current		20 ma
Power supply to plate		18 watts
Power supply, total		25 watts
Yoke inductance		2.5 mh
Yoke current		1.6a peak to peak
Circulating power		12.8 watts
AC-DC conversion-efficiency	plate only	71 per cent
	total	51 per cent

The main disadvantage of this circuit is its slow retrace. The best result obtained in the laboratory was $p = 19$ per cent. This agrees with the mathematical theory of resonant sweep as outlined above, for the case that only 6 harmonics were utilized.

It seems difficult to handle higher harmonics with this network, since the branch inductances increase rapidly with N. This results in diminishing returns from the high-order resonators, since they are more loosely coupled to the yoke (Fig. 6). It became necessary, therefore, to try a different approach to the problem.



(a) Yoke Voltage-Current and Pentode Current



(b) Yoke Voltage and Current

Fig. 7—Oscillograms of sweep forming network.

TRANSMISSION LINE RESONATOR

Fig. 8 shows the input reactance of a shorted transmission line. This graph is described by:

$$X_\lambda = Z_\lambda \cdot \tan \omega T \tag{9}$$

where T and Z_λ are, respectively, the delay along the line and its characteristic impedance. If this line is used to terminate a yoke impedance [Fig. 8(a)]:

$$X_y = \omega L_y \tag{10}$$

the system will resonate at all spots, where

$$X_y = -X_\lambda. \tag{11}$$

If we wish these spots Ω_K to coincide with consecutive harmonics of the sweep frequency Ω_1, they must have as contant separation $\Delta\Omega = 2\pi F_1$ along the frequency

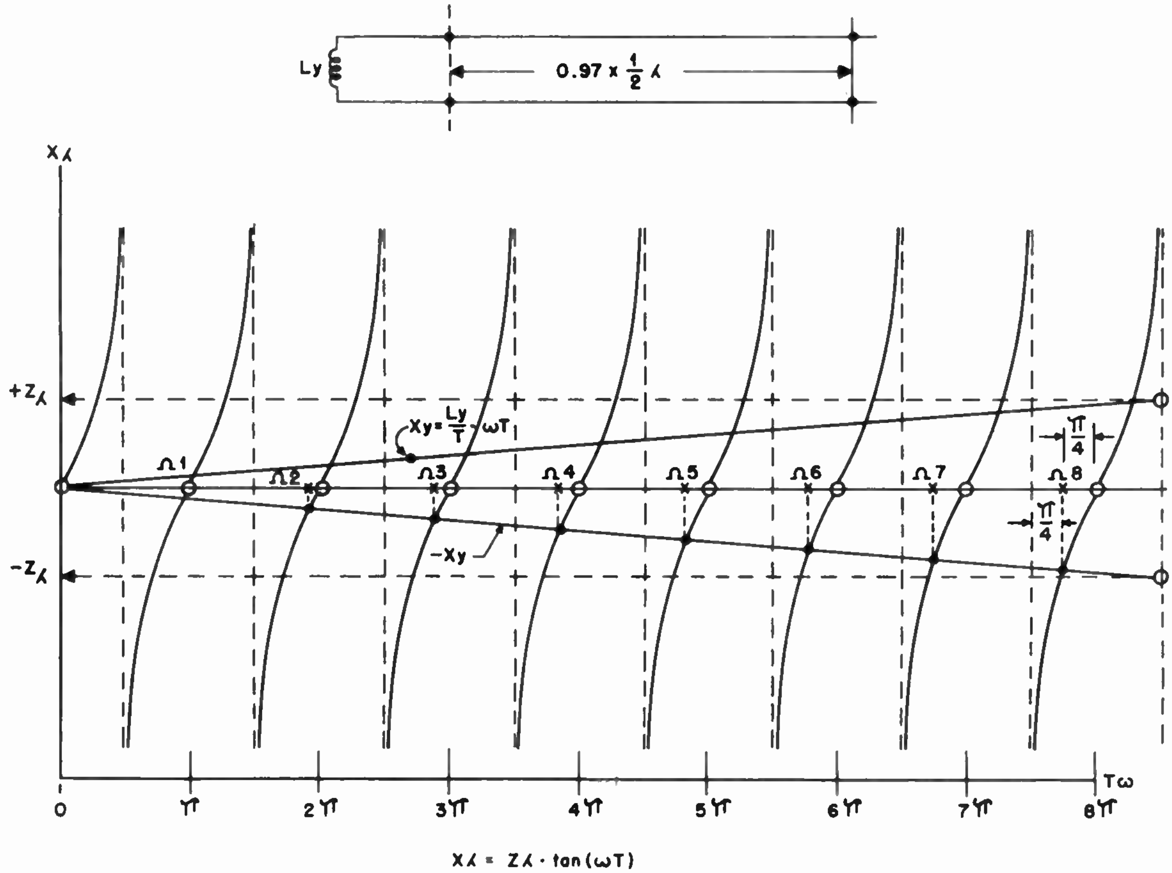


Fig. 8—Sweep forming transmission line.

axis of Fig. 8. This imposes two conditions: 1) the dispersion along the line must be low; 2) at the highest harmonic used, the impedance at the input of the line should not exceed the value Z_λ. From the second condition one can derive the required length of the line. Since

$$X_\lambda = Z_\lambda \quad \text{for} \quad \omega T = N \cdot \pi - \frac{\pi}{4}$$

we find:

$$T = \frac{H}{2}\left[1 - \frac{1}{4N}\right]. \qquad (12)$$

This means: the line is shorter than one-half wavelength by $100/4N$ per cent. If $N=8$ harmonics are to be resonated, the line should measure just 3 per cent less than a halfwave; *i.e.*, it should have a delay of $\frac{1}{2}\cdot 63\cdot 0.97 = 30.5$ microseconds. From the second condition, we can also derive the characteristic impedance of the line-resonator. At the Nth pole, there is:

$$X_\lambda = -Z_\lambda = -NX_y. \qquad (13)$$

Hence

$$2\pi F L_y \leqq \frac{1}{N}\cdot Z_\lambda \qquad (14)$$

i.e., the line impedance should be N times higher than the terminating inductive reactance, taken at sweep frequency. If the yoke reactance X_y is too high, a step-down transformer is needed between line and yoke.

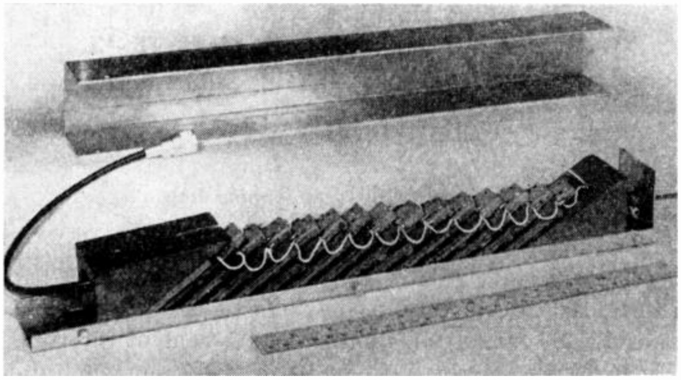


Fig. 9—Sweep forming line: slanting water construction.

LINE RESONATOR CONSTRUCTION

To carry out experiments with resonant sweep, we have constructed a delay line with these specifications:

Total delay	30.5 μsec
Impedance	250 ohms
Cut off frequency	160 kc
Number of sections	12
Dc-resistance	8 ohms
Power handling capacity	20 watts.

Fig. 9 shows an early model of this line, complete with its mica capacitors. Fig. 10 shows an improved version of the line, with the coils impedded in wafers of "Scotchcast." This line carries twice as much copper per unit length, which results in reduced resistance and power dissipation.

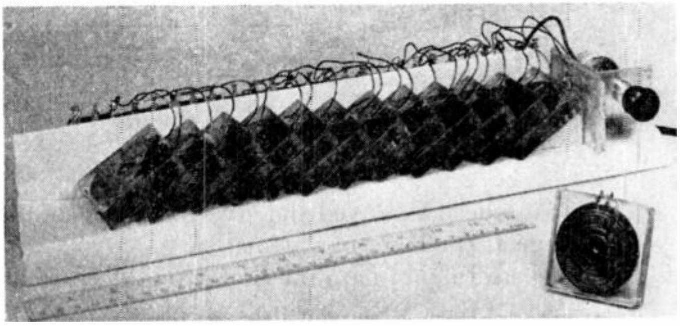
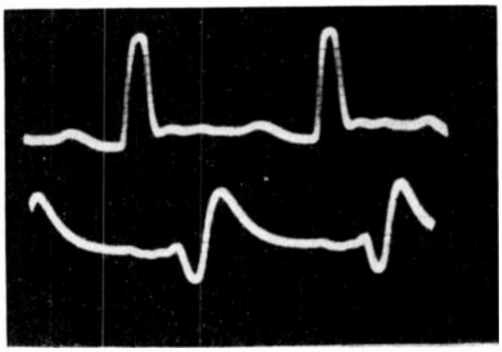
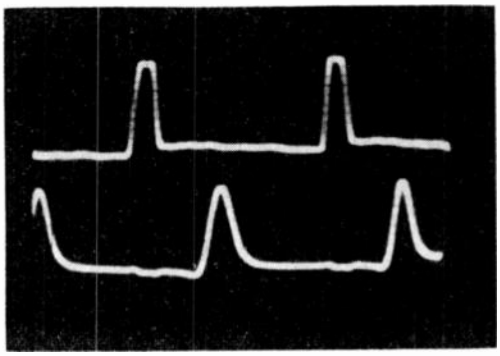


Fig. 10—Sweep forming line: low-loss, slanting wafer type.

When using lines of this type for resonant sweep, it was found from the start that dispersion had to be brought under control before it was feasible to tune and phase the higher harmonics. We found a convenient way to do this, in the "slanting wafer" construction, shown in both Figs. 9 and 10. Fig. 11(a) and (b) shows how the use of tilt in the coil assembly affects the transmission of sync pulses through the above line (reflection-free termination). The "slanting wafer" arrangement offers convenient control of mutual without affecting self-inductance. One can even over-compensate since the mutual inductance changes sign at about 70° tilt angle. Optimum results were obtained with a slant of about 55°.



(a) Slant Angle 0°



(b) Slant Angle 55°

Fig. 11—Dispersion control by slanting wafer construction. Upper curves: pulse input to line. Lower curves: line output across reflection-free termination.

CIRCUIT WITH SWEEP FORMING LINE

Fig. 12 shows the complete circuit for line-resonant sweep. Since the yoke used had the same impedance as the line, the latter is tapped down on the pulse transformer output by $1/\sqrt{8}$. The grid drive at the pentode is a negative going pulse, not a sawtooth. The rate of current charging the primary is thus mainly determined by transformer inductance, and $B+$ voltage.

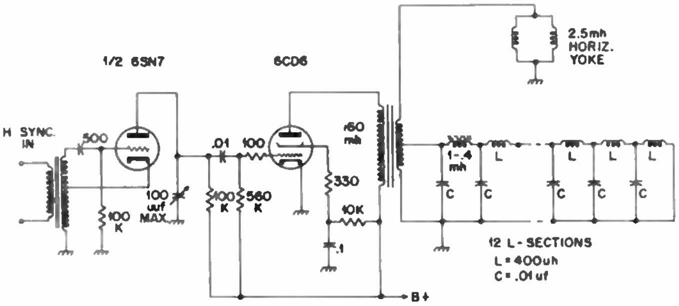


Fig. 12—Circuit with sweep forming line.

Fig. 13(a) shows the yoke voltage and current. Adequate retrace speed (15 per cent) has been achieved in agreement with theory. Sweep linearity is satisfactory. Efficiency was similar to that reported above.

Fig. 13(b) shows the cathode current in the pentode in its phase relation to yoke current and voltage.

In Fig 13(c), the center wave is the current flowing to ground at the far end of the line. Since we have on the line, standing waves at all sweep harmonics, the current waves have their signs inverted for all odd, but not for even terms. This is the equivalent in the Fourier expansion, of replacing the argument t by $-t$. Thus, we find, on the far end, a current sawtooth with half-line delay and inverted slope; and likewise, a delayed pulse voltage with a polarity opposite to that found at the near end [see Fig. 15(b)].

THYRATRON SWEEP CIRCUIT

In all previous systems for resonant sweep, fairly high $B+$ voltages were found necessary (approximately 360 volts). The following describes a system which uses a resonant choke to obtain a high plate voltage from a low voltage power supply. The circuit of Fig. 14 employs a miniature hydrogen thyratron type VC-1258 in a circuit similar to those used in radar modulators.[10] By bringing the choke L_1 into resonance with the capacitance C_1 at the line frequency, a step up of 3:1 and more could be readily obtained, making available 600–700 volts at the thyratron plate, while using only 220 volts as $B-$ supply.

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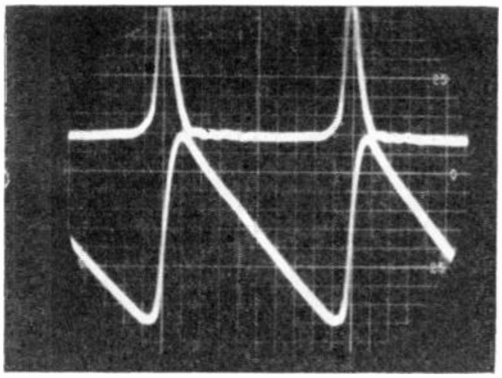
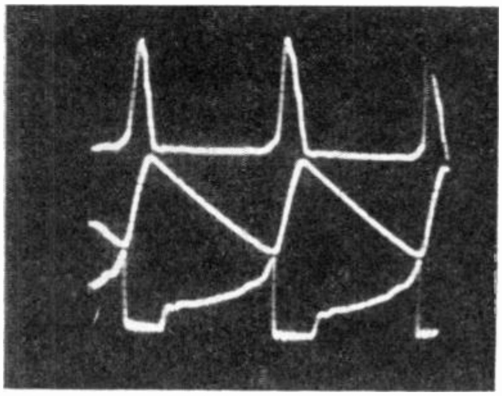
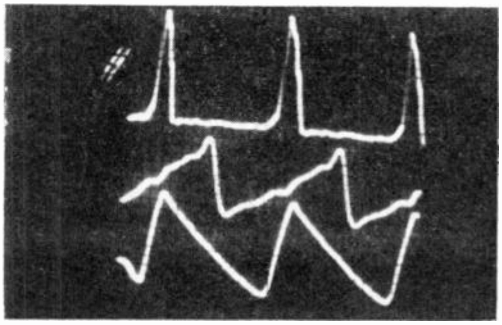
[10] G. N. Glasee and J. V. Lebacgz, "Pulse Generators," Radiation Lab. Series, vol. 5; 1948.



(a) Yoke Voltage and Current



(b) Yoke Waveforms and Pentode Current



(c) Yoke Voltage and Line Current
at Far and at Near End

Fig. 13—Sweep forming line.

The discharge current was a 2.6 ampere pulse, returning through the yoke L_y at the near end of the resonant line. A special low-inductance yoke was wound, to obviate a matching transformer in meeting condition (14). This system could scan a 72° picture tube running at 16 kv.

Fig. 15 shows typical waveforms obtained. Fig 15(a) presents the ac plate voltage (top), the thyratron cathode current (center), and the yoke current (bottom).

Fig. 15(b) shows yoke voltage and current, and, in the center, the voltage pulse at the far end of the line.

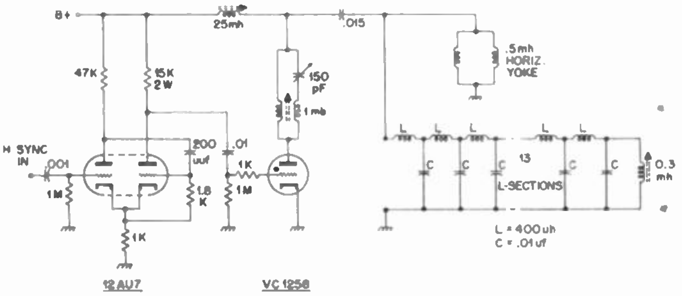
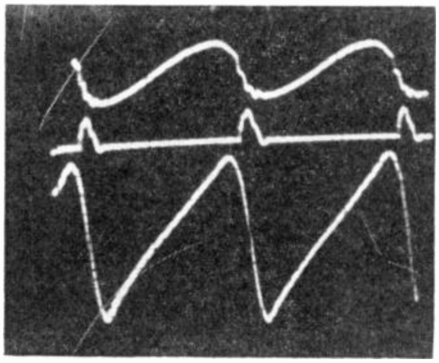


Fig. 14—Thyratron resonant sweep circuit.

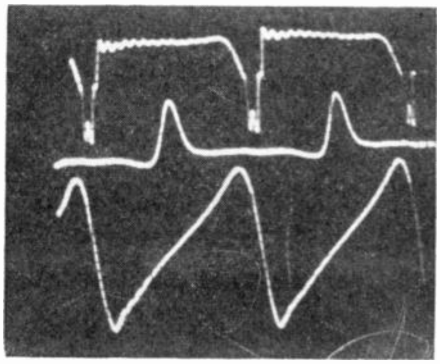
This pulse is indeed a delayed and inverted replica of the yoke voltage at the input of the line.

Typical performance data for thyratron sweep were:

Dc supply	220 volt—160 ma—35 watts
Yoke circuit	0.5 mh—3.7 amperes—13.8 va



(a) Resonant Charge
Thyratron Current
Yoke Current



(b) Yoke Voltage
Far End Line Voltage
Yoke Current

Fig. 15—Waveforms in thyratron circuit.

The conversion efficiency of this circuit was only 40 per cent. Another difficulty was found in the tendency of the thyratron to "ring" after discharge. However, these parasitic oscillations could be removed from the picture by tuning the "bridged-T" network in the plate circuit. In every other respect, the VC-1258 thyratron was found to be stable in operation.

CONCLUSION

The work reported above seems to indicate that resonant sweep is a practical proposition. It can meet, but not beat, the performance standards set by the power feedback type of circuits now in use. There are some difficulties in producing sweep waves with short retrace. For the same reason, kickback high-voltage generation, while feasible, is somewhat less efficient than in current practice. However, the main obstacles to resonant sweep seem to reside more in equipment cost than in technical performance.

APPENDIX

Modified Fourier Components

Suppose an odd, periodic function of time $f_{(t)}$ (period H) is to be approximated by a harmonic series $\sum a_n \sin n\omega t$ in such a way, that the sum of the error-squares becomes a minimum. Assume, further, that this should be done only over a limited range from $t=\tau/2$ to $t=H-(\tau/2)$ (see Fig. 1). The expression

$$G_{(a_n)} = \int_{\tau/2}^{H-(\tau/2)} [f_{(t)} - \sum a_n \sin (n\omega t)]^2 dt. \tag{14}$$

becomes an "extremum," if all $\partial g/\partial a_n$ vanish. It follows:

$$a_n = \frac{\displaystyle\int_{\tau/2}^{H-(\tau/2)} f\cdot \sin (n\omega t) dt}{\displaystyle\int_{\tau/2}^{H-(\tau/2)} \sin^2 (n\omega t) dt}. \tag{15}$$

This expression yields the familiar Fourier coefficients K_n for extended range: $\tau \rightarrow 0$.

As it stands, (15) yields modified components. We have evaluated these for a sawtooth wave as of Fig. 1. The result is:

$$a_n = K_n \cdot \frac{\left(\dfrac{1}{p} - 1\right) \dfrac{n\pi b}{\tan(n\pi p)} + 1}{\left(\dfrac{1}{p} + 1\right) \dfrac{\sin 2n\pi p}{2n\pi p} - 1}. \tag{16}$$

Both sets of data are computed below for $p=1/9$.

TABLE II

Order #	K_n	A_n
1	0.310	0.342
2	0.145	0.145
3	0.088	0.068
4	0.056	0.025
5	0.036	0.010
6	0.022	−0.030
7	0.012	−0.040
8	0.005	−0.040
9	0.000	−0.030

The first four terms of each were used in the construction of Fig. 3.

* * *

IRE Standards on Facsimile: Definitions of Terms, 1956*

(56 IRE 9. S1)

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AM to FS Converter. See *Transmitting Converter, Facsimile.*

Available Line. The portion of the scanning line which can be used specifically for *Picture Signals.*

Bandwidth, Facsimile. In a given *Facsimile System*, the difference in cycles per second between the highest and the lowest frequency components required for adequate transmission of the *Facsimile Signals.*

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* Approved by the IRE Standards Committee, March, 1956. Reprints of this Standard, 56 IRE 9. S1, may be purchased while available from the Institute of Radio Engineers, 1 East 79th Street, New York, N. Y. at $0.60 per copy. A 20 per cent discount will be allowed for 100 or more copies mailed to one address.

Baseband. In a carrier (or *Subcarrier*) wire or radio transmission system, the band of frequencies occupied by the signal before it modulates the carrier (or *Subcarrier*) frequency to form the transmitted line or radio signal.

Note: The signal in the *Baseband* is usually distinguished from the line or radio signal by ranging over distinctly lower frequencies, which at the lower end relatively approach or may include dc (zero frequency). In the case of a *Facsimile Signal* before modulation on a *Subcarrier*, the Baseband includes dc.

Black Recording. In an amplitude-modulation system, that form of *Recording* in which the maximum received power corresponds to the maximum *Density* of the *Record Medium*. In a frequency-modulation system, that form of *Recording* in which the lowest received frequency corresponds to the maximum *Density* of the *Record Medium*.

Black Signal. The signal at any point in a *Facsimile System* produced by the *Scanning* of a maximum *Density* area of the *Subject Copy*.

Black Transmission. In an amplitude-modulation system, that form of transmission in which the maximum transmitted power corresponds to the maximum *Density* of the *Subject Copy*. In a frequency-modulation system, that form of transmission in which the lowest transmitted frequency corresponds to the maximum *Density* of the *Subject Copy*.

Carbon Pressure Recording. That type of *Electromechanical Recording* in which a pressure device acts upon carbon paper to register upon the *Record Sheet*.

Carrier Beat. The undesirable heterodyne of signals each synchronous with a different stable reference oscillator causing a pattern in received copy. Where one or more of the oscillators is fork controlled, this is called *Fork Beat*.

Converter, Facsimile. A device which changes the type of modulation.

Definition. Distinctness or clarity of detail or outline in a *Record Sheet*, or other reproduction.

Delay Distortion. See *Envelope Delay Distortion*.

Delay Equalizer. A corrective network which is designed to make the *Phase Delay* or *Envelope Delay* of a circuit or system substantially constant over a desired frequency range.

Density (in Facsimile). A measure of the light-transmitting or -reflecting properties of an area. It is expressed by the common logarithm of the ratio of incident to transmitted or reflected light flux.

Note: There are many types of *Density* which will usually have different numerical values for a given material; *e.g.*, Diffuse Density, Double Diffuse Density, Specular Density. The relevant type of density depends upon the geometry of the optical system in which the material is used.

Direct Recording. That type of *Recording* in which a visible record is produced, without subsequent processing, in response to the received signals.

Drive Pattern. *Density* variation caused by periodic errors in the position of the *Recording Spot*. When caused by gears this is called *Gear Pattern*.

Drum Speed. The angular speed of the transmitter or recorder drum.

Note: This speed is measured in revolutions per minute.

Dual Modulation. The process of modulating a common carrier wave or *Subcarrier* by two different types of modulation (*e.g.*, amplitude- and frequency-modulation) each conveying separate information.

Echo. A wave which has been reflected at one or more points with sufficient magnitude and time difference to be perceived in some manner as a wave distinct from that of the main transmission.

Effective Band (in Facsimile). The frequency band of a *Facsimile Signal* wave equal in width to that between zero frequency and *Maximum Keying Frequency*.

Note: The frequency band occupied in the transmission medium will in general be greater than the *Effective Band*.

Electrochemical Recording. *Recording* by means of a chemical reaction brought about by the passage of signal-controlled current through the sensitized portion of the *Record Sheet*.

Electrolytic Recording. That type of electrochemical recording in which the chemical change is made possible by the presence of an electrolyte.

Electromechanical Recording. *Recording* by means of a signal-actuated mechanical device.

Electronic Line Scanning. That method of *Scanning* which provides motion of the *Scanning Spot* along the scanning line by electronic means.

Electronic Raster Scanning. That method of *Scanning* in which motion of the *Scanning Spot* in both dimensions is accomplished by electronic means.

Electrostatic Recording. *Recording* by means of a signal-controlled electrostatic field.

Electrothermal Recording. That type of *Recording* which is produced principally by signal-controlled thermal action.

Elemental Area. Any segment of a *Scanning Line* of the *Subject Copy* the dimension of which along the line is exactly equal to the *Nominal Line Width*.

Note: Elemental area is not necessarily the same as the *Scanning Spot*.

End-of-Copy Signal. A signal indicating termination of the transmission of a complete *Subject Copy.*

Envelope Delay. The time of propagation, between two points, of the envelope of a wave.

Note: The *Envelope Delay* is measured by the slope of the phase shift in cycles plotted against the frequency in cycles per second. If the system distorts the envelope the *Envelope Delay* at a specified frequency is defined with reference to a modulated wave which occupies a frequency bandwidth approaching zero.

Envelope Delay Distortion. That form of distortion which occurs when the rate of change of phase shift with frequency of a circuit or system is not constant over the frequency range required for transmission.

Note: Envelope Delay Distortion is usually expressed as one-half the difference in microseconds between the maximum and minimum *Envelope Delays* existing between the two extremes of frequency defining the channel used.

Facsimile (in electrical communications). The process, or the result of the process, by which fixed graphic material including pictures or images is scanned and the information converted into signal waves which are used either locally or remotely to produce in record form a likeness (*Facsimile*) of the *Subject Copy.*

Facsimile Signal (Picture Signal). A signal resulting from the *Scanning* process.

Facsimile-Signal Level. The maximum *Facsimile Signal* power or voltage (rms or dc) measured at any point in a *Facsimile System.*

Note: It may be expressed in decibels with respect to some standard value such as 1 milliwatt.

Facsimile System. An integrated assembly of the elements used for *Facsimile.*

Facsimile Transient. A damped oscillatory transient occurring in the output of the system as a result of a sudden change in input.

Facsimile Transmission. The transmission of *Signal Waves* produced by the *Scanning* of fixed graphic material, including pictures, for reproduction in record form.

Flood Projection. The optical method of *Scanning* in which the *Subject Copy* is flood-lighted and the *Scanning Spot* is defined in the path of the reflected or transmitted light.

Fork Beat. See *Carrier Beat.*

Frame (in Facsimile). A rectangular area, the width of which is the *Available Line* and the length of which is determined by the service requirements.

Framing. The adjustment of the picture to a desired position in the direction of line progression.

Framing Signal. A signal used for adjustment of the picture to a desired position in the direction of line progression.

FS to AM Converter. See *Receiving Converter, Facsimile.*

Gear Pattern. See *Drive Pattern.*

Grouping. Periodic error in the spacing of *Recorded Lines.*

Halftone Characteristic. A relation between the *Density* of the recorded copy and the *Density* of the *Subject Copy.*

Note: The term may also be used to relate the amplitude of the *Facsimile Signal* to the *Density* of the *Subject Copy* or the record copy when only a portion of the system is under consideration. In a frequency-modulation system an appropriate parameter is to be used instead of the amplitude.

Index of Cooperation, Scanning or Recording Line. In rectilinear *Scanning* or *Recording,* the product of the total length of a scanning or recording line by the number of scanning or recording lines per unit length.

Note 1: The International Index of Cooperation (diametral index of cooperation) is based on drum diameter and is defined by the International Radio Consultative Committee (CCIR). It is $1/\pi$ times the *Scanning Line Index of Cooperation.*

Note 2: For a scanner and recorder to be compatible the *Indices of Cooperation* must be the same.

Ink Vapor Recording. That type of *Recording* in which vaporized ink particles are directly deposited upon the *Record Sheet.*

Jitter (in Facsimile). Raggedness in the received copy caused by erroneous displacement of *Recorded Spots* in the direction of *Scanning.*

Kendall Effect. A spurious pattern or other distortion in a facsimile record caused by unwanted modulation products arising from the transmission of a carrier signal and appearing in the form of a rectified *Baseband* that interferes with the lower sideband of the carrier.

Note: This occurs principally when the single sideband width is greater than half the *Facsimile* carrier frequency.

Light Carrier Injection. The method of introducing the carrier by periodic variation of the scanner light beam, the average amplitude of which is varied by the *Density* changes of the *Subject Copy.*

Magnetic Recording. *Recording* by means of a signal-controlled magnetic field.

Maximum Keying Frequency (Fundamental Scanning Frequency). The frequency in cycles per second numerically equal to the *Spot Speed* divided by twice the *Scanning Spot X Dimension.*

Maximum Modulating Frequency. The highest *Picture*

Frequency required for the *Facsimile* transmission system.

Note: The *Maximum Modulating Frequency* and the *Maximum Keying Frequency* are not necessarily equal.

Multipath. See *Multipath Transmission.*

Multipath Transmission (Multipath). The propagation phenomenon which results in signals reaching the radio receiving antenna by two or more paths.

Note: In *Facsimile, Multipath* causes *Jitter.*

Multiple Spot Scanning. The method in which *Scanning* is carried on simultaneously by two or more *Scanning Spots,* each one analyzing its fraction of the total scanned area of the *Subject Copy.*

Noise. Any extraneous electrical disturbance tending to interfere with the normal reception of a transmitted signal.

Nominal Line Width. The average separation between centers of adjacent scanning or recording lines.

Overlap *X*. The amount by which the *Recorded Spot X Dimension* exceeds that necessary to form a most nearly constant *Density* line.

Note: This effect arises in that type of equipment which responds to a constant *Density* in the *Subject Copy* by a succession of discrete *Recorded Spots.*

Overlap *Y*. The amount by which the *Recorded Spot Y Dimension* exceeds the *Nominal Line Width.*

Phase Delay. In the transfer of a single frequency wave from one point to another in a system, the time delay of a part of the wave identifying its phase.

Note: The *Phase Delay* is measured by the ratio of the total phase shift in cycles to the frequency in cycles per second.

Phase Distortion. See *Phase-Frequency Distortion.*

Phase-Frequency Distortion. Distortion due to lack of direct proportionality of phase shift to frequency over the frequency range required for transmission.

Note 1: Delay Distortion is a special case.

Note 2: This definition includes the case of a linear phase-frequency relation with the zero frequency intercept differing from an integral multiple of π.

Phasing. The adjustment of picture position along the scanning line.

Phasing Signal. A signal used for adjustment of the picture position along the scanning line.

Photosensitive Recording. Recording by the exposure of a photo-sensitive surface to a signal-controlled light beam or spot.

Picture Frequencies. The frequencies which result solely from *Scanning Subject Copy.*

Note: This does not include frequencies which are part of a modulated carrier signal.

Picture Inversion. A process which causes reversal of the black and white shades of the *Recorded Copy.*

Picture Signal. See *Facsimile Signal.*

Ready-to-Receive Signal. A signal sent back to the *Facsimile Transmitter* indicating that a *Facsimile Receiver* is ready to accept the transmission.

Receiver, Facsimile. The apparatus employed to translate the signal from the communications channel into a *Facsimile* record of the *Subject Copy.*

Receiving Converter, Facsimile (FS to AM Converter). A device which changes the type of modulation from frequency shift to amplitude.

Record Medium. The physical medium on which the *Facsimile Recorder* forms an image of the *Subject Copy.*

Record Sheet. The medium which is used to produce a visible image of the *Subject Copy* in record form. The *Record Medium* and the *Record Sheet* may be identical.

Recorded Spot. The image of the *Recording Spot* on the *Record Sheet.*

Recorded Spot *X* Dimension. The effective *Recorded Spot* dimension measured in the direction of the recorded line.

Note 1: By effective dimension is meant the largest center-to-center spacing between *Recorded Spots* which gives minimum peak-to-peak variation of *Density* of the recorded line.

Note 2: This term applies to that type of equipment which responds to a constant *Density* in the *Subject Copy* by a succession of discrete *Recorded Spots.*

Recorded Spot *Y* Dimension. The effective *Recorded Spot* dimension measured perpendicularly to the recorded line.

Note: By effective dimension is meant the largest center-to-center distance between recorded lines which gives minimum peak-to-peak variation of *Density* across the recorded lines.

Recorder, Facsimile. That part of the *Facsimile Receiver* which performs the final conversion of electrical *Picture Signal* to an image of the *Subject Copy* on the *Record Medium.*

Recording (in Facsimile). The process of converting the electrical signal to an image on the *Record Medium.*

Note: See *Direct Recording, Electrochemical Recording, Electrolytic Recording, Electromechanical Recording, Electrostatic Recording, Electrothermal Recording, Ink Vapor Recording, Magnetic Recording,* and *Photosensitive Recording.*

Recording Spot (in Facsimile). The image area formed at the *Record Medium* by the *Facsimile Recorder.*

Reproduction Speed. The area of copy recorded per unit time.

Ringing. See *Facsimile Transient.*

Scanner. That part of the *Facsimile Transmitter* which systematically translates the *Densities* of the *Subject Copy* into signal-wave form.

Scanning (in Facsimile). The process of analyzing successively the *Densities* of the *Subject Copy* according to the elements of a predetermined pattern.

Note: The normal *Scanning* is from left to right and top to bottom of the *Subject Copy* as when reading a page of print. Reverse direction is from right to left and top to bottom of the *Subject Copy.*

Scanning Line Frequency. See *Stroke Speed.*

Scanning Line Length. The total length of scanning line is equal to the *Spot Speed* divided by the *Scanning Line Frequency.*

Note: This is generally greater than the length of the *Available Line.*

Scanning Spot (in Facsimile). The area on the *Subject Copy* viewed instantaneously by the pickup system of the *Scanner.*

Scanning Spot *X* Dimension. The effective scanning spot dimension measured in the direction of the scanning line on the *Subject Copy.*

Note: The numerical value of this will depend upon the tvpe of system used.

Scanning Spot *Y* Dimension. The effective scanning spot dimension measured perpendicularly to the scanning line on the *Subject Copy.*

Note: The numerical value of this will depend upon the type of system used.

Signal Contrast (in Facsimile). The ratio expressed in decibels between *White Signal* and *Black Signal.*

Signal Frequency Shift. In a frequency shift *Facsimile System,* the numerical difference between the frequencies corresponding to *White Signal* and *Black Signal* at any point in the system.

Simple Scanning. Scanning of only one *Scanning Spot* at a time during the *Scanning* process.

Skew (in Facsimile). The deviation of the received *Frame* from rectangularity due to asynchronism between *Scanner* and *Recorder.* Skew is expressed numerically as the tangent of the angle of this deviation.

Spot Projection. The optical method of *Scanning* or *Recording* in which the *Scanning* or *Recording* spot is defined in the path of the reflected or transmitted light.

Spot Speed. The speed of the *Scanning* or *Recording* spot within the *Available Line.*

Note: This is generally measured on the *Subject Copy* or on the *Record Sheet.*

Stagger. Periodic error in the position of the *Recorded Spot* along the recorded line.

Start Record Signal. A signal used for starting the process of converting the electrical signal to an image on the *Record Sheet.*

Start Signal. A signal which initiates the transfer of a *Facsimile* equipment condition from standby to active.

Stop Record Signal. A signal used for stopping the process of converting the electrical signal to an image on the *Record Sheet.*

Stop Signal. A signal which initiates the transfer of a *Facsimile* equipment condition from active to standby.

Stroke Speed (Scanning or Recording Line Frequency). The number of times per minute, unless otherwise stated, that a fixed line perpendicular to the direction of *Scanning* is crossed in one direction by a *Scanning* or *Recording Spot.*

Note: In most conventional mechanical systems this is equivalent to *Drum Speed.* In systems in which the *Picture Signal* is used while *Scanning* in both directions, the *Stroke Speed* is twice the above figure.

Subcarrier. A carrier which is applied as a modulating wave to modulate another carrier.

Subject Copy. The material in graphic form which is to be transmitted for *Facsimile* reproduction.

Synchronizing (in Facsimile). The maintenance of predetermined speed relations between the *Scanning Spot* and the *Recording Spot* within each scanning line.

Synchronizing Signal (in Facsimile). A signal used for maintenance of predetermined speed relations between the *Scanning Spot* and *Recording Spot* within each scanning line.

Tailing (Hangover). The excessive prolongation of the decay of the signal.

Transmitter, Facsimile. The apparatus employed to translate the *Subject Copy* into signals suitable for delivery to the communication system.

Transmitting Converter, Facsimile (AM to FS Converter). A device which changes the type of modulation from amplitude to frequency shift.

Underlap *X*. The amount by which the center-to-center spacing of the *Recorded Spots* exceeds the *Recorded Spot X Dimension.*

Note: This effect arises in that type of equipment which responds to a constant *Density* in the *Subject Copy* by a succession of discrete *Recorded Spots.*

Underlap *Y*. The amount by which the *Nominal Line Width* exceeds the *Recorded Spot Y Dimension.*

Useful Line. See *Available Line.*

Vestigial Sideband. The transmitted portion of the sideband which has been largely suppressed by a transducer having a gradual cut-off in the neighborhood of the carrier frequency, the other sideband being transmitted without much suppression.

Vestigial Sideband Transmission. That method of signal transmission in which one normal sideband and the corresponding *Vestigial Sideband* are utilized.

White Recording. In an amplitude-modulation system, that form of *Recording* in which the maximum received power corresponds to the minimum *Density* of the *Record Medium.* In a frequency-modulation system that form of *Recording* in which the lowest received frequency corresponds to the minimum *Density* of the *Record Medium.*

White Signal. The signal at any point in a *Facsimile System* produced by the *Scanning* of a minimum *Density* area of the *Subject Copy.*

White Transmission. In an amplitude-modulation system, that form of transmission in which the maximum transmitted power corresponds to the minimum *Density* of the *Subject Copy.* In a frequency-modulation system, that form of transmission in which the lowest transmitted frequency corresponds to the minimum *Density* of the *Subject Copy.*

Docile Behavior of Feedback Amplifiers*

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When this paper was first submitted to the IRE, the reviewers pointed out one or two references that I had overlooked. These references contained essentially the same results. In revising the paper, I felt that perhaps in the two-terminal-pair case the derivations could be simplified enough to justify publication as a pedagogical exposition of classical results. Out went the Hermitian matrices, out went the positive-definite quadratic forms, out went nearly all of the equations and in came geometry, which I believe offers an interesting route to these results.—*Author's Note.*

***Summary*—A docile amplifier is one that remains stable when connected to any passive network of a specified class. A simplified geometrical approach is used to derive the docility criteria for passive-end-loading, ideal-transformer feedback, bilateral passive feedback, and arbitrary passive feedback.**

INTRODUCTION

A PASSIVE electrical device is one that remains stable in all possible environments that are themselves stable. A docile electrical device, like a docile animal or person, is one that remains stable if the environment is suitably restricted.

The question of docility arises in the design of amplifier circuits to be used in conjunction with passive loading or coupling networks. A docile amplifier is defined here as one that remains stable when connected to any passive network of a specified class. McMillan, Tellegen, and others studied this and related problems and offered stability criteria in various forms (see the bibliography). This paper presents a simplified geometrical approach and gives a tabulation of docility criteria for passive end-loading, ideal-transformer feedback, bilateral passive feedback, and arbitrary passive feedback. A vacuum-tube amplifier problem is considered as an illustrative example.

THE AMPLIFIER MODEL

Fig. 1 shows a linear model that can be used to represent the linear incremental behavior of any three-terminal electrical device. The model contains four independent complex quantities, Z_1, Z_2, Z_s, and Z_a. Each of these quantities is, in general, a function of frequency. Impedances Z_1, Z_2, Z_s describe that part of the device that obeys the reciprocity theorem. Quantities Z_1 and Z_2 are the familiar open-circuit input and output impedances of the amplifier. For example, Z_1 is just equal to the ratio of E_1 to I_1 computed with the

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right-hand end of the amplifier open-circuited. Quantity Z_s is the symmetric part of the transfer impedance. It measures the bilateral effect of I_1 upon E_2, and of I_2 upon E_1. The effect is the same in both directions. The possibility of an antisymmetric component of transfer impedance is accommodated by the presence of element jZ_a, which appears in the figure as two voltage sources: one controlled by current I_1; the other, by current I_2.

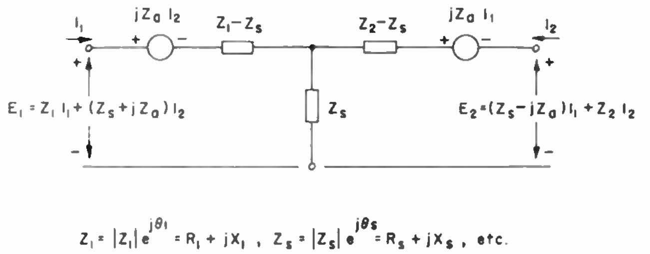


Fig. 1—Linear amplifier model.

Notice the polarities assigned to the two voltage sources. The contribution of I_1 to E_2 through jZ_a and the contribution of I_2 to E_1 through jZ_a are equal and opposite.

The amplifier model shows the antisymmetric impedance Z_a multiplied by the unit imaginary number j. This is a matter of choice and a matter of definition. When defined as shown in Fig. 1, quantity Z_a exhibits some of the properties associated with an impedance.

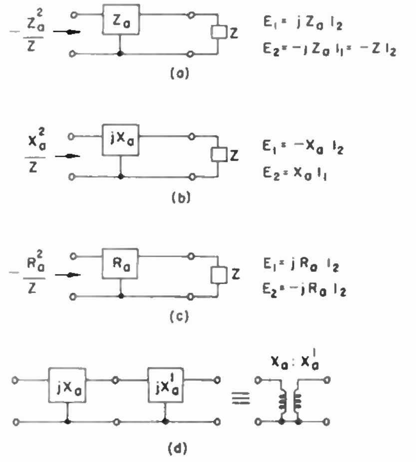


Fig. 2—Elementary amplifier forms. (a) A purely antisymmetric amplifier. (b) A gyrator. (c) A negative-impedance inverter. (d) Two gyrators make one ideal transformer.

The real part of Z_a (that is, the imaginary part of jZ_a) is responsible for the absorption or generation of power, and the imaginary part of Z_a is lossless. To see the effect more clearly consider a purely antisymmetric amplifier in which Z_1, Z_2, and Z_s are all zero. Fig. 2(a) shows such an amplifier together with the corresponding equations. A load impedance Z connected to one end of the amplifier yields the input impedance shown at the opposite end of the amplifier. This can be verified by solving the associated equations for the ratio of E_1 to I_1.

Two cases are of interest. First, suppose that Z_a is purely imaginary, as shown in Fig. 2(b). The load impedance Z is reflected at the opposite end of the amplifier as its inverse multiplied by a positive real number. If Z is purely resistive, the reflected input impedance is purely resistive and has the same sign. If Z is purely imaginary the input impedance is purely imaginary. Hence an amplifier consisting solely of jX_a is a lossless device. A lossless antisymmetric circuit is usually called a gyrator. [The name arises from the analogy between this circuit and the behavior of a gyroscope or top. Set a gyroscope spinning about a vertical axis and then push on it from the east in an attempt to tilt the axis westward. The gyroscope axis will respond to this force by tilting not westward but north (or south, depending on the direction of spin). If a push from the east tilts the gyroscope north, then by rotational symmetry a push from the north will tilt it west. With reference to the two mechanical coordinates, however, the gyroscope is antisymmetric. A westward push produces a *positive* northward motion; a northward push produces a *negative* westward motion.]

Now suppose that Z_a is purely real, as shown in Fig. 2(c). This device might be called a negative impedance inverter, since it inverts the load impedance and multiplies it by a negative real number. If the circuit is driven at the left by a signal source and loaded at the right with a positive resistance, the negative impedance inverter supplies power to the load and also to the driving source. If the load resistance is negative, however, the inverter will absorb power from both the load and the driving source.

The cascade combination of a gyrator and a negative impedance inverter could be classified as a negative impedance converter. The input impedance of a negative impedance converter is proportional to the negative of the load impedance. There are other interesting combinations. For example, two gyrators in cascade are equivalent to an ideal transformer, as indicated in Fig. 2(d).

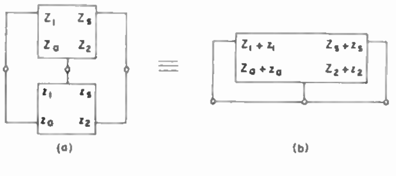


Fig. 3—Replacement of a loaded amplifier by an equivalent short-circuited amplifier.

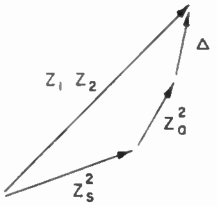
THE SHORT-CIRCUIT EQUIVALENCE

Fig. 3(a) shows the amplifier Z connected to a three-terminal loading and feedback network z. Both the amplifier and the attached network may be represented by models of the type shown in Fig. 1. It follows directly from the form of the circuit equations that the combination shown in Fig. 3(a) may be replaced by an equivalent short-circuited amplifier, as indicated in Fig. 3(b). The equivalent amplifier has component impedances that are the sums of the corresponding impedances in the original amplifier and its load network. This means that we can study the effect of various classes of three-terminal load networks by short-circuiting the amplifier and permitting various classes of alterations in its component impedances. Henceforth we can let Z_1, Z_2, Z_s, and Z_a denote either the amplifier impedances or the combined impedance components of the amplifier and its three-terminal load. The choice will be clear from the context.

SHORT-CIRCUIT EQUILIBRIUM

When the amplifier shown in Fig. 1 is short-circuited, the terminal voltages E_1 and E_2 vanish; and the currents I_1 and I_2 are related through a pair of homogeneous linear equations. (The amplifying system is presumably driven by an independent signal source but the drive may be ignored for the purposes of a stability analysis.) The two equations represent short-circuit equilibrium. The equations are satisfied if I_1 and I_2 both vanish, but this is a trivial solution. In order to permit nonzero equilibrium currents the determinant Δ of the short-circuit equations must vanish. The expression for Δ is given in Fig. 4. Short-circuit currents can exist only at those frequencies for which Δ vanishes.

For the present let the frequency be fixed while we consider the effects of changes in the real and imaginary componenets of Z_1, Z_2, Z_s, and Z_a.



$$\Delta = Z_1 Z_2 - (Z_s + jZ_a)(Z_s - jZ_a)$$
$$= Z_1 Z_2 - (Z_s^2 + Z_a^2)$$

Fig. 4—Short-circuit equilibrium diagram.

STRUCTURE OF THE EQUILIBRIUM DIAGRAM

The vector diagram shown in Fig. 4 contains squares and products of complex numbers. The simple geometrical properties of such squares and products are presented in Fig. 5. Consider the complex number $1+ja$. As the imaginary part of the number is varied, the square of the number moves along a parabola, as shown. The parabolic character of the locus is obvious from the fact that the real part of the square plus the magnitude of the square is a constant. The real part of the complex number has been normalized to unity in Fig. 5. For a non-unity real part the locus would be magnified in proportion to the square of the real part. Hence, in general, the locus is a parabola with focus at the origin and focal length equal to the square of the real part.

Now consider the complex vector representing the product of the two bracketed expressions in Fig. 5. The imaginary parts have been written as $a+b$ and $a-b$.

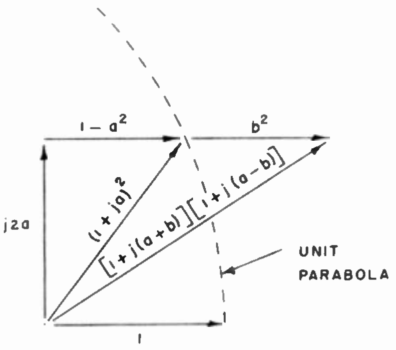
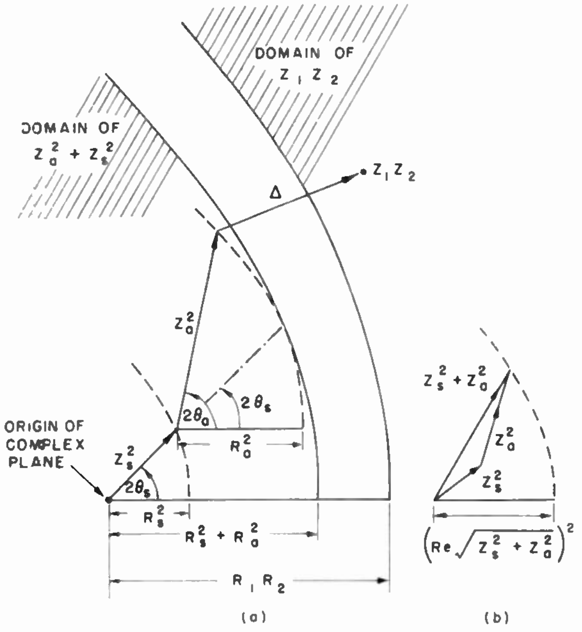


Fig. 5—The product of two complex numbers.

There is no loss of generality, since a and b can be chosen to give any desired imaginary parts. The product of the two bracketed quantities lies on or to the right of the parabola for all values of a and b. The real parts have been normalized to unity in Fig. 5. However, for non-unity real parts it follows directly that the product of two complex numbers cannot lie on the concave side of a parabola with focus at the origin and focal length equal to the product of the two real parts.



(a) (b)

Fig. 6—Detailed structure of the equilibrium diagram.

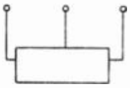
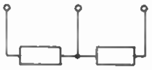
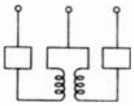
The vector diagram of Fig. 4 may now be structured more fully as, shown in Fig. 6. The focal lengths of all parabolas are indicated by braces. The tacit assumption is made that R_1 and R_2 are positive. This will be justified shortly.

PASSIVE END-LOADING

The attachment of a passive two-terminal load at each end of an amplifier permits certain variations of parameters in the equivalent short-circuit model. Since a passive two-terminal impedance has a positive real part, parameters R_1 and R_2 can be increased but not decreased. Reactances X_1 and X_2, however, are left completely arbitrary. Since end-loading provides no external feedback around the amplifier, the transfer components Z_s and Z_a remain fixed. Inspection of Fig. 6 shows that Δ cannot vanish if the focal length indicated in Fig. 6(b) is less than R_1R_2. This inequality fills its proper place in Table I.

TABLE I

CRITERIA FOR DOCILE BEHAVIOR

Class No.	Passive Load Amplifier	 Either Bilateral or General	 End Loading	 Ideal Transformer Feedback
1	general	$R_s^2+R_a^2$	$(\mathrm{Re}\sqrt{Z_s^2+Z_a^2})^2$	R_s^2
2	symmetric (bilateral) ($Z_a=0$)	R_s^2	R_s^2	R_s^2
3	antisymmetric ($Z_s=0$)	R_a^2	R_a^2	0
4	resistive ($X_s=X_a=0$)	$R_s^2=R_a^2$	$R_s^2+R_a^2$	R_s^2
5	reactive ($R_s=R_a=0$)	0	0	0
6	unilateral (Z_s+jZ_a)	$R_s^2+R_a^2$	0	R_s^2
7	real ($X_s=R_a=0$)	R_s^2	$R_s^2-X_a^2$	R_s^2
8	imaginary ($R_s=X_a=0$)	R_a^2	$R_a^2-X_s^2$	0
9	real unilateral $\begin{pmatrix}X_s=R_a=0\\ R_s=-X_a\end{pmatrix}$	R_s^2	0	R_s^2
10	imaginary unilateral $\begin{pmatrix}R_s=X_a=0\\ X_s=R_a\end{pmatrix}$	R_a^2	0	0

The amplifier in Fig. 1 is docile (assuredly stable for a given load class) if and only if (a) the amplifier is open-circuit stable, (b) R_1 and R_2 are positive at all real frequencies, (c) the tabulated quantity is less than R_1R_2 at all real frequencies.

LOSSLESS FEEDBACK

The attachment of an arbitrary lossless three-terminal network to an amplifier permits us to vary the imaginary parts X_1, X_2, X_s, and X_a in the equivalent short-circuit model. Inspection of Fig. 6(a) shows that Δ cannot vanish if $R_s^2+R_a^2$ is less than R_1R_2. Notice that the quantity $Z_s^2+Z_a^2$ can be carried to the boundary of its domain by a proper choice of either X_s or X_a, whichever is being varied. Hence Δ can be made just as small by arbitrary lossless bilateral (nongyratory) loading as by arbitrary lossless loading.

PASSIVE FEEDBACK

The lossless-feedback inequality requirement can be restated in the following form:

$$|R_s+jR_a| < \sqrt{R_1R_2} \qquad (R_1, R_2 \text{ positive}). \quad (1)$$

What happens if the feedback network is not lossless? Can resistive feedback loading be used to accomplish a further reduction of Δ? The answer is yes, but only if the feedback network itself violates a stability requirement, is therefore active, and can supply power to the amplifier. To insure passivity of the feedback network we shall impose a similar inequality upon its resistive components.

$$|r_s + jr_a| \leqq \sqrt{r_1 r_2} \qquad (r_1, r_2 \text{ positive}). \quad (2)$$

With this notation, the equivalent short-circuited amplifier has resistive components R_s+r_s, R_a+r_a, and so forth.

We shall now show that

$$\begin{aligned} |(R_s + r_s) + j(R_a + r_a)| &\leqq |R_s + j R_a| \\ &+ |r_s + jr_a| < \sqrt{R_1 R_2} \\ &+ \sqrt{r_1 r_2} \leqq \sqrt{(R_1 + r_1)(R_2 + r_2)}. \quad (3) \end{aligned}$$

The first inequality in this expression is a consequence of the fact that the magnitude of the sum of two complex numbers is less than, or at most equal to, the sum of their magnitudes. The second inequality can be obtained by direct addition of (1) and (2). The third inequality has the simple geometrical interpretation shown in Fig. 7. Elementary normalization of R_1 and R_2 is involved. The dimensions of Fig. 7 may be verified by a consideration of the proportionality of various right triangles in the diagram.

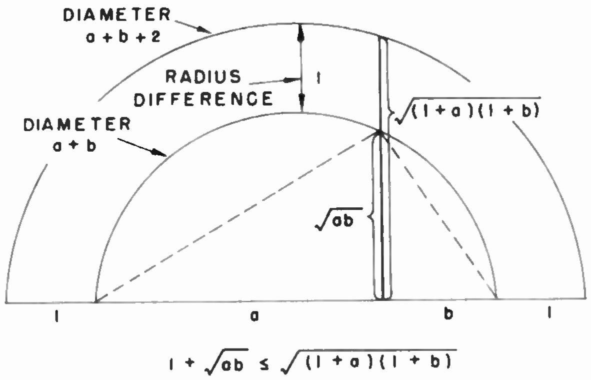


Fig. 7—An inequality involving two positive real numbers.

As a direct result of relation (3) we have

$$|(R_s + r_s) + j(R_a + r_a)| < \sqrt{(R_1 + r_1)(R_2 + r_2)}. \quad (4)$$

This is the desired result. Relations (1), (2), and (4) state, in effect, that an amplifier docile in a lossless environment will remain docile when connected to any network that is itself docile in a lossless environment.

The argument begins to run in circles. We shall stop it by accepting relation (2) as a definition of passivity. Therefore an amplifier docile in an arbitrary lossless environment is also docile in an arbitrary passive environment.

Eq. (1) is of the "less than" type; relation (2) of the "less-than-or-equal-to" type. This distinction permits a perfectly lossless feedback network but not a perfectly lossless amplifier. A perfectly lossless amplifier model actually represents a physical system on the verge of instability. It is reasonable therefore to let (1) represent docility, and to let (2) stand for passivity.

IDEAL-TRANSFORMER FEEDBACK

An ideal transformer may be thought of as an idealization resulting from a limiting process. Before the limit is reached the transformer reactances are very large but finite. The transformer exhibits reciprocity, so that its Z_a is zero. Hence the effect of ideal-transformer feedback upon the equivalent short-circuited amplifier is to leave X_a unaffected and make X_1, X_2, and X_s very large. In terms of Fig. 6 this means that we must move far out to the left of the origin where the parabolas are separated by great distances. Quantity Z_a becomes negligible in comparison with Z_s, and quantity R_a therefore drops out of the criterion, as indicated in Table I. The argument can be made rigorous by a more detailed consideration of the elementary limiting process.

CRITERIA FOR DOCILE BEHAVIOR

Table I summarizes the docility criteria for three classes of passive loading and ten amplifier types. The amplifier classifications are concerned with transfer properties and say nothing about the input and output impedances Z_1 and Z_2. For example, a "reactive" amplifier, class 5, may have positive input and output resistances. (R_1 and R_2 must, in fact, be positive if the docility criterion is to be met.)

The additional qualifications given at the bottom of the table arise from the following considerations. We assume that the amplifier impedances come originally from linear differential equations and each impedance is an analytic function of the complex frequency $s = \sigma + j\omega$. Each of the load classes considered here permits open-circuiting the amplifier. Unless the amplifier is open-circuit stable (that is, unless the impedance functions are free of poles for non-negative finite values of σ) sustained voltage oscillations will appear at the open amplifier terminals and docility will be violated. Similarly, if either R_1 or R_2 reaches zero or goes negative at any real frequency ($\sigma = 0$), sustained oscillations can be produced by a properly chosen passive end load, leaving the opposite end of the amplifier open.

If conditions (b) and (c) in Table I are met, it is clear from the geometry of Fig. 6 that for real frequencies the angle of complex vector Δ can never pass through the value π. In other words, the Nyquist plot of Δ does not encircle the origin. This fact, together with a classical result from function theory tells us that Δ has just exactly as many poles as it has zeros in the interior of the right half of the complex-frequency plane. Since Δ is a sum of products of amplifier impedances and since these impedances have no right-half-plane poles, it follows that Δ has no right-half-plane zeros. This assures stability of the equivalent short-circuited amplifier when the docility criteria are satisfied.

Table II shows the same information in a different form. All quantities and relations are expressed in terms of the classical open-circuit impedances, Z_{11}, Z_{12}, Z_{21}, Z_{22}.

TABLE II

Criteria for Docile Behavior in Terms of the Open-Circuit Impedances Z_{11}, Z_{12}, Z_{21}, Z_{22}

Class No.	Amplifier \ Passive Load	Either Bilateral or General	End Loading	Ideal Transformer Feedback
1	general ($Z_{12} \neq Z_{21}$)	$\left\lvert \frac{Z_{12}+\bar{Z}_{21}}{2} \right\rvert^2$	$(\text{Re}\,\sqrt{Z_{12}Z_{21}})^2$	$\left(\frac{R_{12}+R_{21}}{2}\right)^2$
2	symmetric ($Z_{12}=Z_{21}$)	R_{12}^2	R_{12}^2	R_{12}^2
3	antisymmetric ($Z_{12}=-Z_{21}$)	X_{12}^2	X_{12}^2	0
4	resistive ($Z_{12}=\bar{Z}_{21}$)	$\lvert Z_{12}\rvert^2$	$\lvert Z_{12}\rvert^2$	R_{12}^2
5	reactive ($Z_{12}=-\bar{Z}_{21}$)	0	0	0
6	unilateral ($Z_{21}=0$)	$\left\lvert \frac{Z_{12}}{2} \right\rvert^2$	0	$\left(\frac{R_{12}}{2}\right)^2$
7	real ($X_{12}=X_{21}=0$)	$\left(\frac{R_{12}+R_{21}}{2}\right)^2$	$R_{12}R_{21}$	$\left(\frac{R_{12}+R_{21}}{2}\right)^2$
8	imaginary ($R_{12}=R_{21}=0$)	$\left(\frac{X_{12}-X_{21}}{2}\right)^2$	$-X_{12}X_{21}$	0
9	real unilateral ($X_{12}=Z_{21}=0$)	$\left(\frac{R_{12}}{2}\right)^2$	0	$\left(\frac{R_{12}}{2}\right)^2$
10	imaginary unilateral ($R_{12}=Z_{21}=0$)	$\left(\frac{X_{12}}{2}\right)^2$	0	0

($Z_{11}=Z_1$, $Z_{22}=Z_2$, $Z_{12}=Z_s+jZ_a$, $Z_{21}=Z_s-jZ_a$)

The names given to the various amplifier classes in Tables I and II are not particularly apt. Some make more sense in terms of Z_s and Z_a; others suggest themselves when we think in terms of Z_{12} and Z_{21}. Let the reader take his choice.

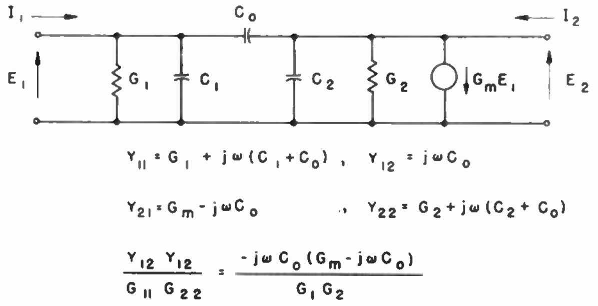


Fig. 8—Linear model of a vacuum-tube amplifier.

An Illustrative Example

Since the linear vacuum-tube amplifier model shown in Fig. 8 is both short-circuit and open-circuit stable, the docility criterion may be stated on either the admittance basis or the impedance basis. The admittance basis is more convenient.

Suppose that we want to find the lowest possible frequency of oscillation under passive end loading. On the short-circuit-admittance basis (the dual of the open-circuit-impedance basis) the docility criterion for end loading restricts the complex quantity $Y_{12}Y_{21}/G_{11}G_{22}$ to the concave side of the unit parabola shown in Fig. 9. We find that as the frequency ω is increased from zero, the quantity $Y_{12}Y_{21}/G_{11}G_{22}$ describes a parabolic locus that intersects the critical unit parabola at a frequency

$$\omega_0 = \frac{G_m}{2C_0}\,\frac{1}{\sqrt{f(f-1)}} \tag{5}$$

where

$$f = \frac{G_m^2}{4G_1G_2} \tag{6}$$

is the focal length of the locus. Incidentally, quantity f

happens to be equal to the low-frequency matched power gain of the amplifier. For a power gain f considerably larger than unity (the usual case), (5) can be rewritten as an approximate power-gain docile-bandwidth product

$$f\omega_0 \approx \frac{G_m}{2C_0}. \tag{7}$$

From (6) and (7) we find

$$\omega_0 \approx \frac{2G_1G_2}{G_0G_m}. \tag{8}$$

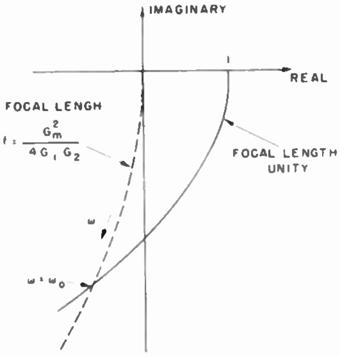


Fig. 9—Locus of $Y_{12}Y_{21}/G_{11}G_{22}$ as ω increases.

For a chosen load the oscillations may start at a complex frequency whose imaginary part ω is less than ω_0. As the amplitude grows, however, the nonlinear behavior of the actual device will bring about a reduction in the effective value of G_m, and the oscillations will therefore probably settle at a real frequency greater than ω_0. Such a gross simplification of the nonlinear effects is legitimate when the equilibrium amplitude of oscillations is not too large, and when the steady-state waveform is nearly sinusoidal; in short, when the system is quasi-linear.

CONCLUDING REMARKS

It is apparent that the docility criterion for arbitrary feedback is a severe restriction and that an amplifier satisfying such a requirement is indeed a very docile animal and not really a power amplifier at all. For this load type the criterion becomes useful in the design of feedback oscillators, since we may wish to calculate the nondocile real-frequency range over which a tuned feedback network can produce oscillations.

The criterion for end-loading is of interest in the analysis of cascaded amplifiers. An amplifier docile under end-loading is a respectable and dependable device. Passively loaded at one end, it presents a passive impedance at its opposite end. Hence a cascade of such devices is itself docile for loading at the two extreme terminations. The design may violate the criterion in a certain band of real frequencies if the terminations are controlled in this region with a sufficient margin of safety.

Some grounded-base and grounded-emitter junction transistors fail to meet the end-loading docility requirement in a middle band of real frequencies, although they are both open-circuit-stable and short-circuit-stable and docile at both high and low frequencies.

ACKNOWLEDGMENT

The author is grateful to Dr. R. B. Adler, of the Department of Electrical Engineering and the Research Laboratory of Electronics, M.I.T., for helpful discussions.

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A Note on Bandwidth*

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Summary—**The concept of "bandwidth" is commonly used as a measure of the range of frequencies over which a network has an approximately constant gain. In this note the notion of bandwidth is extended to networks with arbitrary transfer characteristics. Specifically, it is defined in terms of the maximum allowable variance of the output of a network (to within a multiplicative constant) from that of an "ideal" network, the input being a band-limited signal. The maximum bandwidth of such an input signal is termed the bandwidth of the network under consideration.**

INTRODUCTION

CONSIDER a time-invariant linear four-terminal network N. Let $e_i(t)$ and $e_{N0}(t)$ be its input and output signals. The relation between e_i and e_{N0} is determined by the transfer function $\overline{H}_N$ of N.

The familiar concept of bandwidth characterizes concisely one aspect of the transfer function; it is a measure of the width of a contiguous band of approximately constant gain. Bandwidth thus involves a comparison of the network with an ideal resistor. Frequently, however, a network is called upon to perform functions other than providing faithful transmission. In a computing circuit, for example, a network might be required to simulate an integrator. It is our object to extend the bandwidth concept to such cases.

THE EFFECTIVE BANDWIDTH

Let $\overline{H}_I$ denote an "ideal" transfer function, which might be viewed as the characterization of an ideal network, I, although I need not be physically realizable. Now apply identical inputs to N and I, and denote the outputs by e_{N0} and e_{I0}. To evaluate the performance we form the output error

$$\epsilon'(\alpha, t) \stackrel{\Delta}{=} e_{N0}(t) - \alpha e_{I0}(t) \tag{1}$$

or, taking Fourier transforms of this equation,

$$\overline{E}'(\alpha, j\omega) \stackrel{\Delta}{=} \bar{e}_{N0} - \alpha \bar{e}_{I0} = (\overline{H}_N - \alpha \overline{H}_I)\bar{e}_i \tag{2}$$

where α is a real constant which has been introduced in order to enable us to adjust the relative scale of the outputs for best fit; in other words, we compare the shapes of the outputs, regardless of scale. ϵ', $\overline{E}'$ are functions of α, t and $e_i(t)$.

We can say little more unless e_i is specified. Let us now choose e_i as follows:

$$\bar{e}_i = \bar{e}_1 \stackrel{\Delta}{=} \begin{cases} 1, & |\omega| \leqq \omega_m \\ 0, & |\omega| > \omega_m \end{cases} \tag{3}$$

i.e., a band-limited signal of bandwidth ω_m. Then

$$e_i(t) = e_1(t) = \frac{\omega_m}{\pi} \operatorname{sinc} \omega_m t \stackrel{\Delta}{=} \frac{\omega_m}{\pi} \frac{\sin \omega_m t}{\omega_m t}. \tag{4}$$

With e_1 as input we drop the apostrophes in (1) and (2), and the fractional rms error of the output is given by[1]

$$\mathcal{E}_\alpha^2(\omega_m) = \frac{\int_{-\infty}^{\infty} \epsilon^2(\alpha, t)dt}{\int_{-\infty}^{\infty} \alpha^2 e_{I0}^2(t)dt} = \frac{\int_{-\infty}^{\infty} |\overline{E}(\alpha)|^2 d\omega}{\int_{-\infty}^{\infty} |\alpha \overline{H}_I|^2 d\omega}$$

$$= \frac{\int_{-\omega_m}^{\omega_m} |\overline{E}(\alpha)|^2 d\omega}{\int_{-\omega_m}^{\omega_m} |\alpha \overline{H}_I|^2 d\omega} = \frac{\int_{-\omega_m}^{\omega_m} |\overline{H}_N - \alpha \overline{H}_I|^2 d\omega}{\int_{-\omega_m}^{\omega_m} |\alpha \overline{H}_I|^2 d\omega}, \tag{5}$$

where the first step follows from Parseval's theorem.

$$\int_{-\infty}^{\infty} |f(t)|^2 dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} |\bar{f}(j\omega)|^2 d\omega.$$

We now adjust α so as to minimize this expression. This requires

$$\alpha = \frac{\int_0^{\omega_m} \operatorname{Re}(\overline{H}_I \overline{H}_N^*) d\omega}{\int_0^{\omega_m} |\overline{H}_I|^2 d\omega} = \frac{\int_{-\omega_m}^{\omega_m} \overline{H}_I \overline{H}_N^* d\omega}{\int_{-\omega_m}^{\omega_m} |\overline{H}_I|^2 d\omega}. \tag{6}$$

The minimum is (integrations between 0 and ω_m)

$$\mathcal{E}^2(\omega_m) = \frac{\int |\overline{H}_I|^2 d\omega \int |\overline{H}_N|^2 d\omega - \left[\int \operatorname{Re}(\overline{H}_I \overline{H}_N^*) d\omega\right]^2}{\left[\int \operatorname{Re}(\overline{H}_I \overline{H}_N^*) d\omega\right]^2}. \tag{7}$$

We define ω_m as the *effective* (*or rms*) *bandwidth* of N with respect to I, associated with the error $\mathcal{E}$.

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[1] A similar result is obtained if normalization is carried out with respect to the output.

THE OVER-ALL ERROR

It may happen that the over-all fractional rms error defined by

$$\mathcal{E}_\infty = \lim_{\omega_m \to \infty} \mathcal{E}(\omega_m) \tag{8}$$

is small compared with one. Its reciprocal is then useful as a figure of merit measuring the "nearness" of N and I. The input e_i, (4), then becomes a unit impulse and the outputs of N and I become $W_N(t)$ and $W_I(t)$, the impulse response or weighting functions of these networks. It is then easy to show that

$$\mathcal{E}_\infty{}^2 = \frac{\int_0^\infty W_I{}^2(t)dt \int_0^\infty W_N{}^2(t)dt - \left[\int_0^\infty W_I(t)W_N(t)dt\right]^2}{\left[\int_0^\infty W_I(t)W_N(t)dt\right]^2}. \tag{9}$$

This can be done by a repetition of our considerations in the time domain. Alternatively, (7) could be converted with the aid of the Fourier transform representation of the delta function, bearing in mind that $\overline{W} = \overline{H}$.

SOME EXTENSIONS

In the foregoing we have confined our attention to the case where the band was centered on zero frequency. Similar considerations apply to a band centered on any other frequency.

Our considerations apply to the case of a frequency-band of constant intensity as input. Simpler and rather obvious results obtain for single frequency inputs.

The considerations of this paper are applied to analog computers in a separate paper.[2]

EXAMPLES

A Differentiator

The simple RC network of Fig. 1 is to be used as a

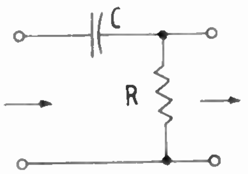

Fig. 1

differentiator. Writing $T \triangleq RC$ we have

$$\begin{cases} \overline{H}_I = j\omega T; \\ \overline{H}_N = \dfrac{j\omega T}{1 + j\omega T}. \end{cases}$$

We notice that proper operation requires

$$\omega T \ll 1.$$

Under this assumption

$$\overline{H}_N \cong j\omega T(1 - j\omega T) = j\omega T - (\omega T)^2.$$

Now

$$\text{Re}\,(\overline{H}_I \overline{H}_N{}^*) = \text{Re}\,\frac{(\omega T)^2}{1 - j\omega T} = \frac{(\omega T)^2}{1 + (\omega T)^2} = |\,\overline{H}_N\,|^2.$$

Therefore, using (7),

$$\mathcal{E}^2 = \frac{\int |\,\overline{H}_I\,|^2 - \int |\,\overline{H}_N\,|^2}{\int |\,\overline{H}_N\,|^2} \cong \frac{(\omega_m T)^5}{5} \cdot \frac{3}{(\omega_m T)^3}$$

$$= \frac{3}{5}(\omega_m T)^2,$$

or

$$\omega_m T \cong \sqrt{5/3}\,\mathcal{E} = 1.29\,\mathcal{E}.$$

An Integrator

The network of Fig. 2 is to be used as an integrator.

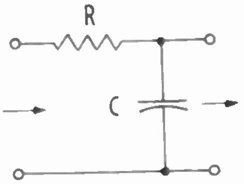

Fig. 2

Thus

$$\begin{cases} \overline{H}_I = \dfrac{1}{j\omega T}, \\ \overline{H}_N = \dfrac{1}{1 + j\omega T}. \end{cases}$$

We fail if we try to evaluate $\mathcal{E}$, (7), as some of the integrals do not converge. Indeed we must conclude that the error is infinite: a somewhat surprising result at first sight. It becomes intelligible if we notice that N does not function at all as an integrator at zero frequency. In

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[2] Amos Nathan, "The rms error as a design criterion of linear electronic differential analyzers," to be published.

fact we must impose the condition

$$\omega T \geqq \omega_1 T \gg 1.$$

As upper limit of the frequency band let us take infinity.

The limits of integration in (7) must here be replaced by ω_1 and ∞. Now

$$\mathrm{Re}\,(\overline{H}_I \overline{H}_N^*) = \mathrm{Re}\left(\frac{1}{j\omega T}\,\frac{1}{1 - j\omega T}\right) = \frac{1}{1 + \omega^2} = |\overline{H}_N|^2$$

as in the preceding section, and

$$\int_{\omega_1}^{\infty} |\overline{H}_I|^2 d\omega = \int_{\omega_1}^{\infty} \frac{1}{(\omega T)^2}\, d\omega = \frac{1}{T}\cdot\frac{1}{\omega_1 T}$$

$$\int_{\omega_1}^{\infty} |\overline{H}_N|^2 d\omega = \int_{\omega_1}^{\infty} \frac{1}{1 + (\omega T)^2}\, d\omega$$

$$\cong \frac{1}{T}\int_{\omega_1}^{\infty}\left[\frac{1}{(\omega T)^2} - \frac{1}{(\omega T)^4}\right] d\omega$$

$$= \frac{1}{T}\left[\frac{1}{\omega_1 T} - \frac{1}{3(\omega_1 T)^3}\right].$$

Finally

$$\mathcal{E}^2 \cong \frac{1}{3(\omega_1 T)^3}(\omega_1 T) = \frac{1}{3}\,\frac{1}{(\omega_1 T)^2},$$

or

$$\omega_1 T \cong \sqrt{3}\,\mathcal{E} = 1.73\,\mathcal{E}.$$

If the same network were to be used as an integrator in a differential analyzer, it would be required to operate during T_c, the computing time, only. The following approach might therefore be preferable.

We describe network I by its impulse response:

$$W_I(t) = \begin{cases} 1(t), & t \leqq T_c \\ 0, & t > T_c \end{cases}.$$

The impulse response of N is proportional to

$$W_N(t) = \begin{cases} E^{-t/T}(t), & t \leqq T_c \\ 0, & t > T_c \end{cases}.$$

Assuming $T \ll T_c$ we obtain

$$\int_0^{\infty} W_I^2 dt = T_c;$$

$$\int_0^{\infty} W_N^2 dt = \int_0^{T_c} \epsilon^{-2t/T} dt$$

$$\cong T\left[1 - \left(\frac{T_c}{T}\right) + \frac{4}{3}\left(\frac{T_c}{T}\right)^2\right];$$

$$\int_0^{\infty} W_I W_N dt = \int_0^{T_c} \epsilon^{-t/T} dt$$

$$\cong T\left[1 - \frac{1}{2}\left(\frac{T_c}{T}\right) + \frac{1}{6}\left(\frac{T_c}{T}\right)^2\right];$$

and from (9),

$$\mathcal{E}_\infty^2 = \frac{5}{12}\left(\frac{T_c}{T}\right)^2,$$

or

$$T_c/T \cong \sqrt{12/5}\,\mathcal{E}_\infty = 1.55\,\mathcal{E}_\infty$$

whence we might calculate the permissible duration of computation for a given error.

A word of caution is in order: our result holds strictly only for the specific input considered, which is here an impulse at $t = 0$.

Measurement of Microwave Dielectric Constants and Tensor Permeabilities of Ferrite Spheres*

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***Summary*—The Bethe-Schwinger cavity perturbation theory is applied to measurements of the microwave dielectric constants and tensor permeabilities of small spherical samples of ferrites. For the dielectric constant measurements, a cavity opened at a position of minimum transverse wall currents is used. A frequency-shift method is used for measuring the real part of the dielectric constant and a cavity-transmission method is used for measurement of the loss tangent. Circularly-polarized cavity methods yield effective scalar permeabilities of which the real and the imaginary parts are measured in a manner similar to the dielectric measurements. These scalar permeabilities yield sufficient information to describe completely the tensor components. Experimental data are given for a polycrystalline magnesium-manganese ferrite, to illustrate the techniques described.**

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INTRODUCTION

IN ORDER to analyze new ferrites for possible microwave applications, and to correlate the results obtainable with the fundamental physical properties of the ferrites, precise physical measurements are necessary. A description is given of techniques and apparatus used in this laboratory for the measurement of the microwave dielectric constants and tensor permeabilities of ferrites. The quantities completely describe the microwave properties of a material with a superposed steady magnetic field. More information is needed if, for instance, fast-rising magnetizing pulses are to be applied. The experimental technique is designed for small sample studies partially because experimental ferrites, especially single crystals, are usually available only in small sizes.

The dielectric constant is a scalar defined by the equation,

$$D = \epsilon E$$

where

$$\epsilon = \epsilon' - i\epsilon'' \tag{1}$$

Results are normally given in terms of ϵ' and the loss tangent $\tan \delta = \epsilon''/\epsilon'$.

Polder[1] showed that the permeability of an infinite medium magnetically saturated in the z direction is not a scalar but has a tensor form, given by

$$\begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix} = \begin{bmatrix} \mu & -iK & 0 \\ iK & \mu & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} h_x{}^i \\ h_y{}^i \\ h_z{}^i \end{bmatrix} \tag{2}$$

where h^i is the rf internal magnetic field, b is the rf induction, or flux density, and the components μ and K are complex quantities. The form of the tensor relation may be derived based on a discussion of the rotational symmetry of the magnetization vector about a line in the direction of the magnetic field. Alternatively, the structural physics of the ferrite material may be brought into the derivation of the tensor elements μ and K in terms of physical constants. In discussing the measurements techniques, it is sufficient to treat μ and K phenomenologically. These measured values of μ and K can be interpreted and compared with the predicted values of the theories.

Many uses of ferrites in applications depend on the Faraday rotation property. Relations have been derived[2] describing the rotation in terms of the tensor permeability components and dielectric constant for the case of a linearly-polarized wave in an infinite medium. The rotation angle may be expressed as,

$$\theta = \frac{l}{2}(\beta_- - \beta_+) \tag{3}$$

θ is the angle of rotation of the polarization of the plane wave, l is the path length of the medium and β_- and β_+ are the phase constants of the two circularly-polarized waves of which the linear wave is composed. If losses are ignored, the last are given by

$$\beta_\pm = \frac{\omega}{c}\sqrt{\frac{(\mu' \mp K')\epsilon'}{2}} \tag{4}$$

where μ' is the real part of $\mu = \mu' - i\mu''$; and K' is the real part of $K = K' - iK''$.

The terms μ'' and K'' define the magnetic losses. However in the absence of a magnetic field, the permeability is simply a scalar and the initial μ'' and the ϵ'' primarily determine the insertion loss of the ferrite. The real part of the dielectric constant ϵ' acts as a multiplying factor for the magnetic effects. This discussion illustrates how the six quantities, the real and the imaginary parts of ϵ, μ, and K are all involved in ferrite applications.

CAVITY PERTURBATION THEORY

All measurements to be described are made in resonant microwave cavities. The samples are spheres, small compared to wavelength, so that the microwave field may be considered uniform over the sample. The formulation will follow the perturbation calculations of Bethe and Schwinger.[3,4] The basis of these calculations is the formula given by Muller[5,6] giving the complex frequency shift δf of a resonant cavity, because of some small change, in terms of the increase in the complex cavity energy δw.

$$\frac{\delta_f}{f} = -\frac{\delta_w}{w}. \tag{5}$$

The usual perturbation approximation assumes that the change in stored energy, upon introducing the sample, is small compared to the total stored energy. This approximation is much too stringent, is not necessary, and is usually not satisfied in actual experiments. A more accurate criterion is the smallness of the percentage frequency shift, which is related to the change in the over-all field configurations in the cavity upon introducing the sample. In terms of rf fields and a sample with scalar ϵ and scalar μ_s, (5) becomes

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[1] D. Polder, "On the theory of ferromagnetic resonance," *Phil. Mag.*, vol. 40; pp. 99–115; January, 1949.

[2] C. L. Hogan, "The ferromagnetic Faraday effect at microwave frequencies and its applications," *Bell Sys. Tech. J.*, vol. 31, pp. 1–31; January, 1952; "The ferromagnetic Faraday effect at microwave frequencies and its applications," *Phys. Rev.*, vol. 25, pp. 253–263; January, 1953.

[3] H. A. Bethe and J. Schwinger, "Perturbation theory for cavities," N.R.D.C. Rep. D1-117 Cornell Univ.; March, 1943.

[4] Similar results are obtained using the Slater normal mode method. See B. Lax and A. D. Berk, "Resonance in cavities with complex media," 1953 IRE CONVENTION RECORD, Part 10, pp. 70–74.

[5] J. Muller, "Untersuchung über electromagnetische hohlräume," *Hochfrequenz.*, vol. 57, pp. 157–161; 1939.

[6] C. H. Papas, "Thermodynamic considerations of electromagnetic cavity resonators," *J. Appl. Phys.*, vol. 25, pp. 1552–1553; December, 1954.

$$\frac{\delta f}{f} = \frac{-(\epsilon - 1)\int_{v_s} E^0 \cdot E^i dv - (\mu_s - 1)\int_{v_s} h^0 \cdot h^i dv}{\int_{v_c} (E^{02} + h^{02}) dv} . \tag{6}$$

The superscripts 0 refer to fields in the empty cavity, or applied fields at the sample and the superscripts i to fields inside the sample. v_s refers to integration over the volume of the sample and v_c to integration over the volume of the cavity. The designation μ_s is used to avoid confusion between this scalar μ_s and the diagonal component of the tensor permeability.

Placing the sample alternatively in the positions of maximum E and maximum H fields allows separation of the electric and magnetic measurements.

Electrical Properties

Consider first the electric measurements. Eq. (6) becomes, for the sample properly located in the cavity,

$$\frac{\delta f}{f} = -(\epsilon - 1)\frac{\int_{v_s} E^0 \cdot E^i dv}{\int_{v_c} (E^{02} + h^{02}) dv} . \tag{7}$$

The electrostatic approximation is used to compute the magnitude of the electric field, E^i, in the sample. For a dielectric sphere placed in a parallel electric field E^0, the field is uniform throughout the sphere and is given by

$$E^i = \frac{3E^0}{\epsilon' + 2} . \tag{8}$$

For a TE_{10n} mode rectangular cavity the frequency shift equation becomes,

$$\frac{\delta_f}{f} = \frac{-6(\epsilon - 1)}{(\epsilon + 2)} \frac{v_s}{v_c} . \tag{9}$$

In terms of the real and the imaginary parts of f and ϵ, (9) becomes,

$$\frac{\delta_{f'}}{f'} = -6\frac{(\epsilon' - 1)}{(\epsilon' + 2)} \frac{v_s}{v_c} \tag{10a}$$

$$\frac{\delta_{f''}}{f'} = \frac{18\epsilon''}{(\epsilon' + 2)^2} \frac{v_s}{v_c} . \tag{10b}$$

Small correction terms have been omitted which might be required for a very lossy sample. In the complex frequency concept , the real part of the frequency shift is the measured frequency shift. The imaginary part is given by the change in the loaded Q of the cavity.

$$\frac{\delta_{f''}}{f} = \delta\left(\frac{1}{2Q_L}\right) \tag{11}$$

$$\delta\left(\frac{1}{Q_L}\right) = \frac{Q_L{}^e - Q_L{}^s}{Q_L{}^e Q_L{}^s} , \tag{12}$$

where $Q_L{}^e$ is the loaded Q of the empty cavity and $Q_L{}^s$ is the loaded Q of the cavity with the sample in place. The final equation for the loss term is then

$$\frac{Q_L{}^e - Q_L{}^s}{Q_L{}^e Q_L{}^s} = \frac{36\epsilon''}{(\epsilon' + 2)^2} \frac{v_s}{v_c} . \tag{13}$$

This equation and (10a) give the dielectric constant and loss factor in terms of directly measurable quantities.

Ferromagnetic Properties

The ferromagnetic measurements require different techniques because of the tensor character of the permeability. To diagnonalize the tensor new field coordinates are required.[7] Written in these coordinates, assuming the steady applied field to be in the z direction, (2) becomes

$$\begin{bmatrix} b_x - ib_y \\ b_x + ib_y \\ b_z \end{bmatrix} = \begin{bmatrix} \mu + K & 0 & 0 \\ 0 & \mu - K & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} h_x{}^i - ih_y{}^i \\ h_x{}^i + ih_y{}^i \\ h_z{}^i \end{bmatrix} , \tag{14}$$

where $h_x = \mp ih_y$. Minus ih_y relates to $\mu + K$. By equating components,

$$\left.\begin{aligned} b_x - ib_y &= (\mu + K)(h_x{}^i - ih_y{}^i) \\ b_x + ib_y &= (\mu - K)(h_x{}^i + ih_y{}^i) \\ b_z &= h_z{}^i \end{aligned}\right\} . \tag{15}$$

The first two of the new field coordinates represent two alternating fields of equal amplitude, in space and time quadrature, which constitute circularly-polarized waves. $h_x{}^i \mp ih_y{}^i$ are positive and negative circularly-polarized waves, respectively, and h_z is the steady applied field. A positive circularly-polarized wave is defined as a wave which rotates in the direction of the positive current in a solenoid producing the steady magnetic field. This is the same as that of the electronic precession. The convention agrees with Hogan's Figs. 1 and 2 and (14) and (15), but not with his (13). The magnetic flux is then related to the magnetic field by an effective scalar permeability for a circularly-polarized

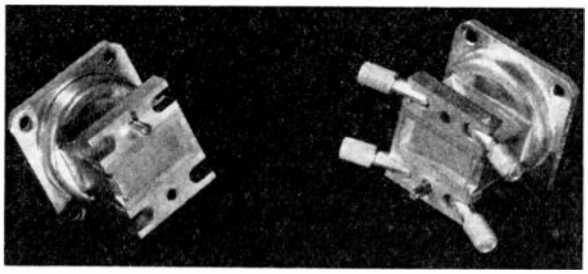

Fig. 1—TE_{103} mode rectangular cavity which is opened at a position of minimum wall currents.

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[7] This is analogous to transformation to principal axes in the problem of the moments of inertia of solid bodies or to normal modes of vibration in mechanics. For a discussion of the concepts and details, see J. C. Slater and N. H. Frank, "Mechanics," McGraw-Hill Book Co., New York, N. Y.; 1947. Eq. (15) can be more simply derived by multiplying b_y in (2) by $\pm i$ and adding to b_x.

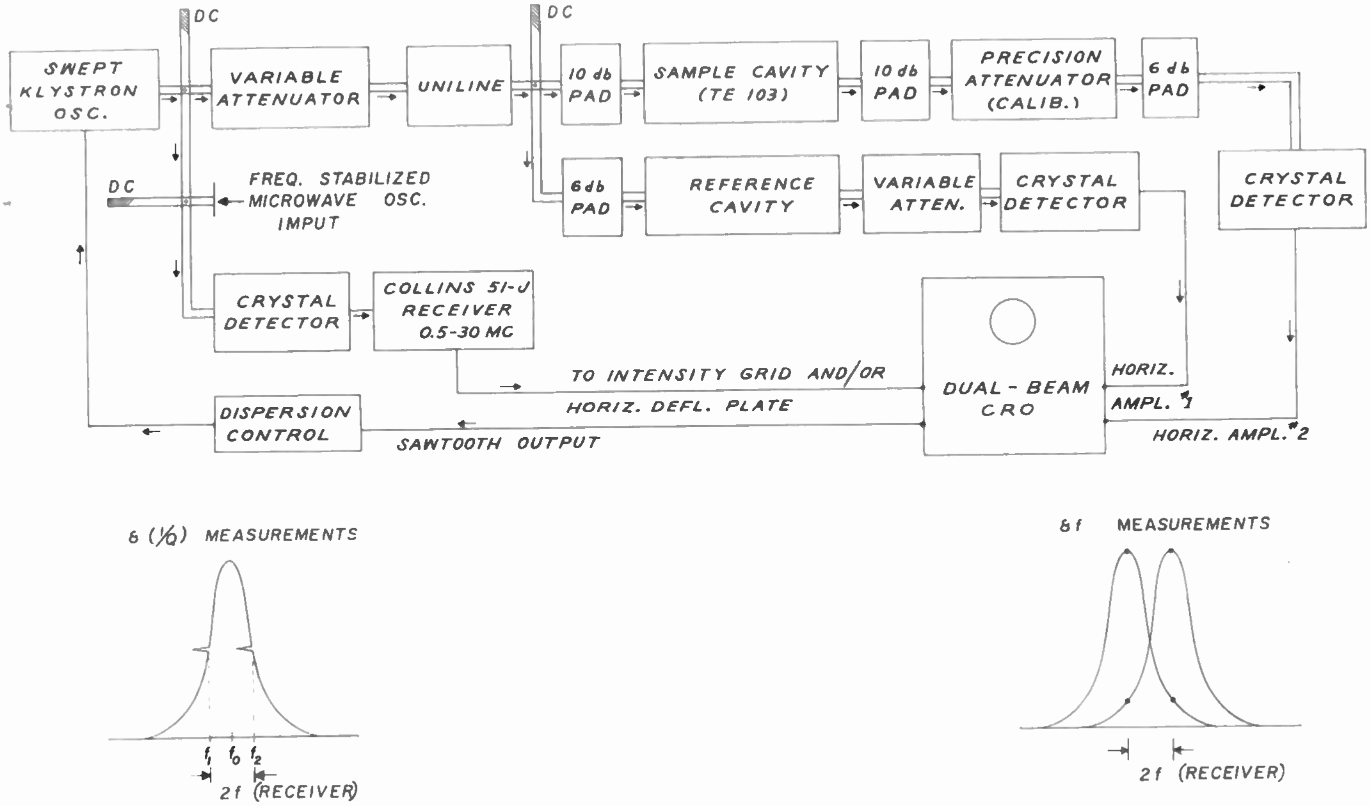

Fig. 2—Swept frequency method for measuring dielectric constant.

wave. Eq. (15) may be written as

$$\left.\begin{aligned} b_\pm &= (\mu \pm K) h_\pm{}^i \\ b_z &= h_z{}^i \end{aligned}\right\}, \tag{16}$$

where the subscripts refer to positive and negative circularly-polarized waves, respectively.

Thus a cylindrical cavity excited alternately by positive and negative circularly-polarized waves may be used to obtain the components of the permeability tensor.

The frequency shift and the change in cavity Q_L are measured for each case. These four quantities are sufficient information to allow calculation of the real and imaginary parts of μ and K. Thus, the individual components of the tensor permeability are measurable.

Sample Shape for Magnetic Measurements

A ferrite sample, small compared to wavelength, is placed in a position of maximum rf magnetic field and zero rf electric field. Combining (16) and (6) yields

$$\frac{\delta f_\pm}{f} = -(\mu \pm K - 1) \frac{\int_{v_s} h_\pm{}^0 \cdot h_\pm{}^i dv}{\int_{v_c} (E_\pm{}^{02} + h_\pm{}^{02}) dv}. \tag{17}$$

For a homogeneous isotropic spherical sample the internal fields $h_\pm{}^i$ are related to the external fields $h_\pm{}^0$ by $h_\pm{}^i = h_\pm{}^0 - 4\pi m \pm /3m$. The $m_\pm$ are rf magnetizations for positive and negative circularly-polarized waves, and are defined by $4\pi m_\pm = b_\pm \cdot h_\pm{}^i$. Using these relations and the general relation $b_\pm = (\mu \pm K) h_\pm{}^i$ results in

$$h_\pm{}^i = \frac{3}{\mu \pm K + 2} h_\pm{}^0 \tag{18}$$

Since the rf field is approximately constant over the sample, (17) becomes

$$\frac{\delta f_\pm}{f} = -3 \frac{(\mu \pm K - 1)}{(\mu \pm K + 2)} \frac{(h_\pm{}^0)^2 v_s}{\int_{v_c} (E_\pm{}^{02} + h_\pm{}^{02}) dv}. \tag{19}$$

Employing the field components, for a TE_{11n} mode cylindrical cavity, by Montgomery,[8] and integrating, gives

$$\frac{\delta f_\pm}{f} = -3 \frac{(\mu \pm K - 1)}{(\mu \pm K + 2)} \frac{(h^0)^2 v_s}{0.1194 v_c}. \tag{20}$$

The evaluation is completed by putting in the magnetic field component for $(h^0)^2$.

$$\frac{\delta f_\pm}{f} = -3 \frac{(\mu \pm K - 1)}{(\mu \pm K + 2)} \frac{v_s}{4\left(1 + \frac{1.37}{n^2} \frac{L^2}{D^2}\right) 0.1194 v_c}. \tag{21}$$

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[8] C. G. Montomery "Technique of Microwave Measurements," McGraw-Hill Book Co., Inc., New York, N. Y., pp. 289, 396–403; 1947.

In the experiments the cavity L was equal to D and was excited in the TE_{112} mode, which simplifies the above equation to

$$\frac{\delta f_\pm}{f} = -3\,\frac{(\mu \pm K - 1)}{(\mu \pm K + 2)}\,\frac{v_s}{0.6416 v_c}\,. \tag{22}$$

The Resonance Condition

Using the effective scalar permeabilities for positive and negative circularly-polarized waves, the rf magnetization may be written as

$$\begin{aligned} m_\pm &= \frac{(\mu \pm K - 1)}{4\pi}\,h_\pm{}^i \\ &= \frac{3(\mu \pm K - 1)}{4\pi(\mu \pm K + 2)}\,h_\pm{}^0. \end{aligned} \tag{23}$$

Eq. (22) becomes

$$\frac{\delta f_\pm}{f} = -4\pi\,\frac{m_\pm}{h_\pm{}^0}\,\frac{v_s}{0.6416 v_c}\,. \tag{24}$$

The results written in this form point out the resonance conditions in a precise manner. When the applied steady magnetic field is varied, the rf magnetization, $m_\pm$ and hence $h_\pm{}^i$ also vary. However, the applied rf field $h_\pm{}^0$ may in an experiment be held essentially constant. Thus, as the steady magnetic field is varied, the imaginary part of the rf magnetization goes through a maximum at resonance. These are the same conditions of resonance described by Kittel.[9]

The intrinsic $\mu \pm K$, which are constants of the ferrite material regardless of sample shape, are defined (16) and take the form

$$\mu \pm K = 1 + \frac{4\pi m_\pm}{h_\pm{}^i}\,. \tag{25}$$

By defining a new $\tilde{\mu} \pm \tilde{K}$ as

$$\tilde{\mu} \pm \tilde{K} = 1 + \frac{4\pi m_\pm}{h_\pm{}^0} \tag{26}$$

the experimental results can be written in a simple manner. Eq. (24) becomes

$$\frac{\delta f_\pm}{f} = -(\tilde{\mu} \pm \tilde{K} - 1)\,\frac{v_s}{0.6416 v_c}\,. \tag{27}$$

Written in terms of real and imaginary parts,

$$\left(\frac{\delta f'}{f'}\right)_\pm = -(\tilde{\mu}' \pm K' - 1)\,\frac{v_s}{0.6416 v_c} \tag{28}$$

$$\delta\left(\frac{1}{2Q}\right)_\pm = (\tilde{\mu}'' \pm K'')\,\frac{v_s}{0.6416 v_c}\,. \tag{29}$$

The forms of the equations also hold for other sample shapes, with $\tilde{\mu} \pm \tilde{K}$ having unique characteristics for each shape.

The relation between $\mu \pm K$ and $\tilde{\mu} \pm \tilde{K}$ is readily derived from (25), (26), and (18), which yield,

$$\mu \pm K = \frac{1 + 2(\tilde{\mu} \pm \tilde{K})}{4 - (\tilde{\mu} \pm \tilde{K})}\,. \tag{30}$$

From the real and imaginary values of $\tilde{\mu} \pm \tilde{K}$, the intrinsic values[10] $\mu \pm K$ are easily calculated.

ELECTRICAL MEASUREMENTS TECHNIQUES

The dielectrics measurements problem was shown to be that of measuring the changes in frequency and Q_L of a resonant cavity when a dielectric sample is introduced. Fig. 1 shows a cavity which has proved satisfactory and which may be separated in the exact center. This does not greatly disturb the wall currents, and the cavity may be opened and closed, with the frequency and transmission returning exactly to their original values. This was not true for some other cavities when, for instance, one wall was made removable.

Spherical samples, 1 and 2 mm in diameter, are suspended through a small hole in the top of the cavity by a nylon thread approximately .0001 inch in diameter. Care must be used in cementing the thread to the sample so as to minimize errors introduced by the cement.

Fig. 2 shows a block diagram of the equipment used for the measurements. It is essentially a cavity Q-meter technique[8] or a modified Birnbaum gas spectrometer.[11] The method consists of a swept frequency microwave oscillator, used as a common source, so as to display simultaneously the resonant curves of two well-isolated cavities on a dual-beam oscilloscope. One of these cavities is the sample cavity and the other a tunable reference cavity. The reference cavity is used as a reference to measure the frequency shift when the sample is inserted in the sample cavity.

For the small frequency shifts experienced in the measurements on the spheres, a heterodyne method is used. Energy from a frequency-stabilized source is mixed in a crystal detector with energy from the swept oscillator. The resultant is fed into a radio receiver tuned to a frequency f_0. When the frequency of the swept oscillator is either higher or lower than the stable frequency by an amount equal to f_0, a signal passes through the receiver. The receiver output is fed to the

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[9] C. Kittel, "Interpretation of anomalous larmor frequencies in ferromagnetic resonance experiment," *Phys. Rev.*, vol. 71, pp. 270–271; February 15, 1947; "On the theory of ferromagnetic resonance absorption," vol. 73, pp. 155–161; January 15, 1948. After this paper was submitted for publication, an article appeared by A. D. Berk and B. A. Lengyel, PROC. IRE, vol. 43, pp. 1587–1591; November, 1955, in which the resonance conditions are brought out in a different but direct manner. By considering resonance for a thin disk it is evident that for generality, the rf magnetization rather than the rf internal fields should be used.

[10] J. H. Rowen and W. von Aulock, "Measurement of the complex tensor permeability of ferrites," *Phys. Rev.*, vol. 96, pp. 1152–1153; November 15, 1954, point out the importance of the distinction between measured permeability of spheres and intrinsic permeability which they measure on disks.

[11] G. Birnbaum, S. J. Kryder, and H. Lyons, "Microwave measurements of the dielectric properties of gases," *J. Appl. Phys.*, vol. 22, pp. 95–102; January, 1951.

intensifier grids of both beams of the oscilloscope producing two markers on the oscilloscope trace $2f_0$ apart. One marker is placed on the resonance peak of one cavity and the other marker on the resonance peak of the other. A Collins 51-J receiver proved to be ideally suited for these measurements for it has continuous tuning from 0.5 to 30 mc and the calibrated frequency is read with an accuracy of one part in 20,000. For moderately large samples these refined measurements are not necessary to obtain accurate results.

The same heterodyne method may be used for measuring the cavity half-power resonant line widths. This gives the Q's for the loss factor measurements. It was found that when the marker is on the steep slope of the resonant curve, the marker is elongated and not well defined. By applying the receiver output to the horizontal plates, as well as to the intensifier grids, the markers become horizontal pips intensified on the tips (see Fig. 2). This allows a more precise measurement of the half-power frequencies.

Transmission Coefficient Technique

The heterodyne method for measuring the Q_L's to determine loss factors has certain features which make for poor accuracy and repeatability. The scope amplifiers must remain in calibration and the base line position is usually not clearly defined. A more accurate measurement technique was devised which uses the change in the transmission of the cavity upon introduction of the sample.[12,13] Fig. 3 shows a block diagram of the circuit used. The technique depends on setting the frequency of a Pound stabilized oscillator accurately on the resonant frequency of the cavity. Fine tuning is accomplished by inserting a micrometer-adjusted needle into the reference cavity. The needle cavity also may be used to measure frequency shifts for some cases. The frequency shift, as a function of needle insertion, was linear over moderate ranges for all sizes of needles used. This allows frequency shift to be calibrated as a constant times the needle insertion.

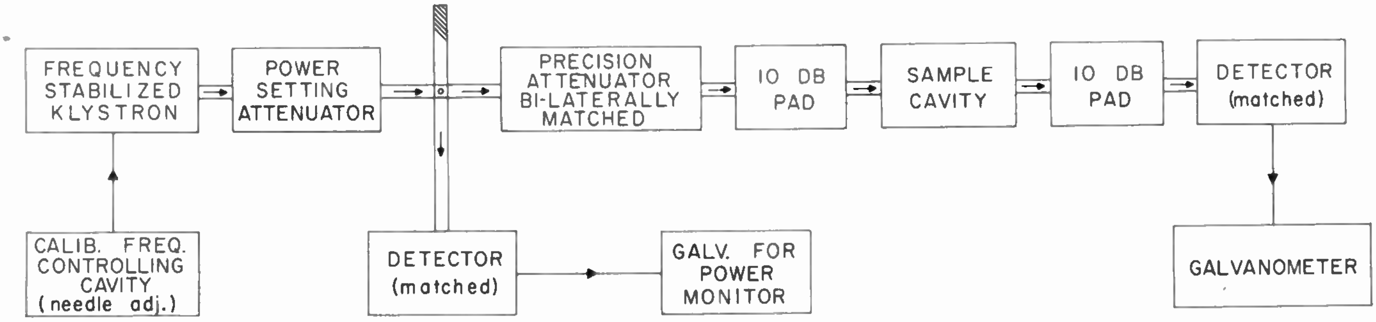

Fig. 3—Cavity transmission method.

A galvanometer is used as a power monitor to insure that the power incident to the bilaterally-matched calibrated attenuator remains constant. The frequency-stabilized oscillators deliver constant power over long periods of time. Only occasional resetting of the input power is required. Another galvanometer is used to monitor the output power which is kept at a fixed level by the calibrated attenuator. The changes in power incident to the cavity are then measured by this attenuator. The constancy of the output power eliminates any need for consideration of crystal characteristics since the crystal operates at a fixed point on this characteristic curve.

Referring to (12) for a known cavity geometry and sample size, only the change in Q_L is required for computation of the loss factor. This equation may be rewritten as follows:

$$\frac{1}{Q_L^s} = \frac{1}{Q_L^e} + \frac{1}{Q_s}. \tag{31}$$

Q_s denotes the sample Q defined as 2π times the ratio of the amount of energy stored in the cavity to the amount of energy lost per cycle in the sample. Thus, (10b) becomes

$$\frac{1}{Q_s} = \frac{36\epsilon''}{(\epsilon' + 2)^2} \frac{v_s}{v_c}. \tag{32}$$

The transmission coefficient for a transmission-type cavity at resonance is[14]

$$\frac{P_0(\omega_0)}{P_i(\omega_0)} = \frac{4Q_L^2}{Q_1 Q_2}, \tag{33}$$

where $P_i(\omega_0)$ is the input power, $P_0(\omega_0)$ is the output power which is held constant and Q_1 and Q_2 are the iris Q's. For small frequency shifts these can be taken to be constant. Designating $P_i^e(\omega_0)$ and $P_i^s(\omega_0)$ as incident powers to the empty cavity and the cavity with the sample, respectively, the following is obtained:

$$\frac{P_i^s(\omega_0)}{P_i^e(\omega_0)} = \left(\frac{Q_L^e}{Q_L^s}\right)^2. \tag{34}$$

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[12] R. C. LeCraw, "Proposal for investigation of the microwave properties of ferrites," Nat. Bur. Standards OED Rep. No. 17-146; March, 1933.

[13] W. A. Yager, J. K. Galt, F. R. Merritt, and E. A. Wood, "Ferromagnetic resonance in nickel ferrite," *Phys. Rev.*, vol. 80, pp. 744–748; 1950.

[14] This follows immediately from eq. (9), p. 291, of reference 8.

The ratio of powers is identical with the square of appropriate voltage ratios since the crystal detector characteristic is not allowed to change during measurements. Eq. (31) can be rewritten as

$$\frac{1}{Q_s} = \frac{1}{Q_L^e}\left(\frac{v_i^s}{v_i^e} - 1\right). \tag{35}$$

Eq. (32) and (35) combine to give

$$\epsilon'' = \frac{(\epsilon' + 2)^2}{36 Q_L^e}\left(\frac{v_i^s}{v_i^e} - 1\right)\frac{v_c}{v_s}. \tag{36}$$

MAGNETIC MEASUREMENTS TECHNIQUES

Fig. 4 shows a block diagram of the equipment used for the magnetic measurements.[15] The frequency shift measurements were obtained by a technique similar to that used for the electric measurements, only the microwave transmission lines and cavity used were different. For simplicity, Fig. 4 relates only to the measurement of loss terms.

The linearly-polarized incident wave is transformed into a circularly-polarized wave by a quarter-wave plate in the cylindrical guide. This wave impinges on the input of a transmission-type cylindrical cavity. A small fraction of the incident energy enters the cavity. The reflected energy upon traversing the quarter-wave plate is transformed back into a linearly-polarized wave, its plane of polarization being normal to that of the original linearly-polarized wave. The reflected energy is then absorbed by a matched absorbing card in the cylindrical guide.

Ellipticity in the circular guide system would introduce measurement errors. To insure a completely circularly-polarized wave, a slotted line and indicator are provided to monitor the adjustment of the quarter-wave plate. A squeeze-clamp, not shown in the figure, is placed on the circular guide just preceding the magnet to provide a fine correction for ellipticity.

A circularly-polarized standing wave is thus set up in the cavity. It should be recognized that the wave is perfectly circularly polarized only at small regions along the axis of the cavity. A similar condition exists in the cylindrical guide.

The circularly-polarized wave transmitted by the cavity is transformed back to a linear wave by a quarter-wave plate in the cylindrical output guide. This linear wave is then passed through a transition to the rectangular guide. If the transmitted wave has ellipticity, it will not be converted properly into a linear wave and there will be reflections from the rectangular waveguide transition back into the cavity. A matched attenuator card is therefore placed at the end of the circular guide normal to the *E* field to eliminate such reflections. Finally the desired microwave energy is detected at a matched crystal detector. The output shown on the galvanometer is kept at a fixed value by the calibrated attenuator to insure operating at a fixed point on the characteristic curve of the crystal. The change in power incident to the cavity is determined by the attenuator.

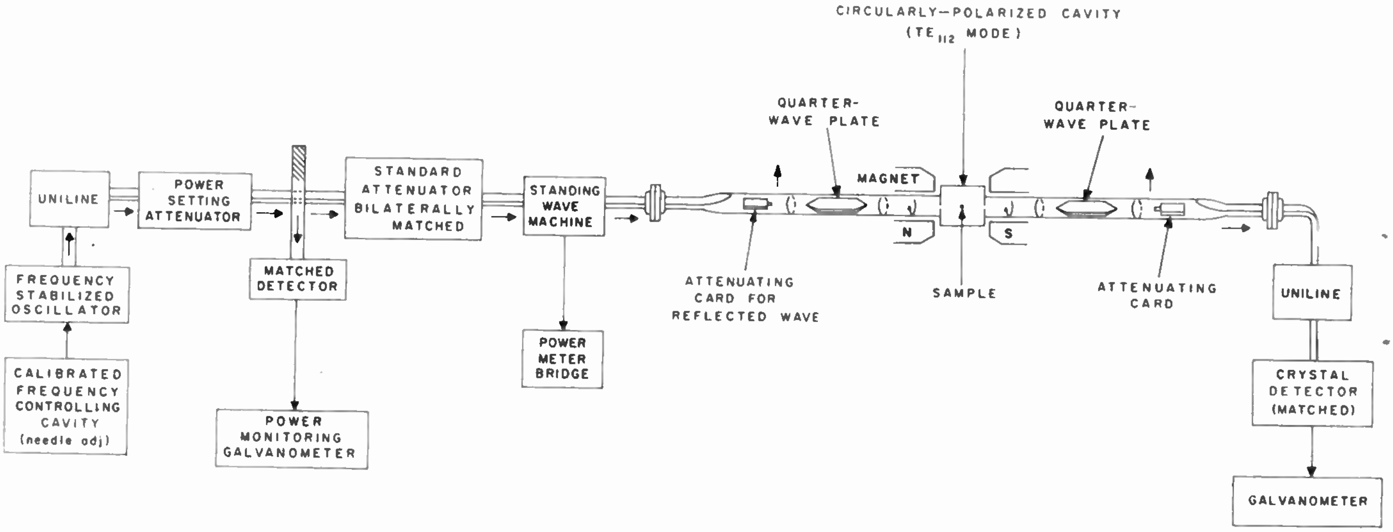

Fig. 4—Circularly-polarized cavity method.

For the frequency shift measurements, the klystron oscillator is swept by a sawtooth voltage as previously described for the electrical measurements.

Fig. 5 shows a series of CRO displays of the cavity resonance, with a 1.25 mm sphere of ferrite. The magnetic field is near but below resonance and the amplifier gain remains constant. The first curve shows mode-splitting when the cavity is excited by a linear wave. The next three curves are for arbitrary elliptical polar-

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[15] E. G. Spencer, R. C. LeCraw, and F. Reggia, "Circularly polarized cavities for measurement of tensor permeabilities," *J. Appl. Phys.*, vol. 26, pp. 354–355; March, 1955. Other quite different circular polarized cavity techniques have been developed at M.I.T. (J. O. Artman and P. E. Tannenwald, *J. Appl. Phys.*, vol. 26, pp. 1124–1132; September, 1955) and at the General Electric Co., Electronics Div., Syracuse, N. Y. (Internal Reports).

ization, and positive and negative circular polarizations, respectively. The sweeping technique allows a further check to insure that a purely positive or negative circular mode is excited, before making cavity transmission measurements with the frequency-stabilized oscillator.

The procedure for taking data is as follows: The Q of the cavity with the sample in place is measured with as high a steady magnetic field as possible. This is the reference Q and is denoted Q_L^r. The stabilized oscillator with the needle cavity is used to measure half-power frequencies of the transmission curve. After measuring Q_L^r, a point-by-point curve is obtained by using the transmission attenuation at this high field as the reference, the oscillator frequency being set to the cavity resonance for each measurement. At this high field real and imaginary parts of the effective permeabilities are taken to be unity and zero respectively. Eq. (29) is rewritten similar to (36), as

$$\frac{1}{2Q_L^r}\left(\frac{v_i^s}{v_i^r}-1\right)=(\tilde{\mu}''\pm\tilde{K}'')\frac{v_s}{0.6416v_c}\cdot \qquad (37)$$

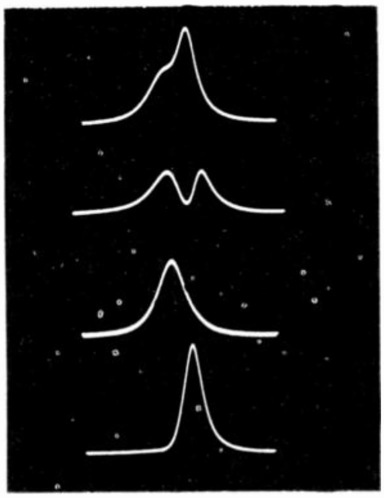

Fig. 5—Cavity resonance lines for TE$_{112}$ mode cylindrical cavity containing 1.25 mm ferrite sphere. The magnetic field is near, but below, resonance. Curve A: Linear polarization. Curve B: Arbitrary elliptical polarization. Curves C and D: Positive and negative circular polarizations, respectively.

The Cavity

Several types of cavities have been constructed for these measurements. It became evident that any asymmetry in the cavity would give rise to errors. The original cavity shown in Fig. 6 was a cylindrical cavity which was excited by two waves in space and time quadrature. The field inside the cavity at the center was thus circularly polarized. This arrangement proved adequate when the swept oscillator was used to measure $\delta(1/Q)$. Small adjustments of phase were required, as the magnetic field was varied, to allow for only a single circular mode. This would not be usable with the cavity transmission method. In Fig. 6, the small "dot" in the center of the cavity is a 1.25-mm diameter ferrite sphere, suspended by a fine nylon thread across the cavity.

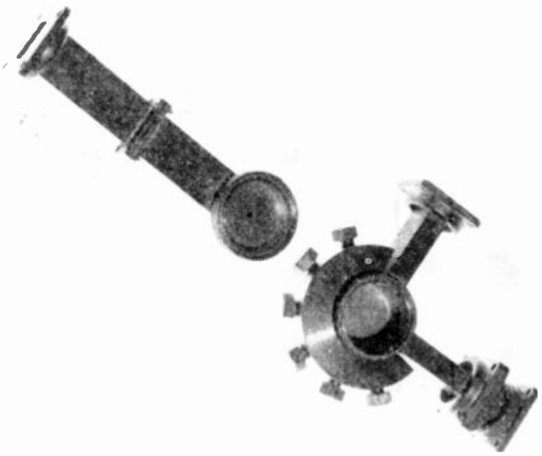

Fig. 6—Circularly-polarized cavity, TE$_{112}$ mode, excited by two linear waves in space and time quadrature. The 1.25-mm ferrite sphere is suspended in exact center by nylon thread.

To avoid possible asymmetry, the cavity was finally designed as a straight-through transmission-type cylindrical cavity operating in the TE$_{112}$ mode. The cavity coupling holes are in the end plates as shown in Fig. 7. To insure a truly cylindrical shape, the body of the cavity, $\frac{1}{4}$ inch thick, was made separate from the end plates. A stainless steel ball bearing, slightly larger than the diameter of the cylinder, was forced through. After silver plating, this same ball was forced through two or three times. The diameter of the ball is known to within 0.0001 inch and varies by a smaller amount.

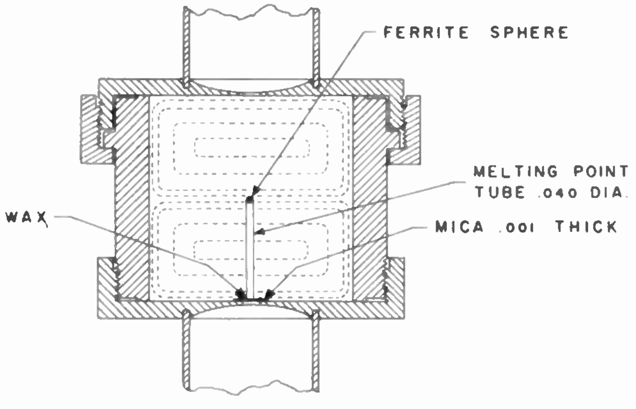

Fig. 7—Standard circularly-polarized cavity TE$_{112}$ mode.

The coupling irises are 0.144 inch in diameter giving a measure cavity insertion loss of 35.5 db. The cavity is well decoupled and gives confidence in the use of the transmission cavity relations derived by Montgomery[8] based on an equivalent circuit model.

The Wall Effect

Measurements of the maximum frequency shifts of a cavity containing a ferrite indicated that a definite wall effect exists.[17,18] Fig. 8 shows the frequency shifts as a function of the distance of a 1.25-mm ferrite sphere from the end wall of a rectangular cavity. The ordinate is the difference between the maximum positive and negative frequency shifts as the magnetic field is varied. It can be seen that to avoid errors the sample must be placed in a position of maximum rf magnetic field well away from all walls. For this reason the cavity used is excited in the TE_{112} mode. The sample is suspended in the exact center of the cavity on the small nylon thread previously described, or is set on the top of a melting point tube which rests on a thin disk of mica placed over the iris, shown in Fig. 7. This has symmetry advantages over the nylon thread suspension. However, the effects of the glass tube and the wax have not been sufficiently evaluated.

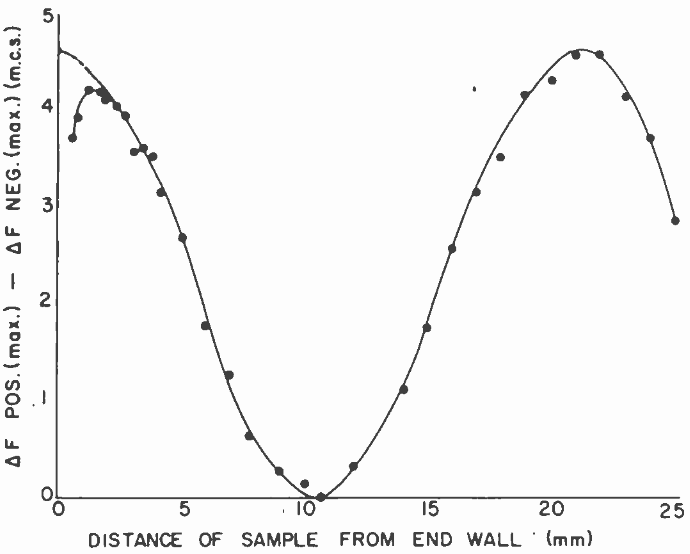

Fig. 8—Difference between ΔF positive (maximum) and ΔF negative (maximum) as a function of distance of sample from the end wall.

It might be emphasized that placing the sample in the center of a TE_{112} cavity has an additional advantage, over placing the sample on the wall of a TE_{111} cavity, other than the wall effects. The variation of the rf magnetic field over the sample in the center of the cavity is only one-half that of the variation at the wall. See, for example, Fig. 7. Thus, the measurements on a sphere in the center of a TE_{112} cavity are to be compared in every respect to a much smaller sphere on the wall of a TE_{111} cavity.

Grinding the Spheres

The spheres were obtained by the high-speed random tumbling of a piece of ferrite in a cylindrical grinder made from a silicon-carbide grinding wheel.[19] For the polycrystalline samples used, spheres of good uniformity were easily obtained.

The Magnet

A 2.5-kw laboratory-built magnet, with 4-inch pole pieces, was used for the measurements. In order to maintain complete symmetry using the transmission-cavity method, it was necessary to drill an axial hole through the pole pieces to accommodate the $1\frac{1}{16}$-inch cylindrical guide. This procedure gave only a 5 per cent reduction in field strength. Current stabilization of the electromagnet to one part in 10^4 was necessary for the point-by-point measurements, and was accomplished by a simple light beam galvanometer and electronic control circuit.

The magnetic fields, which were measured by a commercial rotating coil flux meter, remained uniform over a region in the center of the magnet pole gap approximately three times the diameter of the measuring coil.

EXPERIMENTAL DATA

Measurements are given on a well known magnesium-manganese ferrite, General Ceramics R-1, formerly called 1331, to illustrate the techniques described. It was found that as the sample size was decreased, the real part of ϵ increased asymptotically to the value 13.6, and the loss tangent to the value 13×10^{-4}. The variation with sample size is readily explained as a violation of the cavity perturbation assumption by the larger samples. If only one sample of a particular ferrite were available, the same results would be obtained by making measurements in various size cavities, extrapolating to that value corresponding to the vanishing of the ratio of volume of sample to volume of cavity. The measurements were made on spheres and checked on rods where the experimental accuracy is greater.

Fig. 9 shows curves of the imaginary part of the effective permeability $(\tilde{\mu}''+\tilde{K}'')$ when the cavity is excited by a positive circularly-polarized wave, and the effective permeability $(\tilde{\mu}''-\tilde{K}'')$ when the cavity is excited by a negative circularly-polarized wave. Both are shown as functions of the steady magnetic field H_z^0. These curves may be added and subtracted to obtain $\tilde{\mu}''$ and $\tilde{K}''$ separately. It should be noted that $\tilde{\mu}''$ and $\tilde{K}''$ are almost, but not quite, equal near resonance. Fig. 10 shows similar curves for the real parts of the effective permeabilities, and again μ' is almost, but not quite, equal to $1.3+\tilde{K}'$. The magnitudes of the permeabilities are smaller than those given in the IRE CONVENTION RECORD, Part 8, Page 121, 1955. The Q of the cavity at full magnet current was measured by plotting the transmission as a function of frequency. There was a small amount of heating of the cavity which gave a small spurious frequency shift. Since the Q is 16,000, the half-width measurement is critical. These effects have been eliminated. The experimentally-measured curves are plotted for magnetic fields as low as 125 oersteds. This figure represents the residual magnetism in the electro-

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[17] E. G. Spencer and R. C. LeCraw, "Wall effects on microwave measurements of ferrite spheres," *J. Appl. Phys.*, vol. 26, p. 250; February, 1955.

[18] W. K. Saunders, 1955 IRE CONVENTION RECORD, Part 8, pp. 81–84. Reprints are available as a Diamond Ordnance Fuze Labs. Report.

[19] F. Reggie and W. Stadler, "Ferrite sphere grinder," *Rev. Sci. Instr.*, vol. 26; pp. 731–732; July, 1955.

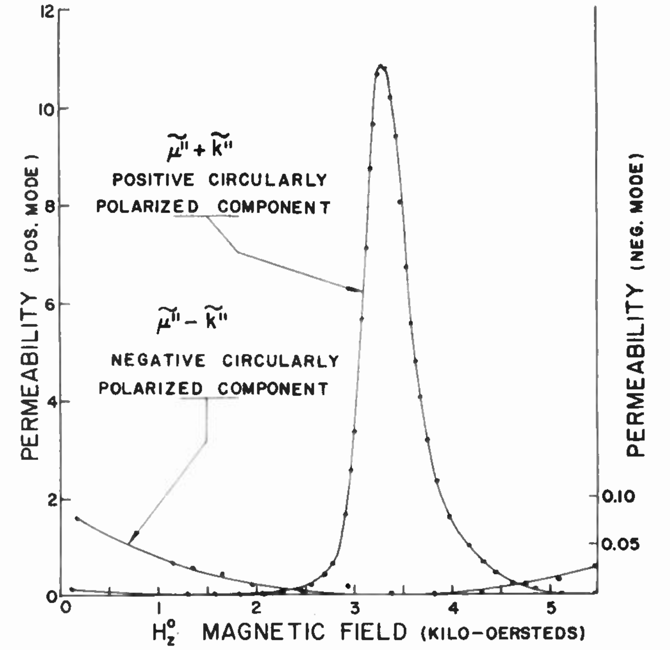

Fig. 9—Imaginary part of effective permeability for positive circularly-polarized modes ($\tilde{\mu}''+\tilde{K}''$) and for negative circularly-polarized modes ($\tilde{\mu}''-\tilde{K}''$).

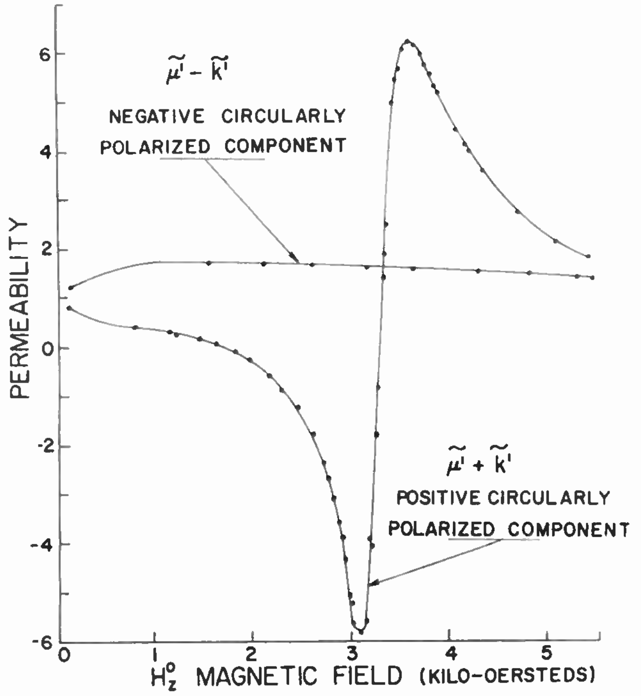

Fig. 10—Real part of effective permeability for positive circularly-polarized modes ($\tilde{\mu}'+\tilde{\mu}\tilde{K}'$) and for negative circularly-polarized modes ($\tilde{\mu}'-\tilde{K}'$).

magnet. Again, the permeability tensor, as written, is valid only for a magnetically-saturated medium. Separate measurements on the same ferrite sample give $4\pi M_s$ to be of the order of 2,300 gauss, where M_s is the saturation magnetization. Considering the demagnetizing field of the sphere, the sample should not be considered saturated for H^0 below approximately 1,000 oersteds.

Polder[1] derived expressions for tensor permeability in terms of the basic physical constants of the material. Yager, Galt, Merritt, and Wood[13] extended the theory to include the phenomenological Landau-Lifschitz damping constant k which arises in the equation of motion of the magnetization vector

$$\frac{dM}{dt} = \gamma\,[M \times H] - \frac{\gamma k}{|M|}\,[M \times (M \times H)], \tag{38}$$

where γ is the gyromagnetic ratio and H is the total internal magnetic field. Hogan's[2] detailed expressions for μ'' and K'' may be rewritten in terms of applied steady magnetic fields as

$$\mu'' \pm K'' = 4\pi M_s k \frac{H_r^0\left(\dfrac{H^{02} + H_r^{02}}{\sqrt{1+k^2}} \pm \dfrac{2H^0H_r^0}{(1+k^2)}\right)}{(H^{02} - H_r^{02})^2 + \dfrac{4k^2}{(1+k^2)}\,H^{02}H_r^{02}}. \tag{39}$$

The steady field H^0 at resonance is given by

$$H_r^0 = \frac{\omega}{\gamma\sqrt{1+k^2}}, \tag{40}$$

where γ is the gyromagnetic ratio. These two equations can be solved for γ and k^{12}. If the narrow line approximations are made, that $1+k^{12}\approx 1$ and $H_r^0 \approx H^0$ near resonance, (39) simplifies to be

$$\mu'' + K'' = \frac{16\pi M_s k}{H_r^0\left[\left(\dfrac{H^0}{H_r^0} - 1\right)^2 + 4k^2\right]} \tag{41}$$

$$\mu'' - K'' = 0.$$

The value of k is then found in terms of the width of the $\mu''+K''$ resonance curve to be

$$k = \frac{\Delta H_{1/2}^0}{H_r^0}, \tag{42}$$

where $\Delta H_{1/2}^0$ is the half-width at half height. $K=0.07$ if the low field half-width is used and 0.08 for the high field value.

Similar type expressions are found for $\mu' \pm K'$:

$$\mu' \pm K' = 1 + \frac{2\pi M_s}{H_r^0} \cdot \frac{\left[\left(\dfrac{H^0}{H_r^0} \pm \dfrac{1}{\sqrt{1+k^2}}\right)\left(\dfrac{H^{02}}{H_r^{02}} + 1\right) + \dfrac{2k^2}{1+k^2}\,\dfrac{H^0}{H_r^0}\right]}{\left[\left(\dfrac{H^{02}}{H_r^{02}} - 1\right)^2 + 4\,\dfrac{H^{02}}{H_r^{02}}\,\dfrac{k^2}{(1+k^2)}\right]}. \tag{43}$$

If the approximations $1+k^2\approx 1$ and $H_r^0 = H^0$ are again made, the equation reduces to

$$\mu' + K' = 1 + \frac{2\pi M_z\left(\frac{H^0}{H_r^0} - 1\right) + k^2}{H_r^0\left[\left(\frac{H^0}{H_r^0} - 1\right)^2 + k^2\right]}$$

$$\mu' - K' = 1 + \frac{2\pi M_z k^2}{H_r^0\left[\left(\frac{H^0}{H_r^0} - 1\right)^2 + k^2\right]}. \qquad (44)$$

The maximum value of the resonance curve is given by

$$(\mu'' + K'')_{\max} = \frac{4\pi M_z}{H_r k}. \qquad (45)$$

Using the two values computed for k, $4\pi M_z$ becomes either 2,440 or 2,930 gauss.

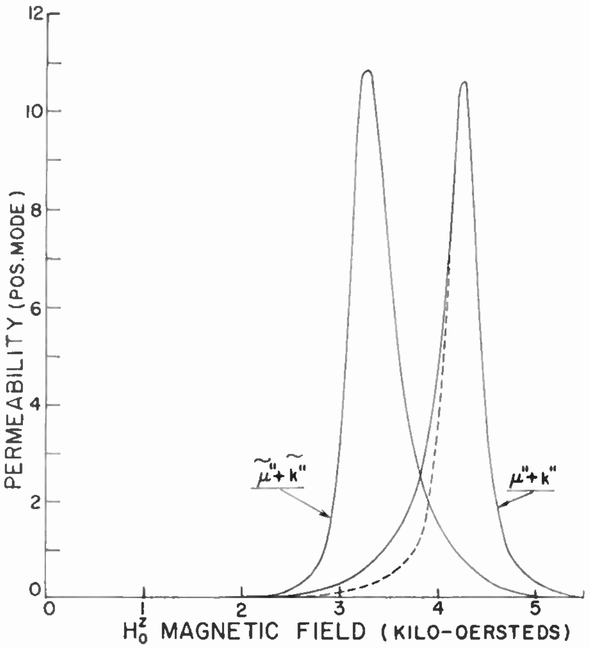

Fig. 11—Intrinsic permeability $(\mu''+K'')$ computed from $(\tilde{\mu}''+\tilde{K}'')$ measurements on a sphere. The dashed line represents the deviation of the theoretical values from the computed intrinsic values.

From the values of $\mu+\tilde{K}$ taken from Figs. 9 and 10, the intrinsic values $\mu+K$ are computed using (30). Fig. 11 is a graph of $\mu''+K''$, the computed intrinsic values, compared with a graph of the measured values. Fig. 12 shows a similar comparison for $\mu'+K'$ with $\mu'+\tilde{K}'$. If in the equation of motion, H is replaced by $H^0-4\pi Ms/3$, all demagnetizing fields cancel. The result is that resonances of the intrinsic and measured curves should be displaced in field by a value of $4\pi Ms/3$. The deduced value of $4\pi Ms$ from these curves is 2,800 gauss. That this computed value does not correspond to the value 2,300 mentioned above is not surprising since the exact position of the intrinsic curve resonance is sensitive to small changes in the measured curve away from resonance.

The real and imaginary parts of the permeability are not independent, being related through the Kramers-Kronig[20] equations. The $\mu'+K'$ curve is seen to have the character of the derivative of the $\mu''+K''$ curve except that the maximum and minimum values correspond to the half-height and not the inflection points of the $\mu''+K''$ curve. For a Landau-Lifschitz line shape the difference between $(\mu'+K')_{\max}$ and $(\mu'+K')_{\min}$ equals $(\mu''+K'')_{\max}$. The measured results show a ratio of 1.1 in these values. Since for a Gaussian curve this would be 1.2, the resultant curve indicates the presence of a certain amount of Gaussian character.

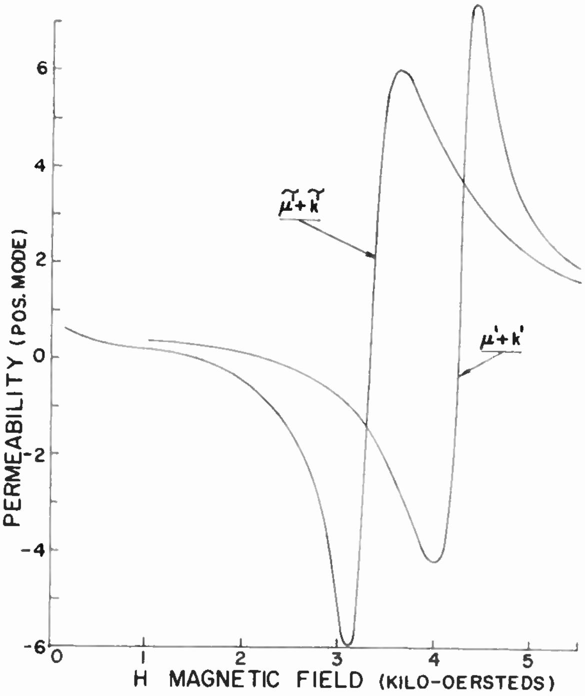

Fig. 12—Intrinsic permeability $(\mu'+K')$ computed from $(\tilde{\mu}'+\tilde{K}')$ measurements on a sphere.

The intrinsic $(\mu''+K'')$ was compared with a plot of (39), normalizing at the maximum and at a point on the high field side. The deviation of this curve from the measured curve is shown by a dashed line in Fig. 11. This difference might be explained as unresolved structure. However, it should be noted that the theoretical expression was originally derived for a single crystal and is being compared with experimental data on polycrystalline material. Considering these facts, the phenomenological Landau-Lifschitz theory agrees quite well with the experimental data.

ACKNOWLEDGMENT

The authors wish to thank R. D. Hatcher and W. K. Saunders for their many helpful suggestions and discussions, J. E. Tompkins for his calculations and comments, and L. A. Ault for his assistance in the measurements.

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The Effect of AGC on Radar Tracking Noise[*]

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Summary—**Radar angle tracking noise, such as that due to angular and amplitude scintillation of the target echo, is increased by the response of the receiver agc (automatic gain control) to the low frequency components of the fading of the echo envelope. An increase in angle tracking noise spectral density by a factor of two to three is representative of what can happen when the radar echo envelope is approximately Rayleigh distributed. This phenomenon has been investigated by analog simulation of the agc, both for an ordinary linear filter in the feedback path and for a nonlinear filter with quick attack and slow release in the loop. Since the increase in tracking noise decreases monotonically with increasing agc time constant, an analysis is presented to describe a particular basic problem which requires the agc time constant to be kept short, namely, the transient rise in average signal strength encountered by a radar when closing rapidly on a target. In fixing the agc time constant, a compromise must be reached between increase in tracking noise and the transient increase in mean output signal strength. Whatever considerations motivate a particular choice of agc time constant, the effect of the agc on angle noise spectral density can be determined from the curves presented. The results obtained show that the use of the nonlinear filter with quick attack and slow release does actually produce the desired result of reducing the transient rise in output signal strength while keeping the increase in noise spectral density constant. The disadvantage of such a filter lies in the change in mean signal output which it causes which is equivalent to a change in mean receiver gain. The stability limits of the agc loop were derived from the linearized theory, agreed well with experiment and were observed experimentally to be no worse with the nonlinear filter in the feedback path.**

DESCRIPTION OF THE BASIC PHENOMENON

FOR THE CASE of a radar target which is composed of many reflecting elements and which subtends an angle small compared to a radar beamwidth, the envelope of the rf echo, including the conical scanning modulation terms, from which angle tracking information is obtained, has already been derived [1] and is

$$E_T = E(t)[1 - b_0\epsilon \cos \omega_s t] + U_a(t) \cos \omega_s t \qquad (1)$$

where

E_T is the total envelope,

$E(t)$ is the envelope which would have been obtained if there were no scan modulation,

b_0 is the fractional scan modulation per unit error error angle ϵ,

ϵ is the tracking error of the antenna with respect to the mean radar center of the target,

U_a is the angular error signal which arises due to the extended nature of the target,

$\omega_s = 2\pi f_s$ and f_s is the scan frequency.

Only the scan modulation terms due to azimuth angular errors, say, are included in (1). Reference 1 demonstrates that $E(t)$ and $U_a(t)$ are independent statistically (asymptotically so, as the number of reflectors approaches infinity) and that $E(t)$ is Rayleigh distributed and $U_a(t)$ is Gaussian. If receiver noise is small compared to the signal, it is possible to add a small noise $n(t)$ to the right side of (1) directly, and remarks applicable to those components of $E(t)$ near the scan frequency f_s apply with equal force to receiver noise at the same frequency. If receiver noise is large, the output video envelope becomes proportional to $E^2(t)$, where E is now the envelope which would be observed if there were no noise, according to the well-known phenomenon of signal suppression. On the other hand at low signal-to-noise ratio many other complicated phenomena are possible in a practical agc and these are not the subject of this paper. If, as is common, the gain becomes completely insensitive to signal amplitude at very low signal-to-noise ratios, the phenomenon discussed in this paper does not occur, but neither can the agc be said to be working. This paper is then concerned primarily with the high signal-to-noise ratio situation, and the noise which is being affected by the agc is primarily that arising out of the fluctuating properties of the echo itself.

The subject may be approached by considering the action of an ideal agc. An ideal agc would keep the signal strength absolutely constant. This statement is a contradiction in itself, however, since the scan modulation on the signal must not be removed by the agc, and if the scan modulation cannot be removed, neither can components of the signal envelope in the vicinity of the scan frequency. On the other hand, it is really not necessary for the agc to work this rapidly; its purpose is usually to correct out changes in the mean signal $\overline{E}$ rather than to remove the fluctuations in $E(t)$. However, the agc time constant may be set so fast that a large part of the low frequency fluctuations of the signal envelope is removed. As a limit towards which such a process could tend, but never reach, it is convenient to think of an output

$$\begin{aligned} G(t)E_T(t) &= \frac{E_d}{E(t)} E_T(t) \\ &= E_d\left[1 - b_0\epsilon \cos \omega_s t + \frac{U_a}{E(t)} \cos \omega_s t\right] \qquad (2) \end{aligned}$$

where E_d is the desired level of the envelope. In terms of the apparent radar center ϵ_0 defined by (17) of reference 1, this output is

$$G(t)E_T(t) = E_d(1 - b_0\epsilon \cos \omega_s t + b_0\epsilon_0 \cos \omega_s t) \qquad (3)$$

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but the random variable $\epsilon_0(t)$ was shown to have an infinite rms value when U_a is Gaussian, $E(t)$ Rayleigh, and the two are independent [1]. In the antenna tracking servo the most important property of the noise is its spectral density at or near zero frequency. Although this spectral density does not turn out to be infinite, it should come as no surprise that it is increased by the agc action, and that this effect is caused by the increase in gain which occurs when the envelope $E(t)$ fades below its mean value.

Using the joint probability density of $E(t)$ and $E(t+\tau)$ given by Rice [2], and assuming that the rf spectrum of the signal is symmetrical around some center frequency, R. B. Muchmore has derived the correlation function of ϵ_0; *i.e.*, of the ratio U_a/b_0E for U_a Gaussian and E Rayleigh distributed [3]. This correlation function can be shown ito be

$$\psi_\epsilon = \frac{\overline{2U_a{}^2}}{b_0{}^2\overline{E^2}}\rho_a(\tau)K(\rho_\alpha(\tau)) \tag{4}$$

where

ψ_ϵ = the correlation function of ϵ_0,
ρ_a = the correlation coefficient of U_a,
ρ_α = the correlation coefficient of α_1 or α_2 (see (1) of reference 1),

$K(\rho)$ = the complete elliptic integral of the first kind. Since for τ equal to zero ρ_a and ρ_α are unity and $\psi_\epsilon(\tau)$ is just the mean square value of ϵ_0, $\psi_\epsilon(0)$ must be infinite, and is because of the properties of the elliptic integral. The spectral density of ϵ_0 at zero frequency is just

$$\begin{aligned}\Phi_\epsilon(0) &= 2\int_{-\infty}^{\infty}\psi_\epsilon(\tau)d\tau \\ &= \frac{\overline{4U_a{}^2}}{b_0{}^2\overline{E^2}}\int_{-\infty}^{\infty}\rho_a(\tau)K(\rho_\alpha(\tau))d\tau. \end{aligned} \tag{5}$$

The ratio of the zero frequency spectral density of ϵ_0 to that of the effective radar center is

$$\begin{aligned}\Lambda^2 &= \Phi_\epsilon(0)/\Phi_a(0) \\ &= \frac{2\overline{E}^2}{E^2}\left[\int_{-\infty}^{\infty}\rho_a(\tau)K(\rho_\alpha(\tau))d\tau \Big/ \int_{-\infty}^{\infty}\rho_a(\tau)d\tau\right] \\ &= \frac{\pi}{2}\left[\int_{-\infty}^{\infty}\rho_a(\tau)K(\rho_\alpha(\tau))d\tau \Big/ \int_{-\infty}^{\infty}\rho_a(\tau)d\tau\right] \end{aligned} \tag{6}$$

where Φ_a is the spectral density of $U_a/b_0\overline{E}$.

By comparing (1) with (2) it can be seen that Λ^2 is the ratio of the spectral densities of angle tracking noise with ideal instantaneous agc and with a very long agc time constant. The spectra of U_a and α_1, hence of $E(t)$, are related and are always of almost the same width. By choosing various particular examples, it can be shown by numerical computation that Λ^2 is about equal to 3 in magnitude in all cases. The angle tracking servo bandwidth of the radar is usually sufficiently narrow that the zero frequency spectral density is an adequate description of the tracking noise.

Discussion of a Specific Type of AGC

The increase in low frequency noise spectral density due to a fast agc can be considered as arising from two effects: the increase in mean gain for constant mean restoring signal, and the additional intermodulation of the gain with the noise U_a, or with the receiver noise, or with the scan frequency components of $E(t)$. The relative importance of these effects may be determined from a consideration of a particular representative agc system, shown in Fig. 1.

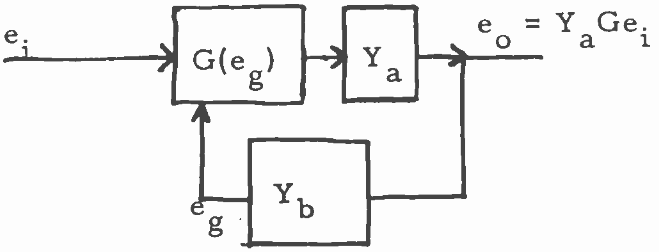

Fig. 1—Block diagram of agc loop.

For this system the relation between receiver gain, G, and the filtered video output, e_g, will be assumed to be

$$\begin{aligned} G &= G_c & &\text{for } e_g \leqq e_c \\ G &= G_c\left(\frac{e_g}{e_c}\right)^{-a} & &\text{for } e_g \geqq e_c \end{aligned} \tag{7}$$

where a is the slope in db/db relating gain to output, and e_c is the clamp level. If e_i is the envelope of the input signal, the output envelope e_0 is given by

$$e_0 = Y_aGe_i. \tag{8}$$

For the purposes of this section, the transfer function Y_a in the forward path will be taken as unity, and the filter Y_b will be taken to be a low pass filter whose time constant is either extremely short, resulting in a very fast agc, or extremely long, resulting in a very slow agc. Hence for the fast agc, $e_g \approx e_0$, while for the slow agc, $e_g \approx \bar{e}_0$ where the bar indicates the time average. It is convenient to introduce the following dimensionless variables:

$$v_0 = e_0/e_c \tag{9a}$$

$$v_1 = G_ce_i/e_c \tag{9b}$$

$$\bar{v}_1 = m \tag{9c}$$

$$v_2 = e_i/\bar{e}_i \tag{9d}$$

$$g = G/G_c \tag{9e}$$

$$v_g = e_g/e_c. \tag{9f}$$

Using (7)–(9), there result the following relations for the very fast agc:

$$v_{0f} = \begin{cases} v_1 & v_1 \leqq 1 \\ v_1^{1/(a+1)} & v_1 \geqq 1 \end{cases} \tag{10a}$$

$$\bar{v}_{0f} = \int_0^1 v_1 p(v_1) dv_1 + \int_1^\infty v_1^{1/(a+1)} p(v_1) dv_1 \tag{10b}$$

$$\bar{g}_f = \int_0^1 p(v_1) dv_1 + \int_1^\infty v_1^{-a/(a+1)} p(v_1) dv_1 \tag{10c}$$

and for the very slow agc there is obtained:

$$v_{0s} = m^{1/(a+1)}\, v_2 \qquad m \geqq 1 \tag{11a}$$

$$\bar{v}_{0s} = m^{1/(a+1)} \qquad m \geqq 1 \tag{11b}$$

$$\bar{g}_s = m^{-a/(a+1)} \qquad m \geqq 1. \tag{11c}$$

It is assumed in the above relations that the gain is affected only by the envelope $E(t)$. Eq. (1) shows that the restoring error signal is proportional to $E(t)$ and hence to v_0. Hence the increase in low frequency noise spectral density for the fast agc compared with the slow agc which arises from the first effect described at the beginning of this section, can be written

$$\Lambda_1^2 = \left[\frac{\bar{g}_f/\bar{g}_s}{\bar{v}_{0f}/\bar{v}_{0s}}\right]^2 = \left[\frac{m\bar{g}_f}{\bar{v}_{0f}}\right]^2. \tag{12}$$

For a Rayleigh distributed input envelope v_1; *i.e.*, one whose distribution is

$$p(v_1) = \frac{\pi}{2}\frac{v_1}{m^2} e^{-(\pi/4)(v_1^2/m)}. \tag{13}$$

Table I presents the values of $\bar{v}_{0s}$, $\bar{v}_{0f}$, $\bar{g}_f$, and Λ_1 for four values of a and m. The values of a equal to 30, 60, 120, and 240 db/db cover the range of gain of most practical agc's, and the values of m equal to 1 (*i.e.*, mean input just at the clamp level), $\sqrt{10}$, 10, and 100 likewise cover the range of mean input levels of most interest. The table shows that Λ_1 is not critical with a, but with increasing m approaches quite closely the asymptote for an ideal infinite gain agc, namely

$$\Lambda_1\Big|_{a\to\infty} = \int_0^\infty \frac{m}{v_1} p(v_1) dv_1 = \frac{\pi}{2} = 1.57. \tag{14}$$

A comparison of Λ_1 with the value of Λ given by the correlation function method shows that the increase in mean gain is the major effect tending to increase the spectral density. Table I also shows that $\bar{v}_{0f}$ is quite constant with increasing m, a result to be expected since the purpose of the agc is to keep the mean output constant.

TABLE I

VALUES OF $\bar{v}_0$, $\bar{g}_f$ AND Λ_1

m \ a	30	60	120	240
1 a)	1.00000	a) 1.00000	a) 1.00000	a) 1.00000
b)	0.79509	b) 0.79253	b) 0.79123	b) 0.79057
c)	0.87726	c) 0.87568	c) 0.87489	c) 0.87457
d)	1.10334	d) 1.10491	d) 1.10573	d) 1.10625
$\sqrt{10}$ a)	1.03784	a) 1.01905	a) 1.00956	a) 1.00479
b)	1.00810	b) 0.99136	b) 0.98292	b) 0.97868
c)	0.42906	c) 0.42416	c) 0.42169	c) 0.42054
d)	1.34590	d) 1.35301	d) 1.35668	d) 1.35855
10 a)	1.07711	a) 1.03846	a) 1.01921	a) 1.00960
b)	1.06903	b) 1.03313	b) 1.01523	b) 1.00631
c)	0.15731	c) 0.15327	c) 0.15125	c) 0.15024
d)	1.47149	d) 1.48356	d) 1.48985	d) 1.49303
100 a)	1.16015	a) 1.07842	a) 1.03879	a) 1.01930
b)	1.15457	b) 1.07596	b) 1.03781	b) 1.01902
c)	0.01766	c) 0.01663	c) 0.01612	c) 0.01588
d)	1.52966	d) 1.54542	d) 1.55368	d) 1.55790

a) $m^{1/a+1} = \bar{v}_{0s}$
b) $\bar{v}_{0f}$
c) $\bar{g}_f$
d) $\Lambda_1 = \bar{g}_f m/\bar{v}_{0f}$

ANALOG SIMULATION OF THE EFFECT OF AGC ON TRACKING NOISE

The effect of agc on tracking noise was studied by simulation on an analog computer as shown in Fig. 2.

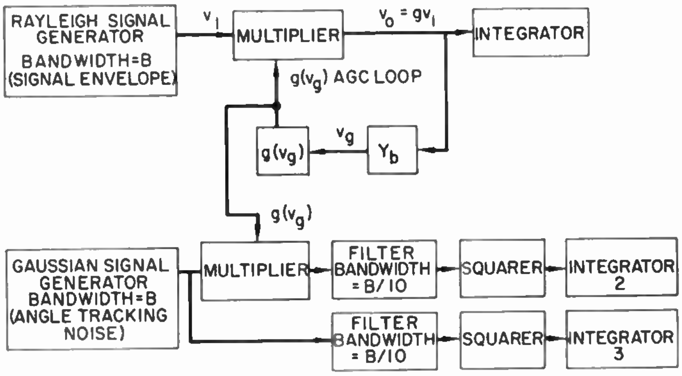

Fig. 2—Setup for simulation of agc.

A Rayleigh distributed input of bandwidth B was applied to the input of the loop which simulated the agc action. The mean output of the loop was measured by integration for a known period of time, which output is proportional to the mean restoring signal per unit angular error. The instantaneous gain control voltage $g(v_g)$ was fed to a separate multiplier which multiplied an independent Gaussian noise voltage, corresponding to either U_a or the high frequency components of $E(t)$, by this same gain $g(v_g)$. Actually the Gaussian noise so multiplied was of bandwidth B also and hence more nearly resembled angular scintillation noise, but the results obtained probably require little or no correction when applied to amplitude scintillation or fading noise. The low frequency spectral density of the scintillation noise was measured before and after passing through the multiplier whose gain was controlled by the agc loop. The measurements were made by passing the noise through a very narrow bandwidth low pass filter, squaring and integrating for a known time; the mean square output recorded from the integrator being proportional to the spectral density. The operating point was always set such that the gain with an infinite time constant agc was unity so that the spectral densities measured could be compared directly and need not be corrected for changes in mean input signal m. Fig. 3 shows how m was effectively changed while still maintaining the mean gain at unity; the gain characteristic was merely extended upward as shown to produce the same effect as a larger m.

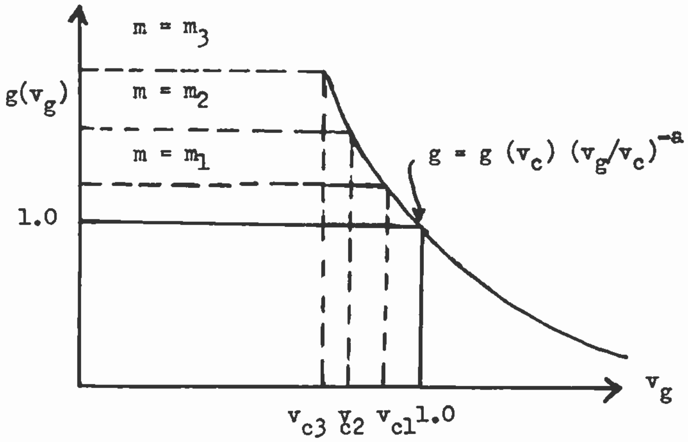

Fig. 3—$g(v_g)$ as used in Fig. 2.

Several filters Y_b were investigated. The results obtained for a single section RC filter were found better with respect to noise than for a critically damped two section filter and it was concluded that the use of higher order filters is unprofitable. For Y_b of the form $(1+p\tau_0)^{-1}$, the incremental closed loop agc time constant can be shown to be τ_0/A,[1] where $A=(a+1)$ is the agc loop gain in db/db; and for Y_b of the form $(1+p\tau_1)^{-2}$ the incremental agc time constant can be shown to be $2\tau_1/A$. It is a significant result of the data taken that the increase in tracking noise spectral density is essentially a function only of the product $B\tau$ where τ is the incremental agc time constant. The results of the simulation study are presented in the curves of Fig. 4 through 9, pp. 805–807.

The single section nonlinear filter in Fig. 10 (p. 808) was studied to see if the noise problem is improved by its use. Its time constant with respect to increasing signals is RC and with respect to decreasing signals is bRC. It does not permit the instantaneous agc gain to be as readily increased during fades as a linear filter of time constant RC, and therefore should not produce as large an increase in the tracking noise. The results actually obtained (see Fig. 6) were as favorable as could possibly be expected; with respect to the increase in noise spectral density. It acted as if its time constant were indeed bRC, at least for b equal to 10 or 20, and for rapidly rising signals its time constant is certainly just RC. The advantages of a fast time constant for tracking a rapidly rising signal, and a slow time constant for noise suppression are both provided. A disadvantage is the reduction in gain, with respect to both signal and noise, which it causes; a reduction which is a function of bandwidth B. The asymptotic reduction in gain for large $B\tau$ can be calculated by solving for x_0 in the relation

$$\int_0^{x_0}(x_0 - x)p(x)dx = b\int_{x_0}^{\infty}(x - x_0)p(x)dx \qquad (15a)$$

with

$$p(x) = \frac{\pi}{2}xe^{-(\pi/4)x}. \qquad (15b)$$

Eq. (15) merely equates the total condenser charge to the discharge for a Rayleigh distributed input. For b equal to 10 and 20, the gain reductions are 1.52 and 1.68 respectively.

The use of nonlinear filters with quick attack and slow release in sound recording on film is discussed in references 4 and 5. Although the application and motivation in this problem are different, the principle of operation is the same. Furthermore, the greater definition in the problem presented here allows for more quantitative expression of the effect of a choice of parameters.

Some data is presented in Fig. 7 for a two section nonlinear filter, but just as for the linear filters, the two section filter gives poorer results than the single section.

One significant result of the simulator study is that for values of the mean input level m greater than three, the scintillation noise spectral density is substantially independent of m. This implies that the output rarely drops below the clamp for $m \geqq 3$. It should also be mentioned that a significant feature of the input signal used in the simulator study was that it did not conform exactly to the Rayleigh distribution. The actual input signal essentially never fell below one-tenth of its mean value. This may be fortunate in that deviations of actual radar echoes from the Rayleigh distribution are often precisely of this character, so that the practical conclusions of this study cannot then be invalid because of this condition.

From Fig. 4 it is observed that for large m the single section filter agc causes the noise spectral density to be increased by about a factor of two for $B\tau$ about 0.07. This situation would arise for example if the fading bandwidth B were 3.5 cps and the closed loop agc time constant were 0.02 second. If the spectral density increase had to be limited to 20 per cent, $B\tau$ would have to be increased nearly to unity. In some applications the tracking noise is sufficiently critical that such a limitation is reasonable, and then if B lies between 1 and 10 cps, τ must lie between 0.1 and 1.0 second. Since this value of τ may be too large to permit satisfactory agc tracking of a rapidly growing mean input, serious consideration might then be given to the nonlinear filter just described.

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[1] This is demonstrated in (23), for example.

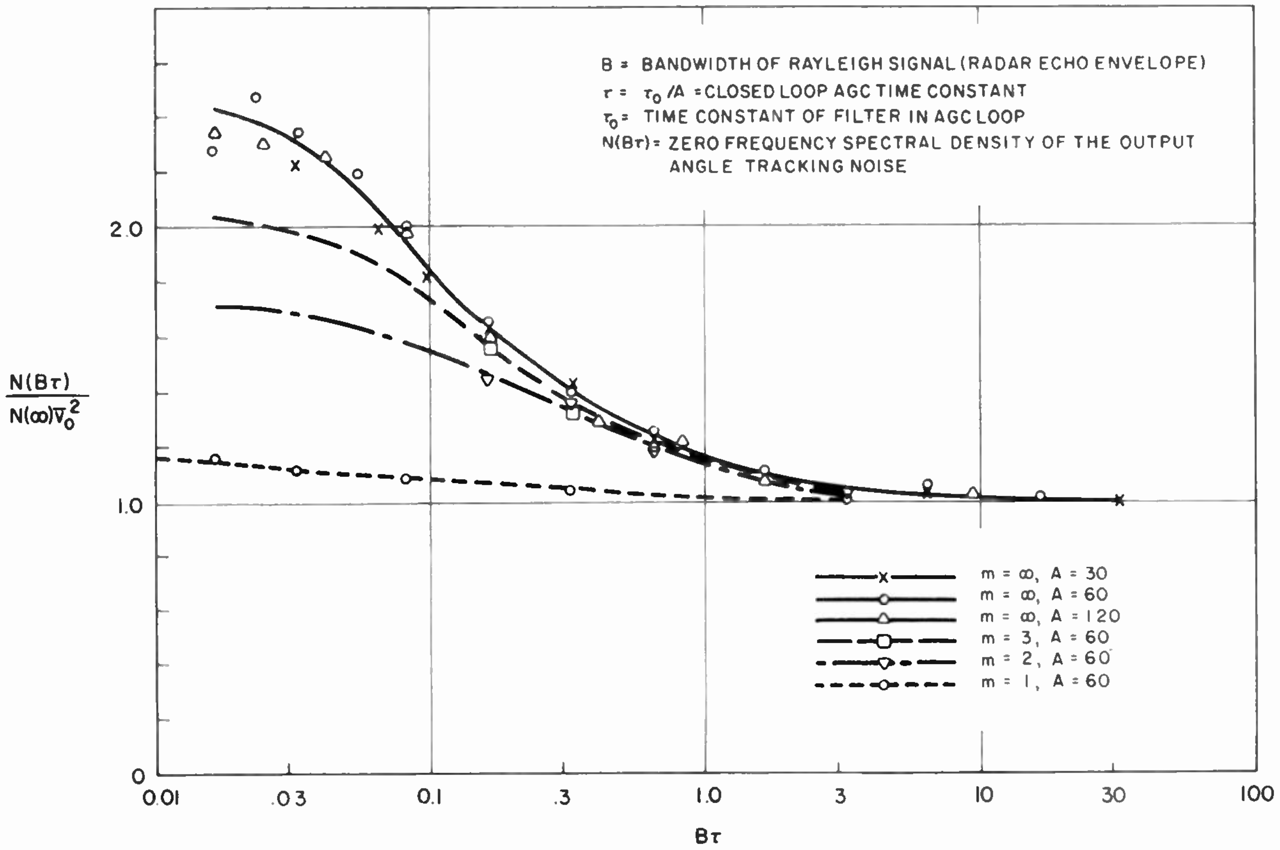

Fig. 4—Noise characteristics of agc with single section linear filter.

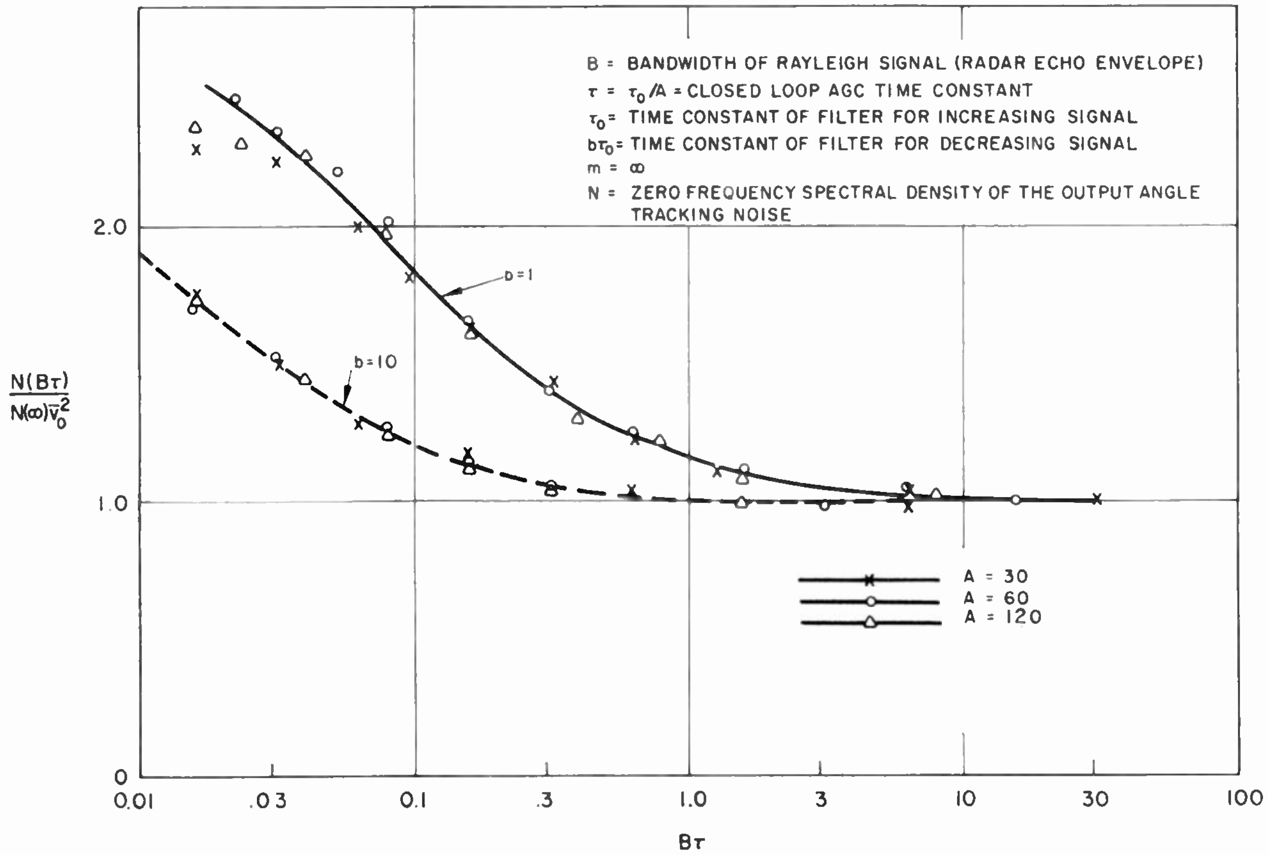

Fig. 5—Noise characteristics of agc with single section filter (showing effect of nonlinear filter).

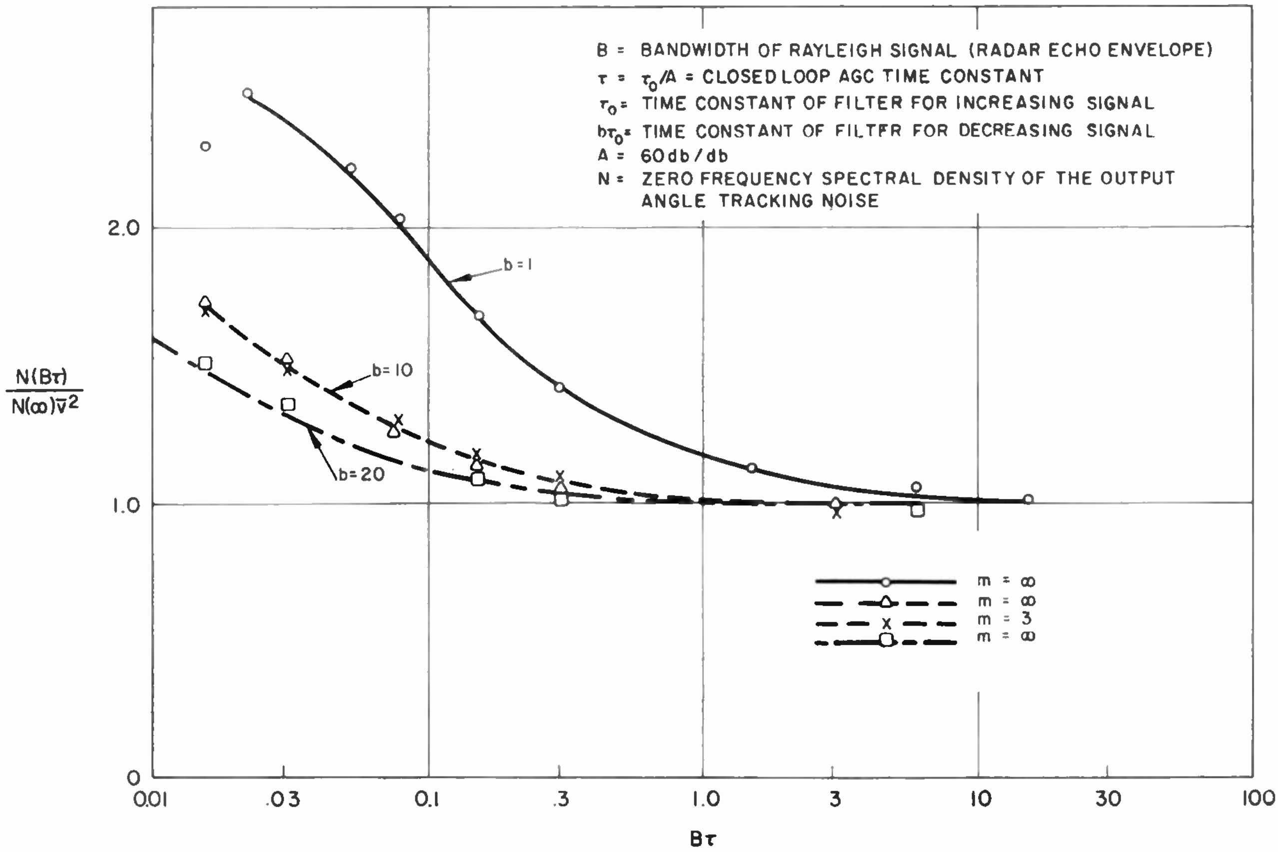

Fig. 6—Noise characteristics of agc with single section filter (showing effect of nonlinear filter).

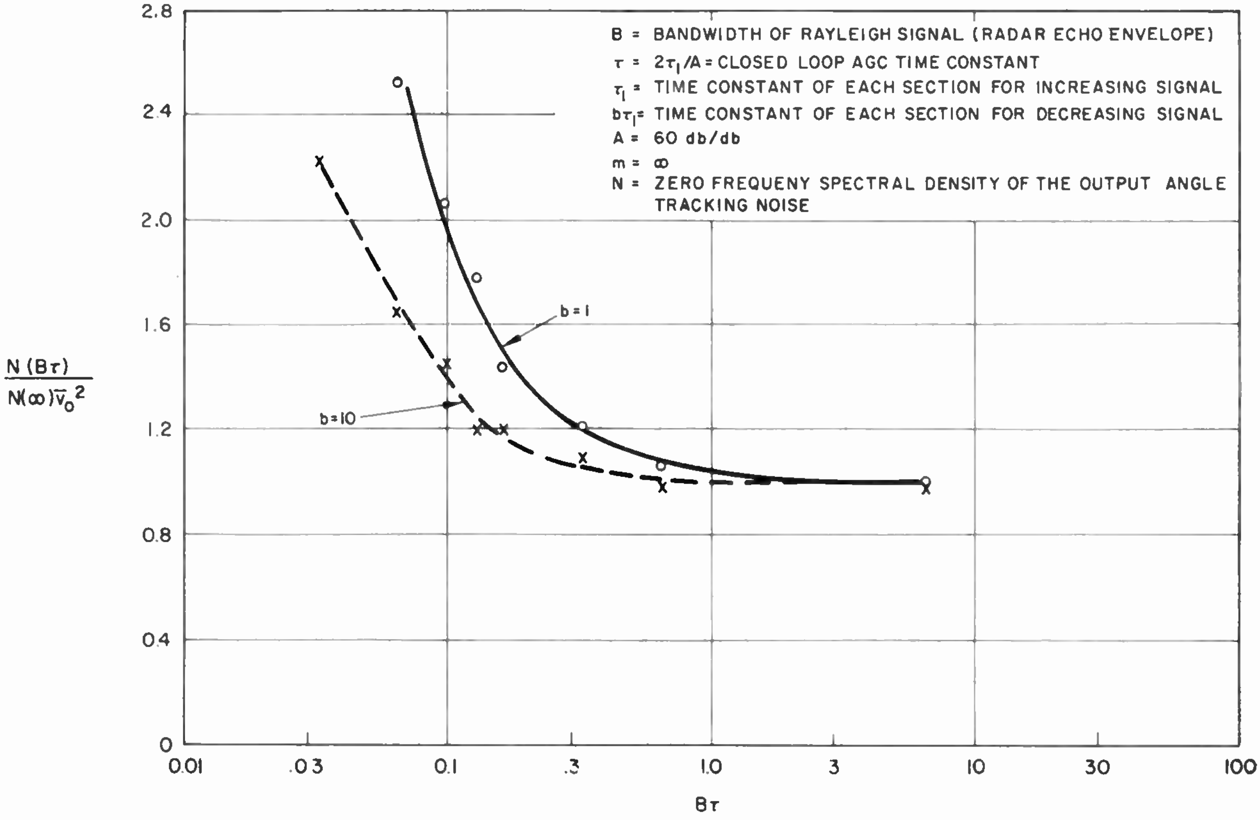

Fig. 7—Noise characteristic of agc with two-section critically damped filter (showing effect of nonlinear filter).

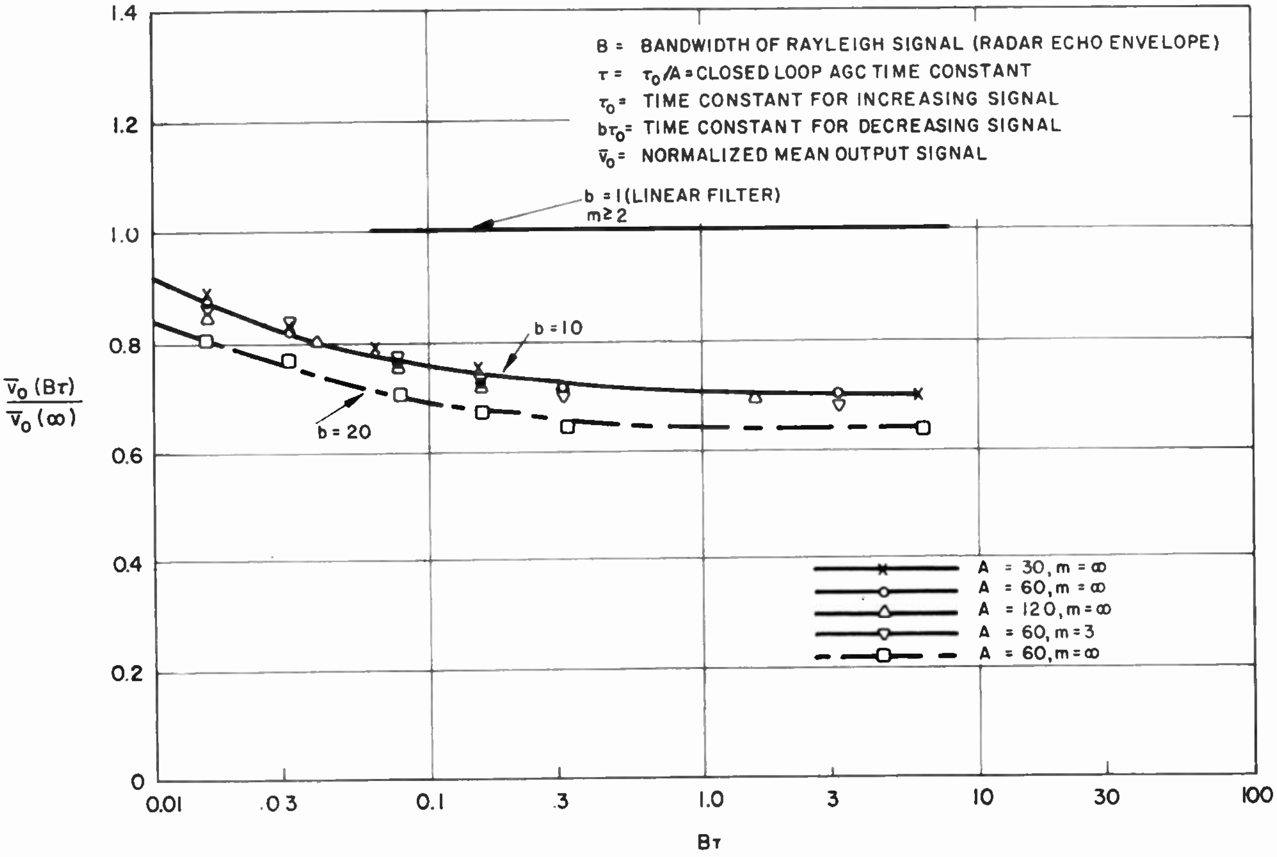

Fig. 8—Gain characteristic of agc with single section nonlinear filter.

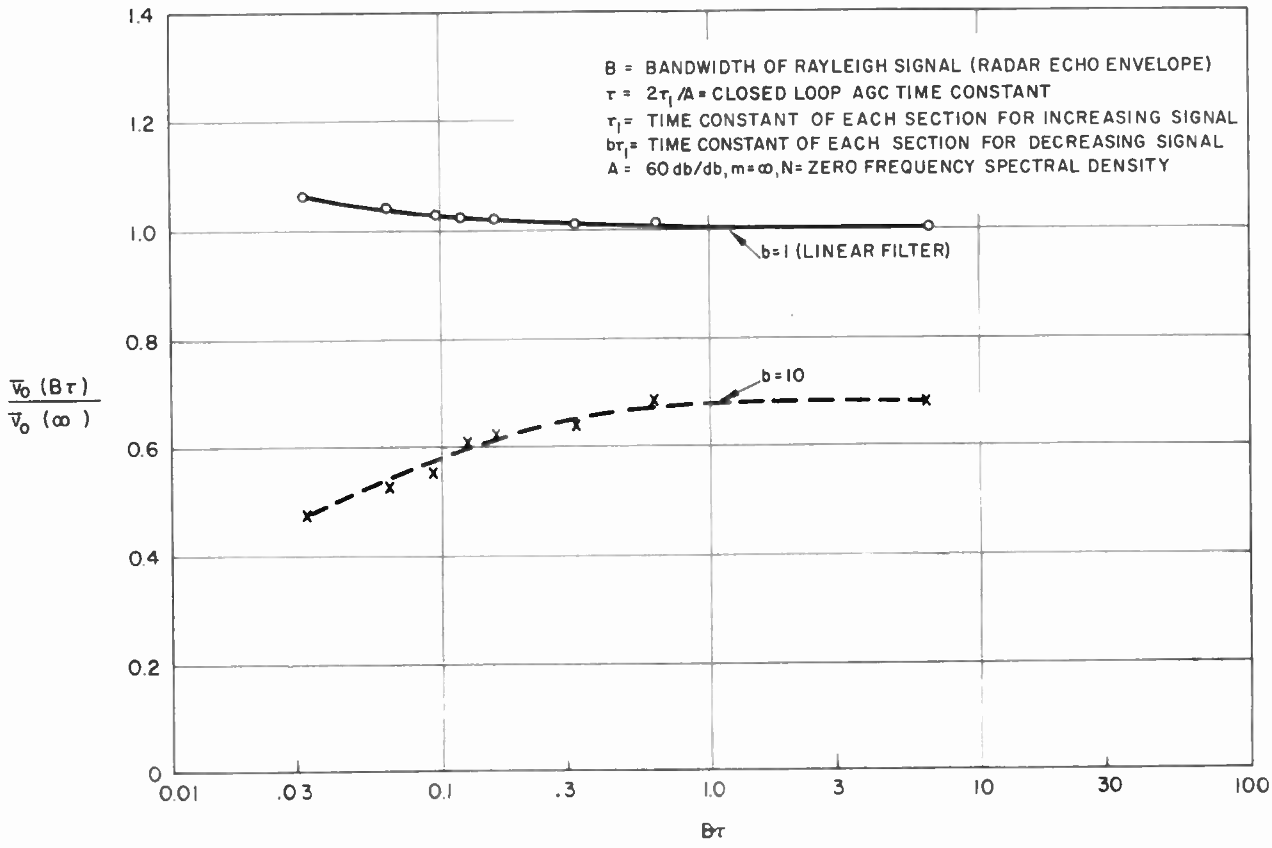

Fig. 9—Gain characteristic of agc with two-section critically damped nonlinear filter.

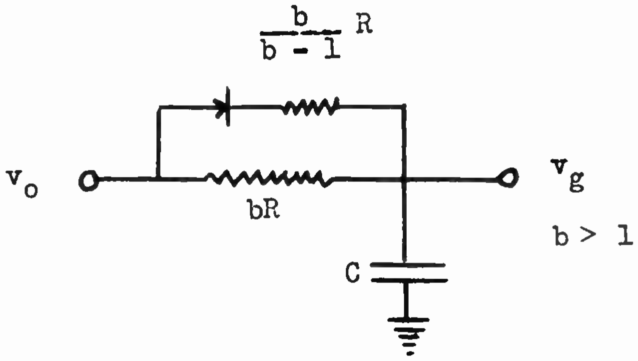

Fig. 10

TRANSIENT RISE IN RECEIVER OUTPUT

A problem which occurs in such situations as a radar mounted in a missile which homes on its target is the rapid rise in signal strength as the missile approaches the target. To prevent saturation due to the rise in output signal e_0, the agc must act sufficiently rapidly that the output never, or only at the very end of the flight, rises by such an amount that saturation occurs. This requirement, generally speaking, calls for a short agc time constant which is contrary to the direction dictated by the noise analysis presented above. The agc which has the type of characteristic shown in Fig. 1 lends itself to an analysis of its transient rise in output much more easily than a more general form. This type of characteristic was implicitly assumed by B. M. Oliver in his treatment of agc [6].

It is shown in Appendix I that when the voltage amplitude of the mean input signal varies as $(T_0/T)^n$ or $(R_0/R)^n$ where T is T_0-t and is the time remaining until impact, the normalized output of an agc of the type assumed here is approximately

$$v_0 \cong e^{n\tau/Tv_0} \tag{16}$$

where τ is the closed loop agc time constant. This function is shown plotted in Fig. 11 for n equal to one. With this result it is possible to examine the question of whether the increase in noise spectral density caused by the agc is really a serious consideration. The transient rise in signal strength is more serious the larger n is. In the case of a missile containing its own active radar, n equals 2. If, for example, study shows that a factor of 2 rise in output voltage causes saturation and is only permissible for values of T less than 0.1 second, (16) only allows τ to be as large as 0.05 second. This choice of agc time constant would mean that $B\tau$ would be about 0.25 if B is 5 cps, say. Fig. 4 then says that the noise spectral density is increased by the agc by about a factor of 1.5. Thus the effect can indeed be serious, and the nonlinear filter may be considered as a possible solution to the problem.

APPENDIX I: TRANSIENT RISE IN OUTPUT SIGNAL

The transient rise in output signal for a time varying input signal with an agc of the form

$$g = \left(\frac{e_g}{e_c}\right)^{-a} = v_g^{-a} \tag{7}$$

can be obtained by expanding the normalized gain function g at any given operating point in a Taylor series

$$g = g_i + g_i'(v_g - v_{gi}) + \text{terms}. \tag{17}$$

Since the output v_0 is just gv_1, it follows that

$$dv_0 = g_i dv_1 + v_{1i} g_i' Y_b dv_0 \tag{18}$$

$$dv_0 = \frac{g_i dv_1}{1 - v_{1i} g_i' Y_b}.$$

g_i can be expressed as v_{0i}/v_{1i} to give

$$\frac{dv_0}{v_{0i}} = \frac{1}{1 - v_{1i} g_i' Y_b} \frac{dv_1}{v_{1i}}. \tag{19}$$

Note that the existence of the clamp or threshold has never been intimated here; in fact, it has been implicitly assumed that the output is well above the clamp at all times, so that the clamp might as well not exist.

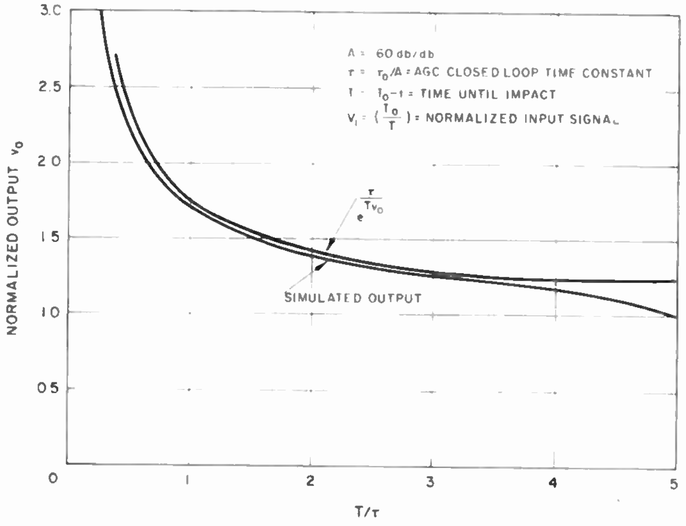

Fig. 11—Transient rise in output.

Eq. (19) is not yet identical to that used by Oliver [6]. Provided $v_{1i}g_i$ remains a constant as the input signal rises, the initial values v_{0i} and v_{1i} can be considered as moving averages or as varying adiabatically and can be replaced by v_0 and v_1, respectively. The Taylor series expansion is then around a variable point, although v_0 does remain relatively constant. However $v_{1i}g_i'$ does not remain a constant unless the output only rises as fast as its static regulation value. In this case we have from (7)

$$g_i' = -av_0^{-(a+1)} = \frac{-a}{v_1} \tag{20a}$$

and

$$v_1 g_{v_1}' = -a \text{ for all values of } v_1. \qquad (20b)$$

Approximately then we have

$$\frac{dv_0}{v_0} = \frac{1}{1 + a'Y_b}\frac{dv_1}{v_1} \qquad (21)$$

where a' equals a as long as the output does not exceed its static equilibrium value, but increases linearly with the ratio of the dimensionless output v_0 to its static equilibrium value, so that it is actually a variable.

Previous studies on the noise indicated that a single time lag for Y_b is about optimum

$$Y_b = \frac{1}{1 + p\tau_0} \qquad (22)$$

and if we use such a filter, (21) with a' set equal to a becomes

$$\frac{d \ln v_0}{dt} = \frac{1}{A}\frac{1 + p\tau_0}{1 + p\dfrac{\tau_0}{A}}\frac{d \ln v_1}{dt}$$

$$= \frac{1}{A}\frac{1 + p\tau_0}{1 + p\tau}\frac{d \ln v_1}{dt} \qquad (23)$$

where

$$\tau = \frac{\tau_0}{a+1} = \frac{\tau_0}{A} \text{ is the agc loop time constant.} \qquad (24)$$

The solution to (23) with $\ln v_1$ equal to a step function of magnitude k_1 is

$$\ln v_0 = k_1\left[e^{-(t/\tau)} + \frac{1}{A}(1 - e^{-(t/\tau)})\right]. \qquad (25)$$

The transient terms go to zero with increasing t and the steady state term k_1/A is just the static equilibrium increase in $\ln v_0$. If we ignore this expected rise in output, the transient output is

$$\ln v_0 = k_1\left(1 - \frac{1}{A}\right)e^{-(t/\tau)} \simeq k_1 e^{-(t/\tau)}. \qquad (26)$$

Since the slope of the mean input is, generally speaking, a monotonically increasing function of time and since the integral of the above transient step response over t is $k_1\tau$, it follows that at time t_b the transient output must be smaller than

$$\ln v_0 < \tau \cdot \left.\frac{d \ln v_1}{dt}\right|_{t_b}. \qquad (27)$$

In the case where v_1 varies as $(T_0/T)^n$ where n is 1 or 2 and T is the time until impact, $T_0 - t$, we have

$$\ln v_0 < n\tau \left.\frac{d \ln \left(\dfrac{T_0}{T}\right)}{-dT}\right|_T = \frac{n\tau}{T} \qquad (28)$$

and since the transient output can in general be expressed as

$$\ln v_0(t) = \ln v_1(t) - \int_0^t e^{-x/\tau} \ln v_1(t - x)\frac{dx}{\tau} \qquad (29)$$

where the upper limit of the integral is either t or infinity, whichever is convenient, provided t equal to zero corresponds to launch and $\ln v_1$ is zero for negative time, it can be shown by simple integration that for v_1 equal $(T_0/T)^n$ the output is

$$\ln v_0(T) = ne^{T/\tau}\int_{T/\tau}^{T_0/\tau}\frac{e^{-x}dx}{x} \simeq -ne^{T/\tau}Ei\left(-\frac{T}{\tau}\right)$$

$$\text{for } \frac{T_0}{\tau} \gg 1. \qquad (30)$$

The most important correction to be applied to the approximation given by (27) or (28) is not so much the use of the more exact solution (30) as it is taking into account the variation of a' with output in (21). In an approximate way this variation can be accounted for as follows: a' is directly proportional to v_0 so that a second approximation to v_0 can be

$$v_0 \simeq e^{n\tau/Tv_0} \qquad (31)$$

where it will be recalled that v_0 as given here does not include the static rise of $1/A$ db/db of input rise. For the case of n equal to one the actual increase in output was obtained by simulation for T_0/τ equal to 5 and this solution, together with the approximation of (31), is shown in Fig. 11. The approximation of (31) corresponds to T_0/τ equal to infinity, which is only important near T equal to T_0. The approximation is observed to be quite good, and, as predicted, is slightly higher than the accurate solution.

APPENDIX II: STABILITY OF THE AGC LOOP

Too short an agc time constant will also produce instability. As regards small ac variations, (21) gives the transfer function as

$$Y_{agc} = \frac{1}{1 + aY_b}. \qquad (32)$$

However, if part of the filtering Y_b is in the feedback loop and other undesired and unavoidable filtering is in the forward loop, call it Y_a, the transfer function is

$$Y_{agc} = \frac{Y_a}{1 + aY_aY_b}. \qquad (33)$$

For Y_a equal to $(1+p\tau_a)^{-N}$ and Y_b a single time lag $(1+p\tau_0)^{-1}$ the transfer function is

$$Y_{agc} = \frac{1 + p\tau_0}{a + (1 + p\tau_0)(1 + p\tau_a)^N}. \qquad (34)$$

The poles of Y_{agc} occur at

$$(1 + p\tau_0)(1 + p\tau_a)^N = - a. \tag{35}$$

The problem of stability lends itself with great facility to the root-locus method [7] especially if N is large (the worst case) and τ_0 is much larger than $N\tau_a$ which we define as τ_T. Referring to Fig. 12 and noting that $\theta + N\theta_2$ must add up to π at instability; *i.e.*, when the pole falls on the imaginary axis, we have

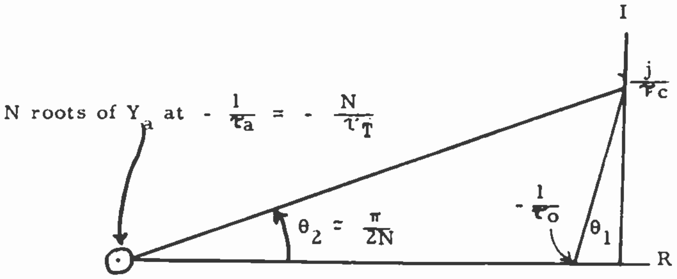

Fig. 12—p plane plot of the imaginary pole of Y_{agc}.

$$\frac{1}{\tau_c} = \frac{N}{\tau_T}\,\frac{\pi}{2N} = \frac{\pi}{2\tau_T} \tag{36}$$

at p equal to j/τ_c

$$\left| (1 + p\tau_0)(1 + p\tau_a)^N \right|$$

$$= \left[1 + \left(\frac{\pi}{2}\,\frac{\tau_0}{\tau_T}\right)^2\right]^{1/2} \left[1 + \left(\frac{\pi}{2N}\right)^2\right]^{N/2}$$

$$\simeq \left[1 + \left(\frac{\pi}{2}\,\frac{\tau_0}{\tau_T}\right)^2\right]^{1/2} > a \text{ for stability} \tag{37}$$

which simplifies into the following condition for stability

$$\frac{\tau_0}{\tau_T} > \frac{2}{\pi}(a^2 - 1)^{1/2} \simeq \frac{2}{\pi} a. \tag{38a}$$

In the vicinity of instability the resonant frequency is

$$f_c = \frac{1}{2\pi\tau_c} = \frac{1}{4\tau_T} \simeq \frac{a}{2\pi\tau_0} \simeq \frac{1}{2\pi\tau} \cdot \tag{38b}$$

By a somewhat similar line of reasoning it is possible to show that if Y_b is a second order filter $(1+p\tau_1)^{-2}$ the condition for stability is

$$\frac{2\tau_1}{\tau_T} > a - 1 \tag{39a}$$

and that near instability the resonant frequency is

$$f_c = \frac{1}{\pi\sqrt{2\tau_1\tau_T}} \simeq \frac{\sqrt{a-1}}{2\pi\tau_1} \tag{39b}$$

These results agreed well with the observed limits of stable operation on the analog computer. It was further observed that with the nonlinear filter in the feedback loop, the limits of stable operation were no worse than the limits set by (38a) or (39a), provided the shorter or rising time constant is substituted for τ_0 or τ_1, respectively.

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Theory of Noisy Fourpoles*

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Summary—**The well-known theory of fourpoles only comprises passive fourpoles and active fourpoles with internal sources of sinusoidal currents or voltages of defined frequencies. This theory is now completed for fourpoles with internal noise sources. Simple equivalent circuits are derived for such networks. They consist of the original but noise-free fourpole cascaded with a preceding noise fourpole in which all noise-sources are concentrated. The latter contains the equivalent noise conductance G_n, the equivalent noise resistance R_n and the complex correlation admittance Y_{cor}. With these quantities the noise behavior of any desired fourpole can be described sufficiently. In particular it is possible to calculate the noise figure F and its dependence on the matching conditions to the signal source of a single fourpole or a group of cascaded fourpoles. The methods of experimental determination of the elements of the noise fourpoles are discussed. The same theory is also useful for mixer-circuits as well as for traveling-wave tubes and transistors, as application results are given for grid controlled electron tubes.**

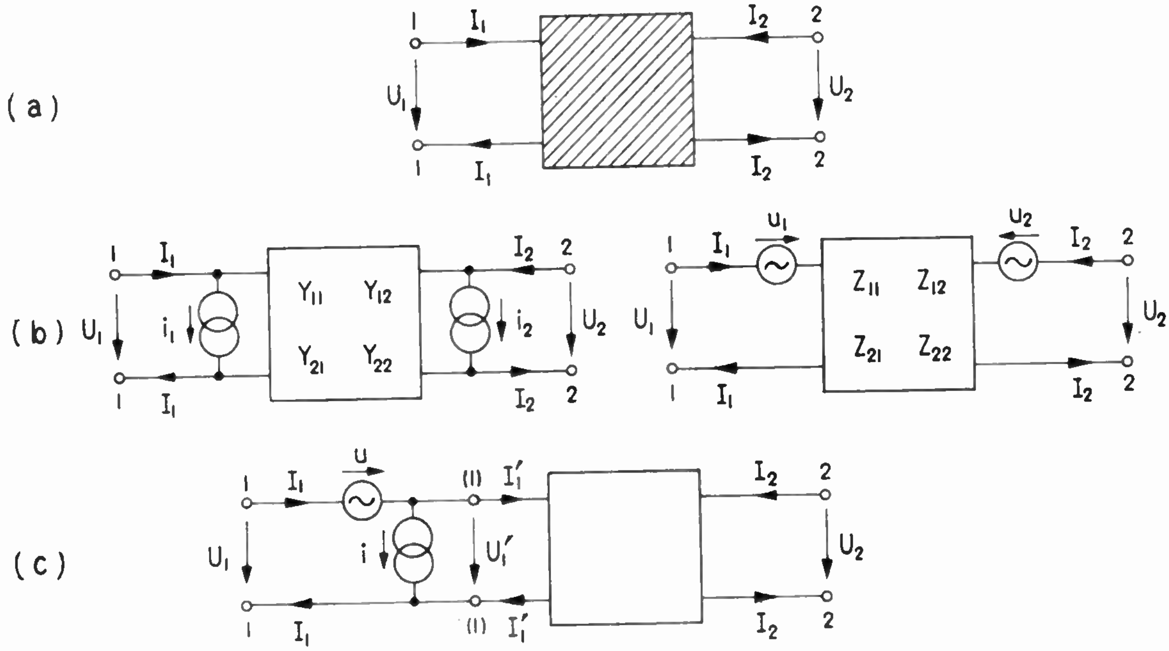

Fig. 1—(a) Fourpole with internal noise sources; (b) equivalent circuit with the outside noise current sources i_1 and i_2 respectively u_1 and u_2; (c) equivalent circuit with noise voltage source u and noise current source i at the input.

Fourpole Equations of Noisy Fourpoles

IN FIG. 1(a) is shown the principal scheme of a fourpole with internal noise sources. The electrical behavior of this fourpole will be described by two linear equations between the input voltage and current U_1 and I_1 and the output voltage and current U_2 and I_2. The special form of these equations depends on the network itself, if the II-admittance matrix or the T-resistance matrix is more convenient as equivalent circuit. But if there are inner noise sources inside the fourpole, these well-known fourpole equations are no more sufficient. They must rather be completed by two noise currents i_1 and i_2 respectively, by two noise voltages u_1 and u_2 to the form

$$
\begin{aligned}
I_1 &= Y_{11}U_1 + Y_{12}U_2 + i_1 \\
U_1 &= Z_{11}I_1 + Z_{12}I_2 + u_1 \\
&\text{or} \qquad\qquad\qquad\qquad (1) \\
I_2 &= Y_{21}U_1 + Y_{22}U_2 + i_2 \\
U_2 &= Z_{21}I_1 + Z_{22}I_2 + u_2.
\end{aligned}
$$

Here i_1 and i_2 (u_1 and u_2) represent the short circuit noise current (open circuit noise voltage) at the input respectively at the output for $U_1 = U_2 = 0$ ($I_1 = I_2 = 0$) caused only by the internal noise sources. Between both noise sources normally a correlation has to be assumed.

The system of Fig. 1 can be represented by the equivalent circuits of Fig. 1(b). In these circuits the noisy four-pole of Fig. 1(a) is replaced by a noise-free but otherwise unchanged fourpole together with the noise current sources i_1 and i_2 (noise voltage sources u_1 and u_2) with an inner infinite (zero) impedance.

In order to characterize the noise qualities of a fourpole it is more convenient to use only noise sources preceding the noise-free fourpole. This is possible by using

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the chain matrix

$$I_1 = AU_2 + BI_2 + i,$$
$$U_1 = CU_2 + DI_2 + u. \qquad (2)$$

All internal noise sources then will be represented at the input side by a noise current source i and a noise voltage source u, as shown in the equivalent circuit of Fig. 1(c). It consists of the noise-free fourpole between the points (*1*)(*1*) and *2 2* and a preceding noise fourpole between the points *1 1* and (*1*)(*1*).

$$u = -\,i_2/Y_{21}$$
$$i = i_1 + uY_{11} = i_1 - i_2(Y_{11}/Y_{21})$$
$$\text{or } u = u_1 + iZ_{11} = u_1 - u_2(Z_{11}/Z_{21})$$
$$i = -\,u_2/Z_{21}. \qquad (4)$$

As equivalent of a noise current source i_2 (noise voltage source u_2) at the output, therefore, a voltage source u (current source i) and an additional current source $-i_2Y_{11}/Y_{21}$ (voltage source $-u_2\,Z_{11}/Z_{21}$) are necessary at the input.

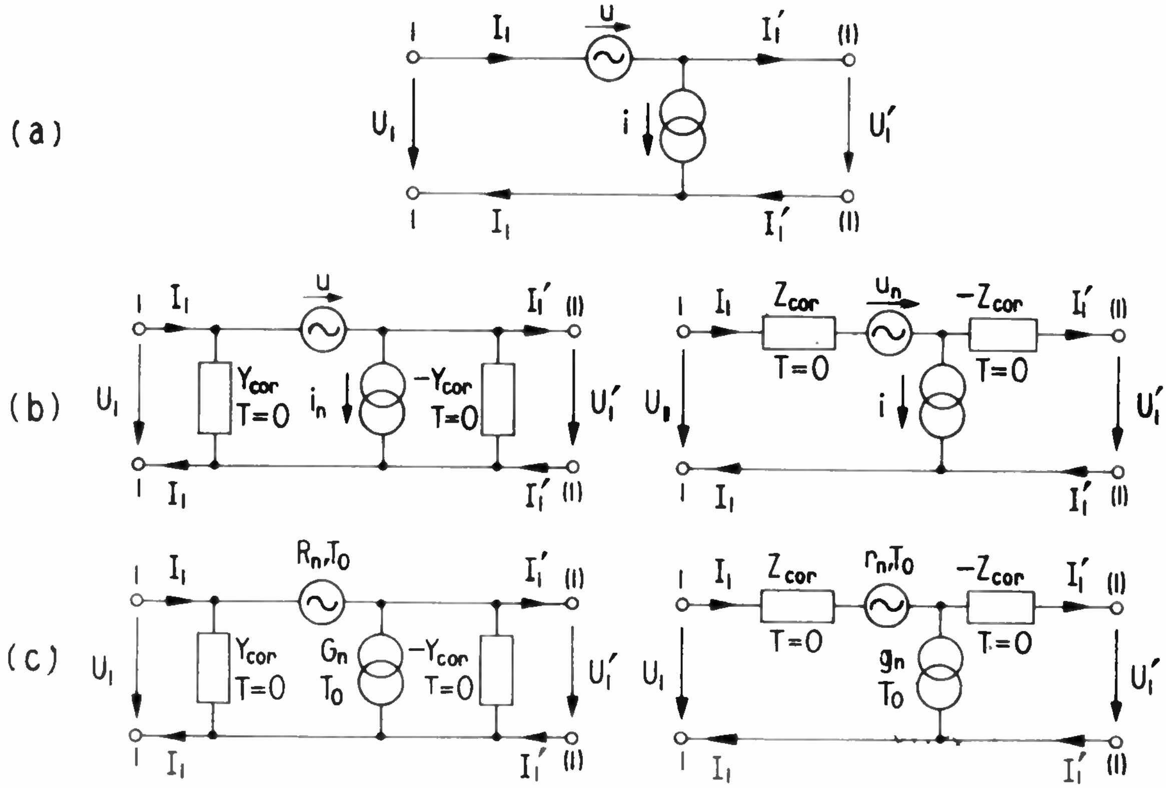

Fig. 2—(a) Noise fourpole with correlated noise sources u and i; (b) noise fourpole with correlation admittance Y_{cor} (correlation impedance Z_{cor}) and uncorrelated noise voltage source u, noise current source i_n (u_n and i); (c) noise fourpole with correlation admittance Y_{cor} (correlation impedance Z_{cor}) and uncorrelated noise sources R_n and G_n (r_n and g_n).

With the current i_1' and the voltage U_1' at the input terminals (*1*)(*1*) of the noise-free fourpole Eq. (2) changes to

$$I_1 = I_1' + i,$$
$$U_1 = U_1' + u. \qquad (2a)$$

By introducing the noise sources i and u in Eq. (1) we get

$$I_1 = Y_{11}(U_1 - u) + Y_{12}U_2 + i$$
$$I_2 = Y_{21}(U_1 - u) + Y_{22}U_2$$
$$\text{or } U_1 = Z_{11}(I_1 - i) + Z_{12}I_2 + u$$
$$U_2 = Z_{21}(I_1 - i) + Z_{22}I_2. \qquad (3)$$

A comparison with Eq. (1) gives the transforming formulas for both of the new noise sources

NOISE FOURPOLE AND CHARACTERISTIC NOISE TERMS

Normally a correlation exists between the two noise sources u and i of the above defined noise fourpole shown in Fig. 2(a). But the noise current i (noise voltage u) can be divided into one part i_n (u_n) not correlated to $u(i)$ and a second part fully correlated to u (i). This second part must be proportional to u (i). As factor of proportionality having the dimension of an admittance (impedance) we introduce the complex correlation admittance $Y_{cor} = G_{cor} + jB_{cor}$ (correlation impedance $Z_{cor} = R_{cor} + jX_{cor}$). We therefore may write

$$i = i_n + uY_{cor}, \quad \text{or} \quad u = u_n + iZ_{cor}. \qquad (5)$$

These new terms Y_{cor} and Z_{cor} corresponding to the well-known correlation coefficient

$$\gamma = \frac{\overline{iu^*}}{\sqrt{\overline{|i|^2}\,\overline{|u|^2}}}$$

are defined by (4, 5, 11)

$$Y_{cor} = \gamma \sqrt{\frac{\overline{|i|^2}}{\overline{|u|^2}}} = \frac{\overline{iu^*}}{\overline{|u|^2}}$$

$$\text{or} \quad Z_{cor} = \gamma \sqrt{\frac{\overline{|u|^2}}{\overline{|i|^2}}} = \frac{\overline{i^*u}}{\overline{|i|^2}}. \tag{6}$$

The correlation between i_1 and u (u_1 and i) in (4) which is not identical with the correlation between i and u, can be expressed by another correlation coefficient

$$\alpha = \frac{\overline{i_1 u^*}}{\sqrt{\overline{|i_1|^2}\,\overline{|u|^2}}} \quad \text{resp.} \quad \frac{\overline{u_1 i^*}}{\sqrt{\overline{|u_1|^2}\,\overline{|i|^2}}}.$$

With it we get the relations

$$Y_{cor} = Y_{11} - \alpha \sqrt{\frac{\overline{|i_1|^2}}{\overline{|u|^2}}} \text{ or } Z_{cor} = Z_{11} - \alpha \sqrt{\frac{\overline{|u_1|^2}}{\overline{|i|^2}}}. \tag{6a}$$

Therefore, the correlation between i and u and also Y_{cor} (Z_{cor}) can be zero even if $\alpha \neq 0$ and a finite correlation exists between i_1 and i_2 (u_1 and u_2). For i_1 (u_1) uncorrelated to i_2 (u_2) is $\alpha = 0$ and we obtain

$$i_n = i_1 \quad \text{or} \quad u_n = u_1 \tag{5a}$$

and

$$Y_{cor} = Y_{11} \quad \text{or} \quad Z_{cor} = Z_{11}. \tag{6b}$$

Introducing (5) into (2a) we get

$$\begin{aligned} I_1 &= I_1' + i_n + uY_{cor} & I_1 &= I_1' + i \\ & \qquad\qquad \text{or} & & \\ U_1 &= U_1' + u & U_1 &= U^1 + u_n + iZ_{cor} \end{aligned} \tag{7}$$

and further

$$\begin{aligned} I_1 &= I_1' + i_n + U_1 Y_{cor} - U_1' Y_{cor} \\ U_1 &= U_1' + u \\ \text{or} \quad I_1 &= I_1' + i \\ U_1 &= U_1' + u_n + I_1 Z_{cor} - I_1' Z_{cor}. \end{aligned} \tag{8}$$

Eq. (8) for the noise fourpole can be realized by the equivalent networks of Fig. 2(b). They only consist of the uncorrelated noise sources u and i_n (u_n and i) and the correlation admittance $+Y_{cor}$ (correlation impedance $+Z_{cor}$) at the input side and the correlation admittance $-Y_{cor}$ (correlation impedance $-Z_{cor}$) at the output side. Both admittances (impedances) are noise-free and have, therefore, the noise temperature $T = 0$. Using the well-known Nyquist formulas

$$\begin{aligned} \overline{|u|^2} &= 4kT_0\Delta f\, R_n & \overline{|u_n|^2} &= 4kT_0\Delta f\, r_n \\ & \qquad \text{or} & & \\ \overline{|i_n|^2} &= 4kT_0\Delta f\, G_n & \overline{|i|^2} &= 4kT_0\Delta f\, g_n, \end{aligned} \tag{9}$$

we express the noise currents and voltages by the characteristic noise terms:

equivalent noise resistance R_n or r_n,
equivalent noise conductance G_n or g_n.

So we get the equivalent networks of Fig. 2(c) for the noise fourpoles. They describe completely the noise behavior of the whole network by the three terms R_n, G_n, and Y_{cor} (r_n, g_n, and Z_{cor}). As Y_{cor} (Z_{cor}) is complex four real characteristic noise terms are needed in fact.

Between the characteristic noise terms of the Π-matrix and those of the T-matrix the following transformation rules exist similar as they exist for fourpole coefficients

$$g_n = G_n + R_n |Y_{cor}|^2 \qquad R_n = r_n + g_n |Z_{cor}|^2$$

$$r_n = \frac{G_n}{|Y_{cor}|^2 + (G_n/R_n)} \quad \text{or} \quad G_n = \frac{r_n}{|Z_{cor}|^2 + (r_n/g_n)}$$

$$Z_{cor} = \frac{Y_{cor}^*}{|Y_{cor}|^2 + (G_n/R_n)} \qquad Y_{cor} = \frac{Z_{cor}^*}{|Z_{cor}|^2 + (r_n/g_n)}.$$

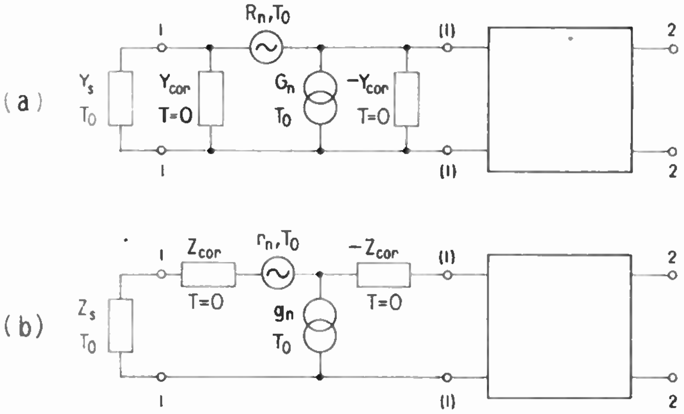

Fig. 3—Equivalent circuit of Fig. 2(c) together with signal source.

THE TOTAL NOISE CONDUCTANCE G_{tot}

In the operation of a fourpole a signal source with the inner admittance $Y_s = G_s + jB_s$ (inner impedance $Z = R + jX$) is connected to the input terminals *1 1*, as Fig. 3 shows. In the case of the Π-circuit in Fig. 3(a) the inner conductance G_s of the signal source delivers a noise current inflow i_s in the terminals *1 1* that is uncorrelated to all other noise sources. Therefore, the sum of noise power at the output of the fourpole comes from the signal source as well as from the fourpole. But the whole noise power can be assumed as engendered by a single total equivalent noise current i_{tot} flowing into the input terminals. As all noise sources of the equivalent network of Fig. 3(a) are located at the left side of the terminals (*1*)(*1*), the short circuit noise current between (*1*)(*1*) must be identical with this total equivalent noise current i_{tot}. It is easy calculated to

$$i_{tot} = i_s + i_n + u(Y_s + Y_{cor}). \tag{11}$$

In (11) each component of i_{tot} is uncorrelated to the other ones. Therefore, the mean square value $\overline{|i_{tot}|^2}$ is equal to the sum of the mean square values of each part

$$\overline{|i_{tot}|^2} = \overline{|i_s|^2} + \overline{|i_n|^2} + \overline{|u|^2}\,|Y_s + Y_{cor}|^2. \tag{12}$$

Introducing the total noise conductance G_{tot} by the Nyquist formula

$$\overline{|i_{tot}|^2} = 4kT_0\Delta f G_{tot} \tag{13}$$

and using (9) we obtain

$$\begin{aligned} G_{tot} &= G_s + G_n + R_n|Y_s + Y_{cor}|^2 \\ &= G_s + G_n + R_n[(G_s + G_{cor})^2 + (B_s + B_{cor})^2]. \end{aligned} \tag{14}$$

and in the case that $G_s \to 0$

$$G_{tot}^0 = G_N + R_N[G_{cor}^2 + (B_s + B_{cor})^2]. \tag{14a}$$

This expression for the total noise conductance shows that a complete characterization of the noise quality needs again the four values R_n, G_n, G_{cor}, and B_{cor} besides the admittance Y_s. The total noise conductance G_{tot}^0 determines the noise behavior of the network in a very simple way. It solely consists of admittances, respectively, conductances and resistances which are independent of the bandwidth of the network. We notice that G_{tot} does not depend on the loading admittance at the output of the fourpole. But it depends on account of the term $R_n|Y_s + Y_{cor}|^2$ upon the real part G_s as well as on the imaginary part jB_s of the source admittance.

The function $G_{tot} = f(B_s)$ is a quadratic parabola, symmetrical to the ordinate $B_s = -B_{cor}$ as shown by Fig. 4. The second differential quotient of the parabola is $2R_n$. The minimum of G_{tot} at the vertex of the parabola is equal to

$$G_{tot\,min} = G_s + G_n + R_n(G_s + G_{cor})^2 \tag{15}$$

respectively for $G_s \to 0$

$$C_{tot}^0{}_{min} = G_n + R_N G_{cor}^2. \tag{15a}$$

Analog relations are valid for the dual T-network, as shown in Fig. 3(b). All noise sources can be replaced by the total equivalent noise resistance

$$R_{tot} = R_s + r_n + g_n|Z_s + Z_{cor}|^2. \tag{16}$$

EXPERIMENTAL DETERMINATION OF THE CHARACTERISTIC NOISE VALUES

The experimental methods to determine the noise current sources f.e. using a noise diode are well known. If G_{tot} is measured as function of the source susceptance B_s we find the value of B_{cor} by the tuning condition for $G_{tot\,min}$. If $G_{tot\,min} - G_s$ is plotted as function of G_s we find corresponding to (14) a quadratic parabola with the second differential quotient equal to $2R_n$ as shown in Fig. 5. In the vertex of the parabola we have the ordinate value $G_{tot\,min} - G_s = G_n$ and the abscissa value $G_s = -G_{cor}$. By measuring $G_{tot} = f(B_s)$ and $G_{tot\,min} = f(G_s)$ we therefore find the four values R_n, G_n, G_{cor} and B_{cor}. Because usually no negative values of G_s are available the vertex of the parabola must be found by extrapolation if $G_{cor} > 0$. But on principle positive as well as negative values of G_{cor} and B_{cor} are possible and also measured. The methods to determine the characteristic noise values r_n, g_n, R_{cor} and X_{cor} for the T-circuit are the same on principle.

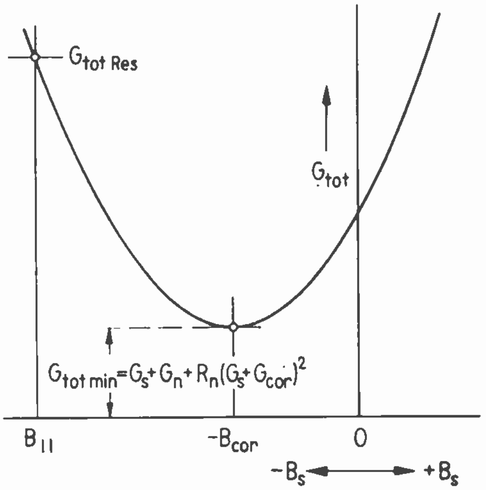

Fig. 4—Total noise admittance G_{tot} as function of the signal source susceptance B_s.

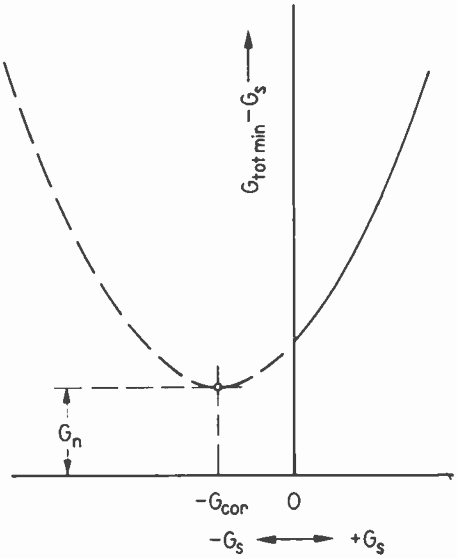

Fig. 5—$G_{tot\,min} - G_s$ as function of the signal source conductance G_s.

CALCULATION OF THE NOISE FIGURE

By introducing the total noise conductance G_{tot} (14) into the well-known definition of the excess noise figure [3, 10, 11]

$$F_z = F - 1 = \frac{\overline{|i_{tot}|^2} - \overline{|i_s|^2}}{\overline{|i_s|^2}} = \frac{G_{tot}}{G_s} - 1 \qquad (17)$$

we obtain

$$F_z = \frac{1}{G_s}(G_n + R_n |Y_s + Y_{cor}|^2). \qquad (18)$$

This function of G_s has its lowest value

$$F_{z\,opt} = 2R_n(G_{cor} + G_{s\,opt}) = 2(R_nG_{cor} + \sqrt{R_nG_{tot}^0})$$
$$= 2[R_nG_{cor} + \sqrt{R_nG_n + (R_nG_{cor})^2 + R_n^2(B_s + B_{cor})^2}] \quad (19)$$

for the optimal internal conductance

$$G_{s\,opt} = \sqrt{\frac{G_n}{R_n} + |jB_s + Y_{cor}|^2} = \sqrt{\frac{G_{tot}^0}{R_n}} \qquad (20)$$

of the signal source. This condition is called *noise matching*. As shown by (17) and (18) the values $F_{z\,opt}$ and $G_{s\,opt}$ depend on the tuning of the signal source. If we choose

$$B_s + B_{cor} = 0 \qquad (21)$$

which condition is independent of the fourpole's input susceptance B_{11} the excess noise figure becomes its absolute minimum

$$F_{z\,min} = 2R_n(G_{cor} + G_{s\,min}) = 2(R_nG_{cor}\sqrt{R_nG_{tot}^0{}_{min}}$$
$$= 2[R_nG_{cor} + \sqrt{R_nG_n + (R_nG_{cor})^2}] \qquad (22)$$

for the corresponding signal source admittance

$$G_{s\,min} = \sqrt{\frac{G_n}{R_n} + G_{cor}^2} = \frac{G_{tot}^0{}_{min}}{R_n} \qquad (23)$$

We call the condition (21) *noise tuning*. To get the minimum noise figure $F_{z\,min}$ the conditions (20) for *noise matching* and (21) for *noise tuning* therefore must be fulfilled together. By (22) the noise figure is solely represented by the products of R_nG_n and R_nG_{cor}.

INFLUENCE OF THE INPUT ADMITTANCE Y_{11}

The input admittance Y_{11} composed of several admittances directly located between the terminals *1 1* of the noisy fourpole may be divided into two principal parts. The first one contains the admittances with the noise power uncorrelated to each of the other noise sources, while the second one contains these other admittances being more or less correlated to the inner noise sources of the fourpole. Let us consider f.e. an hf amplifier using a triode in a neutralized common cathode circuit. Then the whole input admittance Y_{11} consists of the admittance $Y_c = G_c + jB_c$ of the resonance circuit between grid and cathode including the cold input admittance of the tube and delivering uncorrelated noise power and further of the electronic input admittance $Y_{el} = G_{el} + j\omega\Delta C_g$ being closely related to the noise of the electron flow inside of the tube.

In the preceding paragraphs both of these principal parts of noise sources were concentrated into a single noise fourpole to get simple expressions for the noise figure. But this procedure has the decisive disadvantage of preventing a separate discussion of the mentioned two parts of noise, so that G_n and Y_{cor} depend on the noise of the input circuit as well as of the inner noise sources f.e. the electron flow, while R_n is only influenced by the latter one.

To get a complete and separate information on the influence of both these parts of noise sources we therefore propose to transfer the admittance Y_c with uncorrelated noise really located inside of the noisy fourpole to the outside of its terminals *1 1* that is parallel to the admittance Y_s of the signal source. To do this outgrouping of circuit noise (see Table I) it is only necessary to introduce into all equations of the sections "The Total Noise Conductance G_{tot}" and "Experimental Determination of the Characteristic Noise Values".

TABLE I

instead of	the new terms
i_s	$i_y = i_s + i_c$
$\overline{\lvert i_s\rvert^2}$	$\overline{\lvert i_Y\rvert^2} = \overline{\lvert i_s\rvert^2} + \overline{\lvert i_c\rvert^2} = 4kT_0\Delta f(G_s + G_c)$
$Y_s = G_s = jB_s$	$Y = G + jB = Y_s + Y_c = (G_s + G_c) + j(B_s + B_c)$
G_s	$G = G_s + G_c$
$G_s \rightarrow 0$	$G_s + G_c \rightarrow 0$
B_s	$B = B_s + B_c$

It is easy to prove that G_{tot} resp. G_{tot}^0 is unchanged by this transformation while on the other hand the characteristics G_n and Y_{cor} are changed in quantity and physical interpretation [2]. In the above discussed example of an hf amplifier the new terms G_n and Y_{cor} now represent the noise behavior of the electron flow only, while the influence of the resonance circuit including the cold input admittance of the tube is represented by the admittance Y_c.

THE NOISE FIGURE WITH SEPARATED Y_c

To get the influence of Y_c on the noise figure we have to use in (17) the expression of G_{tot} obtained by introducing the new terms given by (24) into (14). So we find

$$F_z = \frac{1}{G_s}(G_c + G_n + R_n|Y_s + Y_c + Y_{cor}|^2) \qquad (18a)$$

and therefore for *noise matching*

$$F_{z\,opt} = 2R_n(G_c + G_{cor} + G_{s\,opt})$$
$$= 2[R_n(G_c + G_{cor}) + \sqrt{R_n(G_c + G_n) + R_n^2(G_c + G_{cor})^2 + R_n^2(B_s + B_c + B_{cor})^2}] \qquad (19a)$$

and in the case that $G_c \rightarrow 0$

$$F_{z\,\mathrm{opt}} = 2(R_nG_{\mathrm{cor}} + \sqrt{R_NG_{\mathrm{tot}}{}^0})$$
$$= 2[R_nG_{\mathrm{cor}} + \sqrt{R_n[G_n + R_nG_{\mathrm{cor}}{}^2 + R_n(B_s + B_c + B_{\mathrm{cor}})^2}], \tag{19b}$$

with the optimal source conductance

$$G_{s\,\mathrm{opt}} = \sqrt{\frac{G_c + G_n}{R_n} + |jB_s + Y_c + Y_{\mathrm{cor}}|^2} \tag{20a}$$

$$G_{s\,\mathrm{opt}} = \sqrt{\frac{G_{\mathrm{tot}}{}^0}{R_n}} \tag{20b}$$

For *noise tuning* the tuning condition

$$B_s + B_c + B_{\mathrm{cor}} = 0 \tag{21a}$$

is valid. We obtain

$$F_{z\,\min} = 2R_n(G_c + G_{\mathrm{cor}} + G_{s\,\min})$$
$$= 2[R_n(G_c + G_{\mathrm{cor}}) + \sqrt{R_n(G_c + G_n) + R_n{}^2(G_c + G_{\mathrm{cor}})^2}] \tag{22a}$$

respectively for $G_c \rightarrow 0$

$$F_{z\,\min} = 2(R_nC_{\mathrm{cor}} + \sqrt{R_nG_{\mathrm{tot}}{}^0{}_{\min}})$$
$$= 2[R_nG_{\mathrm{cor}} + \sqrt{R_n(G_n + R_nG_{\mathrm{cor}}{}^2)}] \tag{22b}$$

with

$$G_{s\,\min} = \sqrt{\frac{G_c + G_n}{R_n} + (G_c + G_{\mathrm{cor}})^2}. \tag{23a}$$

with

$$G_{s\,\min} = \frac{\sqrt{G_{\mathrm{tot}}{}^0{}_{\min}}}{R_n}. \tag{23b}$$

If $G_c \ll G_n$, G_{cor} (22a) and (23a) are identical with (22) and (23). If further $G_{\mathrm{cor}} = 0$ we get

$$F_{z\,\min} \rightarrow 2\sqrt{R_nG_n}, \tag{24}$$

$$G_{s\,\min} \rightarrow \sqrt{G_n/R_n}. \tag{25}$$

Both expressions only imply the noise terms R_n and G_n. They are valid for triodes in uhf region.

For triodes at low frequencies $G_c \gg G_n$, G_{cor} (22a) and (23a) simplify to

$$F_{z\,\min} \rightarrow 2[R_nG_c + \sqrt{R_nG_c + (R_nG_c)^2}], \tag{26}$$

$$G_{s\,\min} \rightarrow \sqrt{G_c{}^2 + (G_c/R_n)} \tag{27}$$

depending on G_c and R_n only.

To study the excess noise figure as function of the noise matching of the signal source it is useful to transform (18a) into the form of a circle. For that purpose we introduce the expressions $F_{z\,\min}$ and $G_{s\,\min}$ by (22a) and (23a) and receive

$$F_z = F_{z\,\min} + R_nG_{s\,\min}\left(m + \frac{1}{m} - 2\right) \tag{28}$$

with

$$m + \frac{1}{m} = \frac{G_{s\,\min}}{G_s}\left[1 + \left(\frac{G_s}{G_{s\,\min}}\right)^2 + \left(\frac{B_s + B_c + B_{\mathrm{cor}}}{G_{s\,\min}}\right)^2\right]. \tag{29}$$

The coefficient m only depends on the quotients $G_s/G_{\min}$, respectively on

$$\frac{B_s + B_c + B_{\mathrm{cor}}}{G_{s\,\min}}$$

and represents the standing wave ratio $U_{\max}/U_{\min}$ of a transmission line with a wave-resistance $Z = 1/G_{s\,\min}$ being connected to the signal source with the inner admittance $G_s + j(B_s + B_c + B_{\mathrm{cor}})$.

In the complex plane with $G_s/G_{\min}$ as abscissa and $(B_s + B_c + B_{\mathrm{cor}})\,G_{s\,\min}$ as ordinate the curves of constant m and therefore also constant noise figure F_z are circles as shown in the well-known matching diagram of Fig. 6. For $G_s = G_{s\,\min}$ and $B_s + B_c + B_{\mathrm{cor}} = 0$ we get $m = 1$ and therefore $F_z = F_{z\,\min}$. The center point of minimum noise figure was already introduced as fulfilling the conditions of noise matching and noise tuning. The points of every circle with extreme values of $B_s + B_c + B_{\mathrm{cor}}$ are fulfilling the condition of noise matching (20a). The locations of this condition are given by the dashed hyperbola

$$\left(\frac{G_{s\,\mathrm{opt}}}{G_{s\,\min}}\right)^2 - \left(\frac{B_s + B_c + B_{\mathrm{cor}}}{G_{s\,\min}}\right)^2 = 1. \tag{30}$$

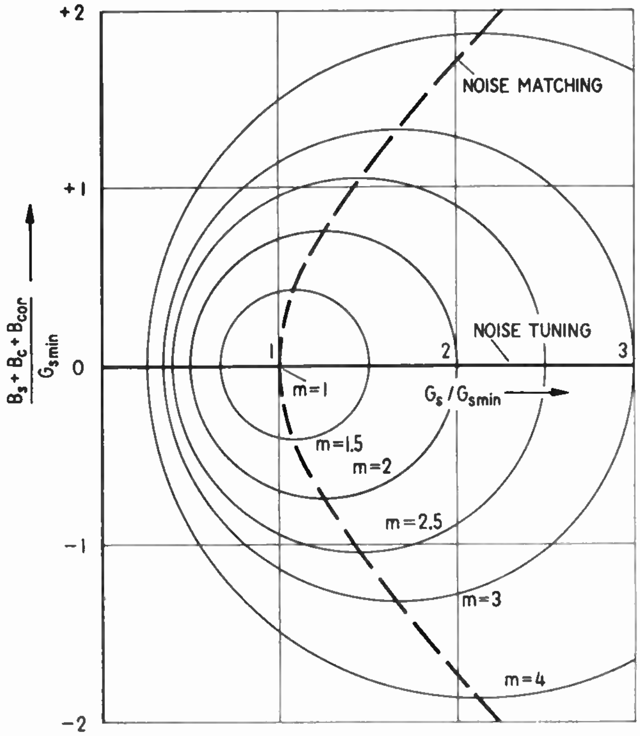

Fig. 6—Noise matching diagram between the signal source and the noise fourpole. The circles are curves for constant noise figure.

Of special interest is the influence of G_{cor} upon the magnitude of $F_{z\,\mathrm{opt}}$ and $F_{z\,\min}$ along this hyperbola for noise matching. In Fig. 7 $F_{z\,\mathrm{opt}}$ corresponding to (19a) is given as function of $B = B_s + B_c$ for a negative value of G_{cor}. This curve is again a quadratic hyperbola symmetrical to $B = -B_{cor}$ and a slope of the asymptotes equal to $\pm R_n$. In the vertex the curve is crossing the center point of Fig. 6 with $F_{z\,opt} = F_{z\,min}$. The point of intersection of the asymptotes has a negative value of $F_{z\,opt} = -2R_n(G_c + G_{cor})$ in our example. The distance

$$2\sqrt{R_n(G_c + G_{cor}) + R_n^2(G_c + G_{cor})^2}$$

between this point and the vertex of the hyperbola is always positive and greater than $2R_n(G_c + G_{cor})$, so that $F_{z\,min}$ remains positive. Positive values of G_{cor} shift the hyperbola to higher values of $F_{z\,opt}$, negative G_{cor} to lower values. For $G_c + G_{cor} \to -\infty$ the vertex and, therefore, $F_{z\,min}$ is going to zero.

We have to notice that the condition for *noise tuning* given by (21a) is independent of the impedance $Y_{11} = G_{11} + jB_{11}$ of the fourpole. For *power matching* the conditions

$$Y_s^* = Y_c + Y_{11} \tag{31}$$

or

$$\begin{aligned} B_s + B_c + B_{cor} &= 0 \\ G_s &= G_c + G_{11} \end{aligned} \tag{31a}$$

are valid. Therefore, power matching is only identical with noise matching and noise tuning if $G_c + G_{11} = G_{s\,min}$ and $B_{cor} = B_{11}$. In this case the diagram of Fig. 6 is identical with the diagram for power matching. If these conditions are not fulfilled the noise figure for power matching is higher than $F_{z\,min}$ and given by

$$\begin{aligned} F_z = \frac{1}{G_c + G_{11}} &[G_c + G_n + R_n(2G_c + G_{11} + G_{cor})^2 \\ &+ R_n(B_{cor} - B_{11})^2]. \end{aligned} \tag{32}$$

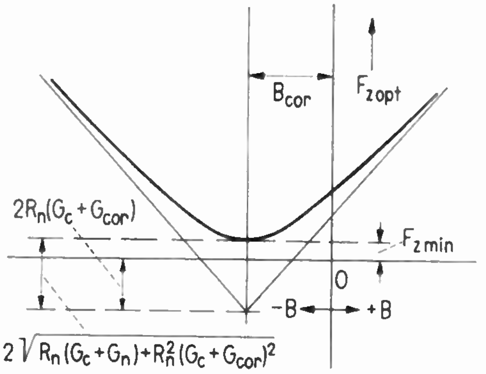

Fig. 7—Noise figure $F_{z\,opt}$ as function of the source susceptance $B = B_s + B_c$. In this example is $(G_c + G_{cor})$ assumed as negative.

The lowest noise figure in this case is not always attained with $G_c = 0$ but sometimes with $G_c > 0$ [5]. Using internal feedback inside of the noisy fourpole the conditions for noise matching, noise tuning and power matching can often be combined. Then the absolute minimum value $F_{z\,min}$ of the excess noise figure occurs together with the reflection-free connection to the signal source.

CHAIN CONNECTION OF NOISY FOURPOLES

The noise figure for chain connection of two noisy fourpoles can be calculated by the same principal method [7]. The result

$$F_z = F_z^{I} + \frac{F_z^{II}}{V_L} \tag{33}$$

is the same as already given by Friis [3]. F_z^I and F_z^{II} are the noise figures of the two fourpoles alone and V_L the available power gain of the first fourpole. The total noise figure of n equal fourpoles chained together each of them with the noise figure F_z^I is

$$F_z^n = F_z^I \frac{1 - (1/V_L)^n}{1 - (1/V_L)}. \tag{34}$$

For $n \to \infty$ then results

$$F_z^\infty = F_z^I \frac{V_L}{V_L - 1}. \tag{35}$$

Fig. 8 shows F_z^n/F_z^I as function of V_L for different numbers of n. Eqs. (33) to (35) show very clearly that the noise figure alone is insufficient for full determination of the quality of a noisy fourpole. But the term F_z^∞ given by (35) seems especially adequate as figure of merit.

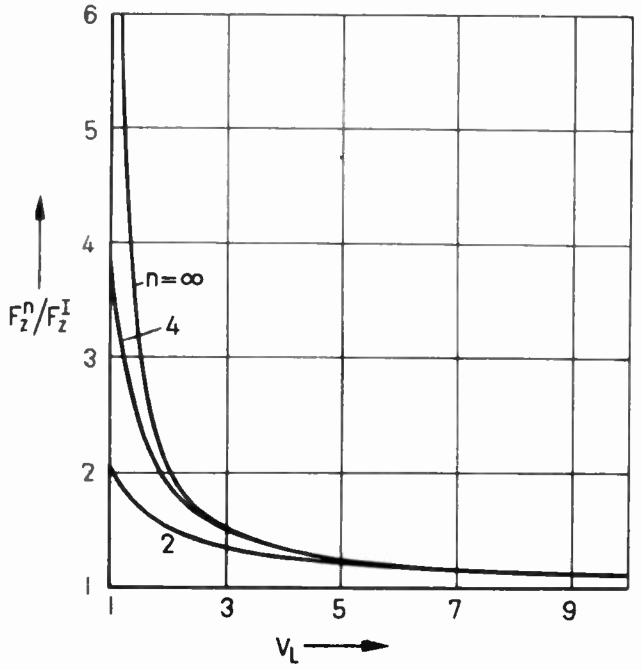

Fig. 8—Relative noise figure of a n-cascaded amplifier as function of the available gain V_L.

MIXER CIRCUITS

The noise properties of mixer stages can also be described by the noise fourpole. Then the short circuit noise currents i_1 and i_2 in Eq. (1) depend on the period of the oscillator frequency ω_0. As i_1 concerns to the input side with the high frequency ω_h and i_2 to the intermediate frequency ω_i in most mixer currents i_1 is practically uncorrelated to i_2. Then we obtain

$$G_n = G_1 \tag{36}$$

with G_1 given by the Nyquist equation

$$\overline{|i_1|^2} = 4kT_0\Delta f G_1$$

and

$$Y_{cor} = Y_{11} \tag{37}$$

where Y_{11} is the mean value of the input admittance for the high frequency ω_h middled over the period of the oscillator frequency ω_o.

Application of the Method

The application of the above considerations on electron tubes was already shown in earlier papers [5, 6, 8]. For triodes at higher frequencies with $C_{ga}=C_{ka}=0$ respectively in neutralized circuits the short circuit noise current i_i is identical with the induced grid noise current i_g at the input side and i_2 with the space charge suppressed shot noise i_a at the output side. R_n is identical with the well-known equivalent noise resistance R_{eq} and independent of frequency in first approximation. The correlation admittance Y_{cor} as measure of the correlation between the input noise sources i and u is found to be zero in first mostly sufficient approximation while the equivalent noise conductance $G_n>0$ up to high frequencies in sufficient approximation is proportional to ω^2(ω=angular frequency) [5, 6]. Only for full correlation between i_g and i_a, G_n would be zero. The two parameters R_n and G_n alone fully prescribe the noise behavior of the electron stream in neutralized triodes.[1]

The minimum noise figure is then given by (25) if G_s is negligibly small. We call this lowest possible value the "electronic noise figure" of the triode. As R_n is independent of frequency while G_n is proportional to the square of the frequency it is possible to calculate this electronic noise figure with help of the low frequency value of R_n and the magnitude of G_n measured f.e. in the 100 mc band. So calculated values agree very well with measured values up to very high frequencies [6].

A feedback over C_{ga} decreases the magnitude of R_n but does not change G_n and gives a finite value of Y_{cor} with a negative conductance G_{cor}. Therefore, the noise figure is lowered by this feedback [2, 8]. In screen grid tubes R_n is again identical with R_{eq}. On behalf of the additional partition noise the admittance G_n is larger than in the comparable triode system. G_n is proportional to ω^n where the exponent n starting with the value 2 for low frequencies increases with frequency. Y_{cor} is no more zero but gets a positive conductance G_{cor} proportional to ω^2 and also a positive susceptance B_{cor}.

This method is also very useful in case of transistors [8, 9] and traveling-wave tubes [1]. It does not only prescribe the noise behavior of the amplifying elements but also gives the possibility of conclusions concerning the location and properties of the noise sources inside of their equivalent networks.

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[1] This is valid if the circuit admittance $Y_e=G_e+jB_e$ including the "cold" input admittance of the tube are considered as grouped outside of the fourpole parallel to the signal admittance as described in the section "Influence of the Input Admittance Y_{11}." If Y_e remains located inside of the fourpole the noise current i_1 is including the noise current inflow belonging to G_e. Then we get $G_n'=G_n+G_e$ and $Y_{cor}'=Y_{cor}+Y_e$ while $R_n'=R_n$ is unchanged [2]. G_n' and Y_{cor}', therefore, represent no more alone the noise behavior of the electron flow but also the quality of the input circuit.

CORRECTION

Joseph E. Rowe, author of the paper, "Design Information on Large-Signal Traveling-Wave Amplifiers," which appeared on pages 200–210 of the February, 1956 issue of PROCEEDINGS OF THE IRE, has informed the editors that as additional calculations were being carried out on the effect on saturation power output and efficiency of loss along the helix of a traveling-wave amplifier, a computer error in the calculations for one curve of the paper was brought to his attention. The error occurred near $y=4.0$ in the $d=0.25$ solution of Figs. 14 and 15 on page 206. It is believed that the error originated in the low-order bits of a MIDAC word and then propagated to the higher-order bits as computations continued.

The error was not apparent in the original data and was not detected by the checking features of the program. Since that time, a parity check has been incorporated in the computer so that computations are halted when a word or an instruction is changed in any way, which should prevent recurrence of this type of error.

The other solutions presented in these figures have been recomputed and found to be correct. The corrected version of Figs. 14, 15, 18, and 19 are presented below. Since the error occurred near $y=4.0$, Figs. 16 and 17, on page 207, were not affected.

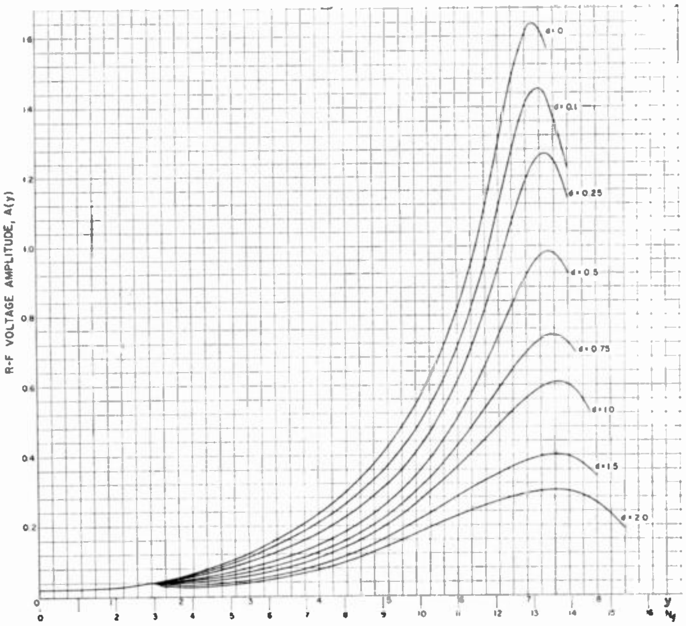

Fig. 14—Amplitude of the rf voltage along the helix with loss as the parameter. $C=0.1$, $QC=0.125$, $A_0=0.0225$, $b=1.5$, $B=1$. $d=0$ for $0 \leqq y \leqq 1.6$ for all curves.

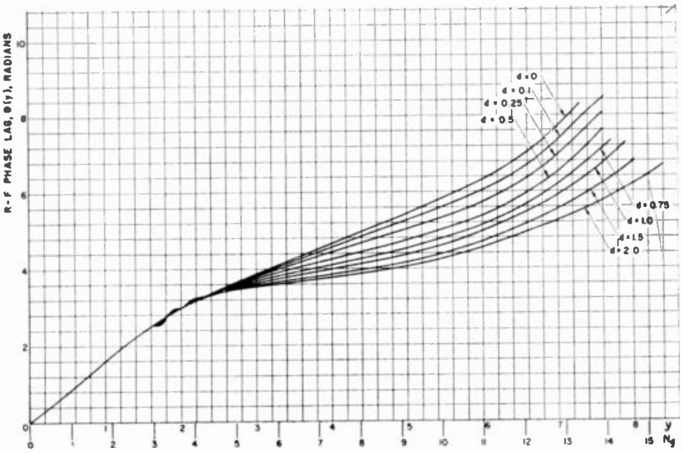

Fig. 15—RF phase lag of the wave relative to the electron stream vs distance along the helix with loss as the parameter, $C=0.1$, $QC=0.125$, $A_0=0.0225$, $b=1.5$, $B=1$. $d=0$ for $0 \leqq y \leqq 1.6$ for all curves.

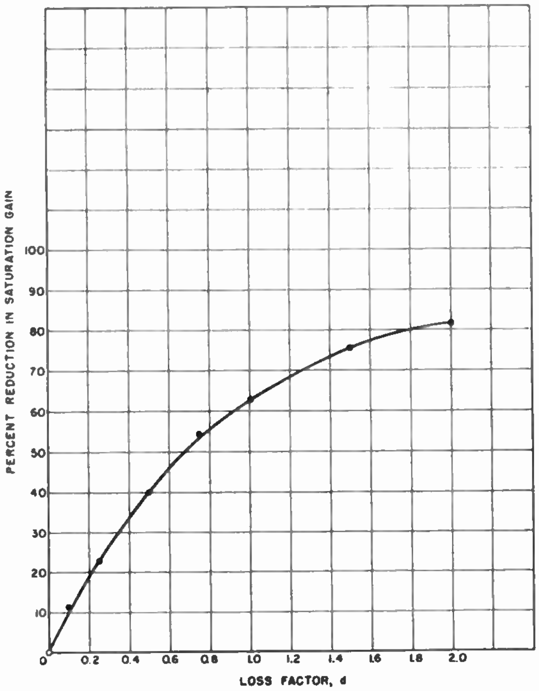

Fig. 18—Per cent reduction in saturation gain vs loss factor for fixed injection velocity. $C=0.1$, $QC=0.125$, $A_0=0.0225$, $b=1.5$, $B=1$. $d=0$ for $0 \leqq y \leqq 1.6$.

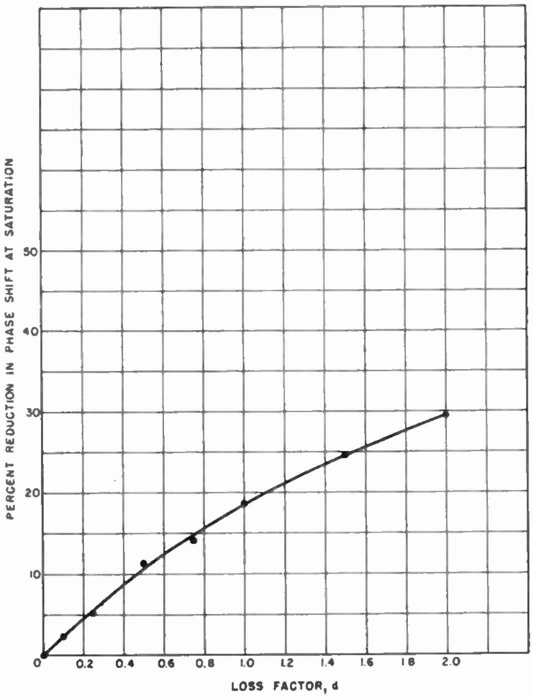

Fig. 19—Per cent reduction in phase shift at saturation vs loss factor for fixed injection velocity. $C=0.1$, $QC=0.125$, $A_0=0.0225$, $b=1.5$, $B=1$. $d=0$ for $0 \leqq y \leqq 1.6$.

Correspondence

Some Applications of Fourier Transforms in Electrical Engineering and Their Interrelationships*

Because of the general interest in Fourier transform applications shown by the PROCEEDINGS OF THE IRE and the TRANSACTIONS OF THE IRE, I should like to make the following contribution.

Engineers, and electrical engineers in particular, like to get visual pictures of the problems they are trying to solve. The great interest in the mathematical tool Fourier transformation theory may well be partly due to that fact. For example, in applications to antennas, loudspeakers, microphones, tapered lines, directional couples, transversal filters, cathode-ray tubes, klystrons, transistors, tape-recording, movie film reproduction, television, pulse communication systems, and superregeneration such visualizations can be done. The question is now: Is it possible to order the different Fourier transform applications in such a way that the different visual pictures fit into each other? An attempt to show that this is possible will be briefly presented in this letter.

Starting with antenna theory we have for the Fraunhofer region the following Fourier pair

$$F(u) = \int_{-d/2}^{d/2} f(x)e^{-i2\pi ux}dx$$

$$f(x) = \int_{-\infty}^{\infty} F(u)e^{i2\pi ux}du$$

where $F(u)$ is the radiation pattern, $f(x)$ is the distribution function along an aperture of length d [$f(x)=0$, $|x|>d/2$] and $u=-k \times \sin\theta$, where k is the wave number and θ the angle between the outgoing rays and a line perpendicular to the x-axis. See Fig. 1. Under the conditions that k is a constant and θ is a variable the pair has also found extensive application in optics and acoustics. On the other hand, if θ is a constant $=-90°$ the pick up point P in Fig. 1 is moved to the negative x-axis. This case constitutes a transitional step to the tapered line case in which the waves travel along the x-axis. See Fig. 2.

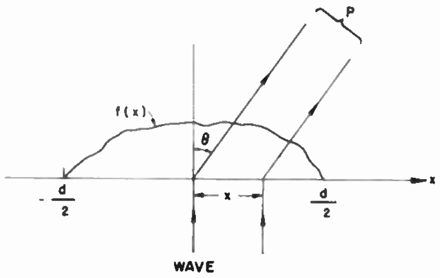

Fig. 1—Diffraction of a wave.

A simple exchange of the concept of reflection for that of coupling immediately connects the Fourier pair for tapered lines with that of directional couplers. In the latter case the reflected waves are traveling in a second coupled transmission line. For lower frequencies it is possible to use a discrete folded directional coupler as shown in Fig. 3.

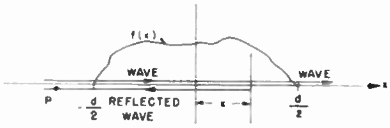

Fig. 2—Reflections in an inhomogeneous medium.

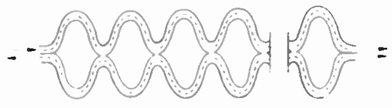

Fig. 3—Folded directional coupler.

Replacing the pieces of transmission lines between the coupling holes by delay networks and the couplings by amplifying devices a distributed amplifier is obtained.

At low frequencies it is possible to use the upper half of the configuration in Fig. 3 and match it at the receiving end. See Fig. 4. The former coupling points are connected to phase-shifting attenuating or amplifying devices. Because of the low frequency the tapping points T_1, T_2, $\cdots$, T_n may be connected together to a common output P. A transversal filter with many features analogous to the grating spectroscope is obtained.

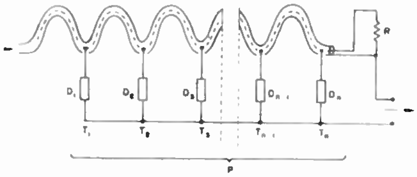

Fig. 4—Transversal filter.

At still lower frequencies the concept of distance completely loses its significance. By putting $x=ct$, $k=f/c$, where c is the velocity of light we obtain the well-known Fourier pair in time-frequency domains:

$$F(f) = \int_{-\infty}^{\infty} f(t)e^{-i2\pi ft}dt$$

$$f(t) = \int_{-\infty}^{\infty} F(f)e^{i2\pi ft}df.$$

In the different cases above we have assumed that the point P is fixed and that the waves move and are added at P. We may, however, just as well assume that we have a fixed field varying sinusoidally with time in the interval $-d/2 \leq x \leq d/2$, and that P constitutes a particle moving through the interval. The field may be transversal or longitudinal and the particle may be of different kinds.

Because the particle P always travels with a velocity less than that of light, we have to introduce a fictitious wavelength $\lambda_e = 1/k_e$. If v is the velocity of the particle

$$k_e = \frac{c}{v}k.$$

The Fourier transform pair is

$$F(k_e) = \int_{-d/2}^{d/2} f(x)e^{-i2\pi k_e x}dx$$

$$f(x) = \int_{-\infty}^{\infty} F(k_e)e^{i2\pi k_e x}dk_e.$$

If P is an electron and $f(x)$ an electric field traverse to the x-axis, the cathode-ray tube case is obtained. Then $F(k_e)$ is the dynamic sensitivity factor. Theoretically the case may be thought of as originating from the tapered line case by exchanging the concept of reflection for that of angular deflection. If the electron P passes through an electric field parallel to the x-axis, the instantaneous velocity v will be changed. If we assume that the velocity change is small, so that the total transit time through the field can be assumed to be constant, then $F(k_e)$ constitutes, for example, the beam coupling factor in the klystron theory. An analogous factor is obtained in the transistor theory. The expression "gap effect" for these factors is perhaps better understood in cases in which P constitutes a particle of a band running in front of a gap having a fixed field distribution as, for instance, in magnetic tape recording or reproduction of movie film.

If instead of a moving point P and a fixed aperture we have a fixed P and a moving aperture the conditions of the scanning problem are fulfilled. Scanning problems in television and optics have been treated by Fourier transformation theory.

The step from the slit problem in optics to optical diffraction of an aperture is very small. Thus we may say that we have returned to our starting point, diffraction in antenna theory.

As a final remark it may be mentioned that the Fourier pair (2) above has obtained a special application in the theory of superregeneration, where $f(t)$ is called "sensitivity pulse."

This letter constitutes a brief summary of a research work[1] in which a more detailed exposition with a large number of references is given.

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This work was supported in part by the Army (Signal Corps), the Air Force (Office of Scientific Research, Air Research and Development Command), and the Navy (Office of Naval Research).

[1] E. Folke Bolinder, "The relationship of physical applications of Fourier transforms in various fields of wave theory and circuitry," *Acta Polytechnica*, Stockholm, Sweden. (To be published.)

Contributors


R. H. DeLano

Richard H. DeLano (A'48–SM'54) was born in Los Angeles, Calif. on August 13, 1925. He received the B.S. and M.S. degrees in 1946 from the California Institute of Technology. From 1946 to 1955, he was senior staff physicist with the Hughes Research and Development Laboratories in what is now the Systems Analysis Department of the Weapon Systems Development Laboratory. His work there was concerned with problems involving random phenomena, radar target amplitude and angle noise, ground clutter, radar tracking and receiver problems, missile control systems, and trajectory analysis and missile systems problems. After a brief stay at the Lockheed Missile Systems Division as Head of the Electronics Analysis Division in the Research Branch in 1955, he helped to found the Systems Research Corp. where he is now a consultant on fire control and armament systems for Republic Aviation Corp.

He is a member of Tau Beta Pi and RESA and is a visiting Assistant Professor at the University of California at Los Angeles.

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J. P. Hagen

John P. Hagen (A'37–SM'47–F'54) was born in Amherst, Nova Scotia. He received the B.A. degree from Boston University, the M.A. degree at Wesleyan, attended Yale University from 1931 to 1933, and obtained the Ph.D. degree in Astronomy from Georgetown University in 1949. He was an assistant in Physics at Wesleyan from 1929 to 1935.

Dr. Hagen joined the Naval Research Laboratory in 1935, serving as head of the rf Research Section from 1935 to 1954. In 1954, he was named the first superintendent of the newly formed Atmosphere and Astrophysics Division. He is the Project Director for Project VANGUARD, and directs and coordinates this project within the Naval Research Laboratory.

His major fields of scientific interest are radio astronomy and upper air research. He has actively participated in several eclipse expeditions, the most recent being to Sweden in 1954.

He is a member of the American Astronomical Society, Sigma Xi, and the Washington Academy of Sciences, and a Fellow of the American Academy of Arts and Sciences. Dr. Hagen was awarded the Presidential Certificate of Merit in 1946.


J. A. Hynek

Joseph A. Hynek was born May 1, 1910 in Chicago, Ill. He received the B.S. degree in 1931 from the University of Chicago. From 1932 to 1935 he was a Fellow at Yerkes Observatory at the University of Chicago and received the Ph.D. degree in 1935.

From 1936 to 1941 he was in the Department of Physics and Astronomy of Ohio State University, serving two years as an instructor, and two years as an assistant professor. He spent the summer of 1941 as an instructor at Harvard College Observatory.

During the war years, 1942 to 1946, Dr. Hynek was on leave to the Applied Physics Laboratory of Johns Hopkins University as supervisor of technical reports.

In 1946 he returned to Ohio State University as an associate professor and Director of the McMillin Observatory. He became Assistant Dean of the Graduate School at Ohio State in 1950. Since 1954 he has been Professor of Physics and Astronomy. In the same year he led the O.S.U. Eclipse Expedition to Iran.

Dr. Hynek is Secretary of the American Astronomical Society and also of the U. S. National Committee of the International Astronomical Union.

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Joseph Kaplan

Joseph Kaplan received the B.S. degree in chemistry in 1924 and the M.A. and Ph.D. degrees in physics in 1926 and 1927, all from Johns Hopkins University. He was National Research Fellow in physics at Princeton University from 1927 to 1928.

Dr. Kaplan was in the Department of Physics of the University of California from 1928 to 1944. He served as chairman of the department from 1938 to 1944 and organized a work program in meteorology in 1940, directing it until 1944. From 1932 to 1943 he taught astrophysics in the Department of Astronomy, and during 1946 to 1947 he directed the Institute of Geophysics at UCLA which he had organized.

For two years, from 1943 to 1945, he was on leave from UCLA to serve as Chief of the Operations Analysis Section of the Second Air Force and later of the Air Weather Service. He was awarded a decoration for Exceptional Civilian Service in 1947. Since 1947 he has been a member of the Air Force Scientific Advisory Board, and is now chairman of the Geophysics Research Panel.

At present he is chairman of the U. S. National Committee for the International Geophysical Year. Formerly, he was chairman of committees of the International Union of Geodesy and Geophysics and the National Science Foundation.

His research activities have been principally concerned with the spectra of diatomic molecules, and in particular with afterglows in nitrogen, oxygen, and their mixtures. Applications of these laboratory results to the spectra of the aurora and airglow have also been emphasized in his studies, which have directed attention to chemical processes in the upper atmosphere.

He has recently been appointed as member-at-large of the National Committee of URSI, member of the National Academy of Sciences-National Research Council delegation to the Tenth General Assembly of the International Union of Geodesy and Geophysics, and special committees of the International Astronomical Union, the International Association of Terrestrial Magnetism and Electricity, and the American Meteorological Society. He is Vice-President of the International Association of Geomagnetism and Aeronomy.

Dr. Kaplan is a Fellow of the American Physical Society, and a member of the American Astronomical Society, the American Geophysical Union, the Meteoritical Society, and the Institute of the Aeronautical Sciences.

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R. C. LeCraw

R. C. LeCraw (S'51–A'53) was born January 10, 1924, at Atlanta, Ga. He attended the Georgia Institute of Technology, graduating with a degree in physics cum laude. During the war, he was a radar technician in the Signal Corps. After the war, he attended Ohio State University, graduating with a Master's degree in physics. While at Ohio State University he also did research at the Antenna Laboratory. After that he did further graduate work and taught electrical engineering at the Georgia Institute of Technology. In 1952, he joined the National Bureau of Standards, Ordnance Electronics Division, which is now the Diamond Ordnance Fuze Laboratories, where he is presently engaged in microwave physics research.

He is a member of Tau Beta Pi, Phi Kappa Phi, Eta Kappa Nu, Pi Mu Epsilon, Phi Eta Sigma, and the American Physical Society.

He recently received the Department of the Army Decoration for Exceptional Civilian Service.

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S. J. Mason (SM'52) was born on June 16, 1921, in New York City, N. Y. He was graduated from Rutgers University, N. J., in 1942, with the B.S. degree in electrical engineering. Dr. Mason attended the Massachusetts Institute of Technology, Cambridge, Mass., from 1945 to 1951, receiving the M.S. degree in 1947 and the D.Sc. degree in 1952.


S. J. Mason

From 1942 to 1945, Dr. Mason was with the Radiation Laboratory of M.I.T. Since 1945, he has been a staff member in the Research Laboratory of Electronics.

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Daniel G. Mazur (A'42–SM'53) was born in Buffalo, N. Y., on February 11, 1916. He received the B.S. in E.E. degree in Electrical Engineering from the Worcester Polytechnic Institute in 1938. From 1940 to 1946 he was with the Naval Air Material Center, Philadelphia, Pa.


D. G. Mazur

Since 1946 he has been at the Naval Research Laboratory engaged in the design and development of rocket telemetering equipment.

Mr. Mazur is presently head of the Electronic Instrumentation Branch, Project VANGUARD.

He is a member of the American Rocket Society.

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John T. Mengel (SM'53) was born in Ballston Lake, N. Y., on April 16, 1918. He received the B.S. degree in physics from Union College in 1939, and was an assistant instructor in physics at Lafayette College from 1939 to 1940. From 1940 to 1942 he was with the General Electric Co., principally in vacuum tube development, and from 1942 until early 1946 was with the Bureau of Ships developing and evaluating special detection devices.


J. T. Mengel

In 1946 Mr. Mengel joined the Naval Research Laboratory as a member of the Rocket Sonde Research Section. Initially responsible for the design and fabrication of the first research nose sections to replace the warheads of the V-2 rockets fired in this country for high-altitude research, he became head of the Electronic Instrumentation Section in 1947 with the responsibility for telemetering and emergency cutoff. In 1954, he was coordinator of guidance in the Rocket Development Branch. He has been head of the Tracking and Guidance Branch of Project VANGUARD since 1955, with the responsibility of acquiring and tracking the earth satellite by radio methods.

Amos Nathan (S'50–A'51–M'55) was born in Germany on October 5, 1920. He entered Palestine in 1933 and received the degree of Dipl. El.-Mech. Engineer from Technion, Israel Institute of Technology, in Haifa, Israel, in 1943.


Amos Nathan

Mr. Nathan served with the British Army from 1942 to 1946. From 1946 to 1948 he was an assistant at Technion. He served as an officer in the Israeli Defense Force until 1953, with technical and administrative appointments in the Signal Corps.

He studied in the United States for one year, receiving the M.S. degree in electrical engineering from Columbia University in 1951. He also spent several months at Chalmers Institute of Technology, in Gothenburg, Sweden, in 1954.

In 1953, Mr. Nathan rejoined the staff of Technion where he is now a lecturer in electrical engineering and has charge of an electronic differential analyzer project. He is doing research in this field and in electronic circuitry.

Mr. Nathan is a member of the Association of Architects and Engineers, Israel and an associate member of IEE, London.

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Irwin Pfeffer (S'47–A'49–M'55) was born in New York, N. Y., on March 17, 1926. He received the B.E.E. degree from Cooper Union School of Engineering in 1948 and the M.S. degree in Electrical Engineering from the California Institute of Technology in 1949.


Irwin Pfeffer

From 1950 to 1951, Mr. Pfeffer was a staff member of the Instrumentation Laboratory, M.I.T., operating the M.I.T. mechanical differential analyzer. In 1951, he joined the Hughes Aircraft Co. as a research engineer working in the field of guided missile simulation and analysis. He is presently with the Ramo-Wooldridge Corp. as head of the guided missile analog computer facility.

Mr. Pfeffer is a member of Tau Beta Pi.

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Frank Reggia (A'55) was born in Northumberland, Pa. on October 30, 1921. He attended George Washington University, and is a graduate of Radio Materiel School at the Naval Research Laboratory in Washington, D. C. While a member of the armed forces, he served as an electronic specialist in both the United States and in the Pacific Theatre. In 1945, he joined the staff of the Microwave Standards Section of the National Bureau of Standards, where he was engaged in research and development in a microwave standards program.


Frank Reggia

Mr. Reggia joined the technical staff of the Diamond Ordnance Fuze Laboratories, Department of the Army, in 1954. Since then he has been engaged in measurement techniques and applications of ferrites at microwave frequencies.

He is a member of the Washington Society of Engineers, and received its annual award in 1953.

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Milton W. Rosen was born in Philadelphia, Pa., on July 25, 1915. He was graduated from the University of Pennsylvania and continued his studies at the University of Pittsburgh and the California Institute of Technology.


M. W. Rosen

Since 1940, Mr. Rosen has been a member of the Naval Research Laboratory's scientific staff. He developed radar and radio control systems for guided missiles and holds three patents on electronic devices. In 1945, he proposed and helped organize a group to explore the upper atmosphere with rockets. The Viking rocket has been developed under Mr. Rosen's direction.

He is the Technical Director for Project VANGUARD. In 1954, he received the James H. Wyld Memorial Award for the application of rocket power.

Mr. Rosen is the author of "The Viking Rocket Story," published in 1955, and he has written numerous articles on rockets and space flight. He is a director of the American Rocket Society and was chairman of the Society's Space Flight Committee which proposed a study of the utility of an earth satellite to the National Science Foundation in 1954.

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For a photograph and biography of Kurt Schlesinger, see page 698 of the May, 1956 issue of Proceedings.

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E. G. Spencer was born on July 21, 1920, at Lynchburg, Va. He received the B.S.E. degree in physics from George Washington University and the M.A. degree in physics from Boston University. He did further graduate work at Massachusetts Institute of

Technology and at the University of Maryland. From 1943 to 1946 he was engaged in microwave radar research at the Naval Research Laboratory. From 1946 to 1949 he was associated with the Cambridge Air Force Research Laboratory, and from 1949 to 1953 with the Naval Research Laboratory. During this time he worked in microwave spectroscopy of gases and paramagnetic and nuclear magnetic resonance of solids. In 1953, he joined the National Bureau of Standards, Ordnance Electronics Division, which is now the Diamond Ordnance Fuze Laboratories. He is at present engaged in microwave physics research.

E. G. SPENCER

Mr. Spencer is a member of the American Physical Society.

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Frederick E. Terman (A'25–F'47) was born in English, Ind., on June 7, 1900. He received the B.A. degree in chemical engineering in 1920 and the E.E. degree in 1922 from Stanford University. In 1924 he received the D.Sc. degree in electrical engineering from M.I.T.

F. E. TERMAN

Dr. Terman has served on the faculty of Stanford University for thirty-one years, since his appointment as an instructor in electrical engineering in 1925. In 1937 he became full Professor and head of the Electrical Engineering Department, in 1945 was appointed Dean of the School of Engineering, and since 1955 has also been Provost.

On leave during World War II, Dr. Terman organized and directed the Radio Research Laboratory set up at Harvard University by the Office of Scientific Research and Development. The laboratory was the chief United States agency developing radar countermeasures.

In 1946 Dr. Terman was decorated by the British government, and in 1948 received the United States' highest civilian award, the Medal of Merit. Harvard University, the University of British Columbia, and Syracuse University have awarded him honorary doctoral degrees.

A past president of the IRE, Dr. Terman received the Institute's Medal of Honor in 1950. He also holds membership in the AIEE, the American Physical Society, and the American Society for Engineering Education. In 1946, he was elected to the National Academy of Sciences.

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James A. Van Allen received the B.S. degree and an honorary Sc.D. degree from Iowa Wesleyan College and the M.S. and Ph.D. degrees in physics from the State University of Iowa. He was a Carnegie research fellow at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington from 1939 to 1941, and was later a physicist there and at the Applied Physics Laboratory of Johns Hopkins University where he participated in the early development of the radio proximity (VT) fuze for gun-fired projectiles.

J. A. VAN ALLEN

During World War II he served as a naval officer with the special duty of introducing the proximity fuze into use in the Pacific fleet. From 1946 to 1950, he was in charge of the high altitude research group of the Applied Physics Laboratory at Johns Hopkins and was engaged in the pioneering use of V-2's in upper atmospheric research. He supervised the development of the Aerobee rocket during this period and received the C. N. Hickman medal from the American Rocket Society in 1949. Since 1951, he has been professor of physics and head of the Department of Physics at the State University of Iowa.

In 1952 he developed the balloon launched rocket (rockoon) technique which is now widely used for the inexpensive attainment of high altitudes.

Dr. Van Allen has been chairman of the Upper Atmosphere Rocket Research Panel since 1947. He is a member of the International Geophysical Year U. S. Technical Panels on Cosmic Rays, on Rocketry, and on the Earth Satellite Program and is chairman of the Working Group on Internal Instrumentation. He is a fellow of the American Physical Society and a member of the American Geophysical Union, the Iowa Academy of Science, and URSI.

Fred L. Whipple was born in Red Oak, Iowa, on November 5, 1906. He attended Occidental College and the University of California, receiving the A.B. degree from the latter in 1927. In 1931, he received the Ph.D. degree from the University of California at Berkeley, and in 1945 was awarded an honorary M.A. degree from Harvard University.

F. L. WHIPPLE

He began his career as a teaching fellow at the University of California from 1927 to 1929, and was a Lick Observatory Fellow for one year, 1930 to 1931.

Since 1931, Dr. Whipple has served in various capacities as a staff member at Harvard College Observatory. He was in charge of the Oak Ridge Station from 1932 to 1937. Since 1932 he has been a faculty member of Harvard University, becoming Chairman of the Department of Astronomy in 1949 and Professor in 1950. He has been Director of the Smithsonian Institution Astrophysical Observatory since 1955.

During World War II, he was in charge of development of confusion reflectors, "Window," as a radar countermeasure. He was the recipient of the Presidential Certificate of Merit for his scientific work during the war. He has been a member of the Upper Atmosphere Rocket Research Panel since 1946, the U. S. Research and Development Board Panel since 1947, and the Scientific Advisory Board to the Air Force since 1953. Also, he is a member of the Technical Panel of the National Committee on Earth Satellite Program, and of the U.S.A. National Committee of URSI. He has received Donohue Medals for the independent discovery of six new comets, and the J. Lawrence Smith Medal of the National Academy of Sciences for research on meteors in 1949.

Dr. Whipple holds membership in Pi Mu Epsilon, Phi Beta Kappa, Sigma Xi, American Academy of Arts and Sciences, American Association for the Advancement of Science, American Astronomical Society, American Meteoritical Society, American Geophysical Union, American Meteorological Society, the New York Academy of Sciences, Astronomical Society of the Pacific, and Solar Associates.

He is the author of the book "Earth, Moon, and Planets" and scientific papers on varied astronomical subjects, such as orbits of comets, asteroids, and meteors, the Earth's upper atmosphere, interstellar medium, and stellar and solar system evolution.

IRE News and Radio Notes

Calendar of Coming Events

Second Annual Radome Symposium, Ohio State Univ., Columbus, Ohio, June 4–6

Second International Congress on Acoustics, Cambridge, Mass., June 17–23

National Telemetering Conference, Biltmore Hotel, Los Angeles, Calif., Aug. 20–21

IRE-West Coast Electronic Manufacturers' Association, WESCON, Pan Pacific Auditorium and Ambassador Hotel, Los Angeles, Calif., Aug. 21–24

Annual Summer Seminar, Emporium Sect., Emporium, Pa., Aug. 24–26

Second RETMA Conference on Reliable Electrical Connections, U. of Pa., Philadelphia, Pa., Sept. 11–12

PGBTS Fall Symposium, Pittsburgh, Pa., Sept. 14–15

Instrument-Automation Conf. & Exhibit, Coliseum, N. Y. C., Sept. 17–21

Symposium on Radio-Wave Propagation, Paris, France, Sept. 17–22

Industrial Electronics Symposium, Manger Hotel, Cleveland, Ohio, Sept. 24–25

National Electronics Conference, Chicago, Ill., Oct. 1–3

Canadian IRE Convention & Exposition, Automotive Bldg., Exhibition Park, Toronto, Can., Oct. 1–3

Second Annual Symposium on Aeronautical Communications, Utica, N. Y., Oct. 8–9

IRE-RETMA Radio Fall Meeting, Hotel Syracuse, Syracuse, N. Y., Oct. 15–17

Conference on Magnetism & Magnetic Materials, Hotel Statler, Boston, Mass., Oct. 16–18

PGED Annual Technical Meeting, Shoreham Hotel, Washington, D. C., Oct. 25–26

East Coast Conference on Aeronautical & Navigational Electronics, Fifth Regiment Armory, Baltimore, Md., Oct. 29–30

Convention on Ferrites, Institute of Electrical Engineers, London, England, Oct. 29–Nov. 2

Conference on Electrical Techniques in Medicine and Biology, Governor Clinton Hotel, N.Y.C., Nov. 7–9

Kansas City IRE Technical Conference, Town House Hotel, Kansas City, Kan., Nov. 8–9

Symposium on Applications of Optical Principles to Microwaves, Washington, D. C., Nov. 14–16

PGVC National Meeting, Fort Shelby Hotel, Detroit, Mich., Nov. 29–30

Second Instrumentation Conference & Exhibit, Biltmore Hotel, Atlanta, Ga., Dec. 5–7

IRE-AIEE-ACM Eastern Joint Computer Conference, Hotel New Yorker, New York City, Dec. 10–12

DATE IS SET FOR 1956 EASTERN JOINT COMPUTER CONFERENCE

The 1956 Eastern Joint Computer Conference has been set for Dec. 10, 11 and 12, 1956 at the Hotel New Yorker, New York City, reports Conference Chairman J. R. Weiner. This year's annual meeting, jointly sponsored by the IRE, American Institute of Electrical Engineers, and the Association for Computing Machinery, will have as its theme, "New Developments in Computers."

In addition to a program of technical papers, the meeting will feature exhibits by many manufacturers in the computing field. Registration fee at the conference is $5 for members of any of the three sponsoring societies, $8 for non-members. Advance registration is $4 for members, $7 for non-members. All registrants will receive a free copy of the proceedings of the conference.

J. W. Leas has been appointed Chairman of the Program Committee. V. N. Vaughn is Chairman of the Publications Committee. J. A. Haddad has been appointed Chairman of the Local Arrangements Committee for the conference. Subcommittee chairmen are: *Exhibits*, Alan D. Meacham; *Finance*, A. R. Mohr; *Hotel*, J. A. Grundy; *Inspection*, Norman Grieser; *Printing*, Paul Magdeburger; *Publicity*, A. J. Forman; and *Registration*, W. P. Heising.

DUBILIER WINS FRENCH MEDAL

William Dubilier, an IRE Fellow and a pioneer in the capacitor field, has been awarded the Gold Medal of the Renaissance Francaise, a French honorary society in the arts and sciences.

Mr. Dubilier, a founder and now Vice-President of the Cornell-Dubilier Electric Corporation in charge of research and development, is one of the few Americans to be so honored for making significant contributions to the scientific and economic progress of the French Republic.

Last year, the scientist received a similar accolade when he was made an honorary member of the French Union of Inventors, and awarded a special medal for "exceptional services rendered to the science of electricity."

ELECTRICAL TECHNIQUES IS SUBJECT OF CONFERENCE

The Ninth Annual Conference on Electrical Techniques in Medicine and Biology will be held at the Governor Clinton Hotel in New York City November 7–9, 1956.

The conference is sponsored by the American Institute of Electrical Engineers, the IRE, and the Instrument Society of America. In addition to the technical sessions, there will be field trips to installations of interest to those attending.

Titles and brief abstracts for proffered papers may be submitted to the conference chairman, E. D. Trout, General Electric Company, X-Ray Department, Milwaukee 1, Wisconsin.

R. F. GUY IS HONORED WITH MARCONI MEMORIAL GOLD MEDAL

R. F. GUY

Raymond F. Guy, a Fellow of the IRE, has been awarded the Marconi Memorial Gold Medal of Achievement by the Veteran Wireless Operators Association. The award was presented at the thirty-first anniversary banquet of the association to Mr. Guy in recognition of his forty years' service to broadcasting.

Mr. Guy's career began when he became a ship's radio officer with the Marconi Wireless Telegraph Company. He ran the submarine blockade during World War I and served further in the Army Signal Corps, after which he returned to get his degree in electrical engineering from Pratt Institute in 1921. Westinghouse Company employed him when it opened the world's second broadcasting station in Newark, New Jersey. Since then Mr. Guy has pioneered not only in standard broadcasting, but also in international broadcasting, television, and frequency modulation.

For over a quarter of a century he has been active in industry affairs such as those of the Television Broadcasters Association, the National Association of Radio and Television Broadcasters, and the Radio Technical Planning Board. From the beginning he has directed the planning and construction of all the transmitting facilities of the National Broadcasting Company as its director of Radio Frequency Engineering. He directed the RCA-NBC frequency-modulation field test in 1940 and the television project at Bridgeport, Connecticut, which led to the adoption of uhf for commercial use.

He is chairman of the NARTB Engineering Advisory Committee, a member of the Voice of America Broadcast Advisory Committee and chairman of its Engineering Subcommittee, and a life member of the VWOA. He was 1950 IRE President.

AERO COMMUNICATIONS SYMPOSIUM TO BE HELD OCT. 8–9

The Second National Symposium on Aeronautical Communications will be held at Hotel Utica, Utica, N. Y., on October 8–9, 1956. It will be sponsored by the PG on Communications Systems.

The 1956 Symposium will stress communications requirements in support of present and future aeronautical activities. The technical papers committee invites the submission of papers on associated topics. It is requested that titles, authors, and a brief abstract of about 200 words be submitted to Fred Moskowitz, 1014 No. Madison St., Rome, N. Y., before July 1.

TRANSACTIONS OF THE IRE PROFESSIONAL GROUPS

The following issues of TRANSACTIONS are available from the Institute of Radio Engineers, Inc., 1 East 79 Street, New York 21, N. Y., at the prices listed below:

Sponsoring Group	Publications	Group Members	IRE Members	Non-Members*
Aeronautical and Navigational Electronics	PGAE-5: A Dynamic Aircraft Simulator for Study of Human Response Characteristics (6 pages)	$ .30	$ .45	$ .90
	PGAE-6: Ground-to-Air Cochannel Interference at 2900 MC (10 pages)	.30	.45	.90
	PGAE-8: June 1953 (23 pages)	.65	.95	1.95
	PGAE-9: September 1953 (27 pages)	.70	1.05	2.10
	Vol. ANE-1, No. 2, June 1954 (22 pages)	.95	1.40	2.85
	Vol. ANE-1, No. 3, September 1954 (27 pages)	1.00	1.50	3.00
	Vol. ANE-1, No. 4, December 1954 (27 pages)	1.00	1.50	3.00
	Vol. ANE-2, No. 1, March 1955 (41 pages)	1.40	2.10	4.20
	Vol. ANE-2, No. 2, June 1955 (49 pages)	1.55	2.30	4.65
	Vol. ANE-2, No. 3, September 1955 (27 pages)	.95	1.45	2.85
	Vol. ANE-2, No. 4, December 1955 (47 pages)	1.40	2.10	4.20
	Vol. ANE-3, No. 1, March 1956 (42 pages)	1.30	1.95	3.90
Antennas and Propagation	PGAP-4: IRE Western Convention, August 1952 (136 pages)	2.20	3.30	6.60
	Vol. AP-1, No. 1, July 1953 (30 pages)	1.20	1.80	3.60
	Vol. AP-1, No. 2, October 1953 (31 pages)	1.20	1.80	3.60
	Vol. AP-2, No. 1, January 1954 (39 pages)	1.35	2.00	4.05
	Vol. AP-2, No. 2, April 1954 (41 pages)	2.00	3.00	6.00
	Vol. AP-2, No. 3, July 1954 (36 pages)	1.50	2.25	4.50
	Vol. AP-3, No. 4, October 1954 (36 pages)	1.50	2.25	4.50
	Vol. AP-3, No. 1, January 1955 (43 pages)	1.60	2.40	4.80
	Vol. AP-3, No. 2, April 1955 (47 pages)	1.60	2.40	4.80
	Vol. AP-3, No. 3, July 1955 (66 pages)	2.05	3.10	6.15
	Vol. AP-3, No. 4, October 1955 (71 pages)	2.10	3.15	6.30
	Vol. AP-4, No. 1, January 1956 (100 pages)	2.65	3.95	7.95
Audio	PGA-7: Editorials, Technical Papers & News, May 1952 (47 pages)	.90	1.35	2.70
	PGA-10: November–December 1952 (27 pages)	.70	1.05	2.10
	Vol. AU-1, No. 2, March–April 1953 (34 pages)	.80	1.20	2.40
	Vol. AU-1, No. 5, September–October 1953 (11 pages)	.50	.75	1.50
	Vol. AU-1, No. 6, November–December 1953 (27 pages)	.90	1.35	2.70
	Vol. AU-2, No. 1, January–February 1954 (38 pages)	1.20	1.80	3.60
	Vol. AU-2, No. 2, March–April 1954 (31 pages)	.95	1.40	2.85
	Vol. AU-2, No. 3, May–June 1954 (27 pages)	.95	1.40	2.85
	Vol. AU-2, No. 4, July–August 1954 (27 pages)	.95	1.40	2.85
	Vol. AU-2, No. 5, September–October 1954 (22 pages)	.95	1.40	2.85
	Vol. AU-2, No. 6, November–December 1954 (24 pages)	.80	1.20	2.40
	Vol. AU-3, No. 1, January–February 1955 (20 pages)	.60	.90	1.80
	Vol. AU-3, No. 2, March–April 1955 (32 pages)	.95	1.40	2.85
	Vol. AU-3, No. 3, May–June 1955 (30 pages)	.85	1.25	2.55
	Vol. AU-3, No. 4, July–August 1955 (46 pages)	1.15	1.75	3.45
	Vol. AU-3, No. 5, September–October 1955 (33 pages)	.90	1.35	2.70
	Vol. AU-3, No. 6, November–December 1955 (36 pages)	.95	1.40	2.85
	Vol. AU-4, No. 1, January–February 1956 (27 pages)	.75	1.10	2.25
	Vol. AU-4, No. 2, March–April 1956 (17 pages)	.55	.80	1.65
Broadcast Transmission Systems	PGBTS-1: March 1955 (102 pages)	2.50	3.75	7.50
	PGBTS-2: December 1955 (54 pages)	1.20	1.80	3.60
	PGBTS-4: March 1956 (21 pages)	.75	1.10	2.25
Broadcast and Television Receivers	PGBTR-1: Round Table Discussion on UHF TV Receiver Considerations, 1952 IRE National Convention (12 pages)	.50	.75	1.50
	PGBTR-5: January 1954 (96 pages)	1.80	2.70	5.40
	PGBTR-6: April 1954 (119 pages)	2.35	3.50	7.00
	PGBTR-7: July 1954 (58 pages)	1.15	1.70	3.45
	PGBTR-8: October 1954 (20 pages)	.90	1.35	2.70
	Vol. BTR-1, No. 1, January 1955—Papers Presented at the Radio Fall Meeting, 1954 (68 pages)	1.25	1.85	3.75
	Vol. BTR-1, No. 2, April 1955 (40 pages)	.95	1.45	2.85
	Vol. BTR-1, No. 3, July 1955 (51 pages)	.95	1.45	2.85
	Vol. BTR-1, No. 4, October 1955 (19 pages)	.95	1.40	2.85

* Public libraries, colleges and subscription agencies may purchase at IRE member rate.

(Continued on page 826)

Papers for PGBTS Symposium Should Be Submitted by July 15

The Sixth Annual Fall Symposium of the Professional Group on Broadcast Transmission Systems will be held in Pittsburgh, Pennsylvania, September 14 and 15. Technical sessions will be held in Mellon Institute Auditorium. Headquarters will be Webster Hall located near the auditorium. P. B. Laeser, Chief Engineer of WTMJ, and C. J. Daugherty, Chief Engineer of WSB-TV, head the symposium committee.

Arrangements in Pittsburgh are being handled by R. W. Rodgers, Chief Engineer of KDKA-TV, James Greenwood, Chief Engineer of WCAE, and Theodore Kenney, Chief Engineer of KDKA. The technical program will involve two sessions on Friday plus one on Saturday morning and a Saturday afternoon tour or exhibition. The annual cocktail party and banquet of the Group will be held at Webster Hall Friday evening.

Members of PGBTS or those interested in submitting papers for consideration are invited to do so prior to July 15. Papers to be considered should be sent to Scott Helt, Chairman, Papers Review Committee, 370 First Avenue, New York 10, New York.

Students From Five Colleges Attend L. A. Section Meeting

The Los Angeles Section and student branches from California Polytechnic, California Institute of Technology, Loyola, UCLA, and USC held a joint meeting in Los Angeles, March 6. The meeting was attended by over three hundred students and members. A dinner was also held.

The afternoon program, under the sponsorship of the Student Relations Committee, with F. O'Halloran as chairman, featured talks by seven representatives from the Professional Groups on Electronic Computers, Nuclear Science, Microwave Theory and Techniques, Automatic Controls, Electron Devices, Telemetering and Remote Control, and Circuit Theory. Each talk was designed to acquaint the students with the type of work he might be called upon to perform should he enter that field.

The after-dinner program consisted of the presentation of national awards to students who had distinguished themselves during the past year and to the chairmen of the student chapter of activity at each of the schools in the area.

The evening program, under the auspices of the Professional Group on Engineering Management, featured W. R. Hewlett, vice-president and co-founder of Hewlett-Packard Company, who spoke on "What's Wrong with the IRE and What You Can Do About It." He was followed by H. L. Hoffman, president and founder of Hoffman Electronic Corp., who predicted that by 1965 the electronics field will have grown into a 21-billion-dollar industry, the largest share of which will be in commercial development. The demand for young engineers will be correspondingly greater. Mobile demonstrators were available at the meetings for the students' inspection.

The March meeting was the largest student branch meeting ever held by the Los Angeles Section.

TRANSACTIONS OF THE IRE PROFESSIONAL GROUPS

(Continued)

Sponsoring Group	Publications	Group Members	IRE Members	Non-Members*
Circuit Theory	Vol. CT-1, No. 1, March 1954 (80 pages)	$1.30	$1.95	$3.90
	Vol. CT-1, No. 3, September 1954 (73 pages)	1.00	1.50	3.00
	Vol. CT-1, No. 4, December 1954 (42 pages)	1.00	1.50	3.00
	Vol. CT-2, No. 1, March 1955 (106 pages)	2.70	4.05	8.10
	Vol. CT-2, No. 2, June 1955 (113 pages)	2.60	3.90	7.80
	Vol. CT-2, No. 3, September 1955 (62 pages)	1.40	2.10	4.20
	Vol. CT-2, No. 4, December 1955 (88 pages)	1.85	2.75	5.55
Communications Systems	Vol. CS-2, No. 1, January 1954 (83 pages)	1.65	2.50	4.95
	Vol. CS-2, No. 2, July 1954 (132 pages)	2.25	3.35	6.75
	Vol. CS-2, No. 3, November 1954—IRE Symposium on Global Communications, June 23–25, 1954, Washington, D. C., and IRE-AIEE Symposium on Military Communications, April 28, 1954, New York, N. Y. (181 pages)	3.00	4.50	9.00
	Vol. CS-3, No. 1, March 1955—Papers Presented at the Symposium on Marine Communications & Navigation, October 13–15, 1954, Boston, Mass. (72 pages)	1.00	1.50	3.00
	Vol. CS-4, No. 1, March 1956—Symposium on Communications by Scatter Techniques, November 14–15, 1955, Washington, D. C. (122 pages)	2.15	3.20	6.45
Component Parts	PGCP-1: March 1954 (46 pages)	1.20	1.80	3.60
	PGCP-2: September 1954—Papers Presented at the Component Parts Sessions at the 1954 Western Electronic Show & Convention, Los Angeles, Calif. (118 pages)	2.25	3.35	6.75
	PGCP-3: April 1955 (44 pages)	1.00	1.50	3.00
	PGCP-4; November 1955 (92 pages)	2.00	3.00	6.00
	Vol. CP-3, No. 1, March 1956 (35 pages)	1.70	2.55	5.10
Electronic Computers	Vol. EC-2, No. 2, June 1953 (27 pages)	.90	1.35	2.70
	Vol. EC-3, No. 3, September 1954 (54 pages)	1.80	2.70	5.40
	Vol. EC-4, No. 2, June 1955 (36 pages)	.90	1.35	2.70
	Vol. EC-4, No. 3, September 1955 (45 pages)	1.00	1.50	3.00
	Vol. EC-4, No. 4, December 1955 (40 pages)	.90	1.35	2.70
	Vol. EC-5, No. 1, March 1956 (62 pages)	1.20	1.80	3.60
Electron Devices	PGED-4: December 1953 (62 pages)	1.30	1.95	3.90
	Vol. ED-1, No. 2, April 1954 (75 pages)	1.40	2.10	4.20
	Vol. ED-1, No. 3, August 1954 (77 pages)	1.40	2.10	4.20
	Vol. ED-1, No. 4, December 1954 (280 pages)	3.20	4.80	9.60
	Vol. ED-2, No. 2, April 1955 (53 pages)	2.10	3.15	6.30
	Vol. ED-2, No. 3, July 1955 (27 pages)	1.10	1.65	3.30
	Vol. ED-2, No. 4, October 1955 (42 pages)	1.50	2.25	4.50
	Vol. ED-3, No. 1, January 1956 (74 pages)	2.10	3.15	6.30
Engineering Management	PGEM-1: February 1954 (55 pages)	1.15	1.70	3.45
	PGEM-2: November 1954 (67 pages)	1.30	1.95	3.90
	PGEM-3: March 1955 (52 pages)	1.00	1.50	3.00
	Vol. EM-3, No. 1, January 1956 (29 pages)	.95	1.40	2.85
Industrial Electronics	PGIE-1: August 1953 (40 pages)	1.00	1.50	3.00
	PGIE-2: March 1955 (81 pages)	1.90	2.85	5.70
	PGIE-3: March 1956 (110 pages)	1.70	2.55	5.10
Information Theory	PGIT-3: March 1954 (159 pages)	2.60	3.90	7.80
	PGIT-4: September 1954 (234 pages)	3.35	5.00	10.00
	Vol. IT-1, No. 1, March 1955 (76 pages)	2.40	3.60	7.20
	Vol. IT-1, No. 2, September 1955 (50 pages)	1.90	2.85	5.70
	Vol. IT-1, No. 3, December 1955 (44 pages)	1.55	2.30	4.65
Instrumentation	PGI-3: April 1954 (55 pages)	1.05	1.55	3.15
	PGI-4: October 1955 (182 pages)	2.70	4.05	8.10
Medical Electronics	PGME-2: October 1955 (39 pages)	.85	1.25	2.55
	PGME-3: November 1955 (55 pages)	1.10	1.65	3.30
	PGME-4: February 1956 (51 pages)	1.95	2.90	5.85
Microwave Theory and Techniques	Vol. MTT-1, No. 2, November 1953 (44 pages)	.90	1.35	2.70
	Vol. MTT-2, No. 3, September 1954 (54 pages)	1.10	1.65	3.30
	Vol. MTT-3, No. 1, January 1955 (47 pages)	1.50	2.25	4.50
	Vol. MTT-3, No. 2, March 1955 (182 pages)	2.70	4.05	8.10
	Vol. MTT-3, No. 3, April 1955 (44 pages)	1.40	2.10	4.20
	Vol. MTT-3, No. 4, July 1955 (54 pages)	1.60	2.40	4.80

* Public libraries, colleges and subscription agencies may purchase at IRE member rate.

(Continued on page 827)

PARIS WILL BE SITE OF SYMPOSIUM ON PROPAGATION

An international symposium on present-day problems in radio-wave propagation, organized by the French National Committee of Scientific Radio-Electricity and by the Société des Radioélectriciens (France), and sponsored by Commissions II, III and IV of U.R.S.I., will be held in Paris on September 17–22, 1956.

The following subjects will be discussed at the symposium: propagation of vhf and uhf (metric, decimetric and centimetric waves) at great distances beyond the horizon; effect of ground surface irregularities on the radiation and the propagation of radio waves; the ionosphere and ionospheric propagation; other topics, particularly propagation of very long waves (frequencies below 20 kc.

Persons desiring to participate in the symposium are invited to contact the Société des Radioélectriciens (Colloque Propagation), 14, Avenue Pierre Larousse, Malakoff (Seine), France, for registration and further information.

TWELFTH NATIONAL ELECTRONICS CONFERENCE LISTS COMMITTEES

More than 100 technical papers and 235 commercial exhibits will be featured at the twelfth annual National Electronics Conference scheduled for the Hotel Sherman in Chicago Oct. 1–3.

R. R. Jenness of Northwestern University has been elected President of the 1956 National Electronics Conference.

Other officers are: K. E. Rollefson, Executive Vice-President; J. M. Gage, Chairman of the Board of Directors; J. S. Powers, Executive Secretary; E. H. Scheibe, Secretary; H. H. Brauer, Treasurer, and C. W. McMullen, Assistant Treasurer.

Arrangements committee chairman this year is E. C. Book, with H. L. Messerschmidt, E. P. Kelly, and R. B. Schulz, heading subcommittees on information, luncheons, and technical sessions, respectively.

Other committees and their chairmen are: Awards, W. O. Swinyard; Exhibits, G. J. Argall; Finance Policy, J. D. Ryder; Procedures, G. T. Flesher; Proceedings, G. W. Swenson, Jr.; Program, L. T. De Vore; Publicity, V. J. Danilov; and Registration, J. W. Powers.

The conference is sponsored each year by American Institute of Electrical Engineers, IRE, Illinois Institute of Technology, University of Illinois, and Northwestern University.

PROFESSIONAL GROUP NEWS

SIX NEW CHAPTERS ANNOUNCED

The Executive Committee, at its meeting of April 10, approved the formation of six new chapters. They are: PGs on Military Electronics, Los Angeles, Dayton, and Syracuse Sections; PG on Medical Electronics, Montreal Section; PG on Electronic Computers, Dayton Section; PG on Microwave Theory and Techniques, New York Section.

TRANSACTIONS OF THE IRE PROFESSIONAL GROUPS

(Continued)

Sponsoring Group	Publications	Group Members	IRE Members	Non-Members*
	Vol. MTT-3, No. 5, October 1955 (59 pages)	$1.70	$2.55	$5.10
	Vol. MTT-3, No. 6, December 1955 (64 pages)	1.75	2.60	5.25
	Vol. MTT-4, No. 1, January 1956 (53 pages)	1.65	2.45	4.95
Nuclear Science	Vol. NS-1, No. 1, September 1954 (42 pages)	.70	1.00	2.00
	Vol. NS-2, No. 1, June 1955 (15 pages)	.55	.85	1.65
	Vol. NS-3, No. 1, February 1956 (40 pages)	.90	1.35	2.70
Reliability and QualityControl	PGQC-2: March 1953 (51 pages)	1.30	1.95	3.90
	PGQC-3: February 1954 (39 pages)	1.15	1.70	3.45
	PGQC-4: December 1954 (56 pages)	1.20	1.80	3.60
	PGRQC-5: April 1955 (56 pages)	1.15	1.75	3.45
	PGRQC-o: February 1956 (66 pages)	1.50	2.25	4.50
Telemetry and Remote Control	PGRTRC-1: August 1954 (16 pages)	.85	1.25	2.55
	PGRTRC-2: November 1954 (24 pages)	.95	1.40	2.85
	Vol. TRC-1, No. 1, February 1955 (24 pages)	.95	1.40	2.85
	Vol. TRC-1, No. 2, May 1955 (24 pages)	.95	1.40	2.85
	Vol. TRC-1, No. 3, August 1955 (12 pages)	.70	1.05	2.10
	Vol. TRC-2, No. 1, March 1956 (22 pages)	1.00	1.50	3.00
Ultrasonics Engineering	PGUE-1: June 1954 (62 pages)	1.55	2.30	4.65
	PGUE-3: May 1955 (70 pages)	1.45	2.20	4.35
Vehicular Communications	PGVC-3: June 1953 (140 pages)	3.00	4.50	9.00
	PGVC-4: June 1954 (98 pages)	2.40	3.60	7.20
	PGVC-5: June 1955 (76 pages)	1.50	2.25	4.50

* Public libraries, colleges and subscription agencies may purchase at IRE member rate.

VEHICULAR COMMUNICATIONS PG PLANS ANNUAL PAPERS AWARD

The PGVC Administrative Committee has authorized establishment of an annual group papers award. A prospectus for the award has been prepared and submitted to the IRE Awards Committee and the Executive Secretary for approval. It is anticipated that the award, which will be for the best technical paper relating to the field of interest of the Group published in an IRE publication during the course of one year, can be initiated with the calendar year beginning July 1, 1956.

Plans are under way for the eighth national meeting of the Group which will be held at the Fort Shelby Hotel in Detroit on November 29–30. A. B. Buchanan is general chairman for the meeting.

In view of the interest expressed in the formation of a PGVC Chapter in New York, plans are being formulated for such a chapter. The new chapter will include members from the Long Island and Northern New Jersey as well as the New York Sections.

Since July 1, 1955, membership in the Group has increased 15 per cent.

MEMBERSHIP GROWS IN PG ON MILITARY ELECTRONICS

The Professional Group on Military Electronics, newest of the IRE Professional Groups, had more than twelve hundred members on its membership rolls by April 1, less than six months after its formation was officially approved by the IRE Executive Committee.

The Group sponsored a symposium on Air Force communications and electronic problems and philosophies and a session on a report from the Nevada Atomic Proving Grounds regarding nuclear effects upon communication systems, and co-sponsored a symposium on the U. S. earth satellite program at the 1956 IRE National Convention.

The Group intends to follow a technical publishing program that will include the broad fields of systems and operations research. The program of TRANSACTIONS for the first year will be integrated into a comprehensive review of the current and future concepts of military electronics within the necessary limits of military security. The first of the four quarterly issues will be devoted to long-range objectives of military operations with a detailed outline of future envisioned technical requirements. The following three issues will then present a broad survey of concepts leading to advanced systems design.

The national officers of the Professional Group on Military Electronics are: C. L. Engleman, Chairman; G. T. Gould, Vice-Chairman; C. R. Busch, Secretary; and H. T. Engstrom, Treasurer. Chairmen of the national standing committees are: W. M. Richardson, *Membership*; J. Q. Brantley, Jr., *Papers and Publications;* and S. E. Petrillo, *Meetings*.

Considerable interest has been expressed in joining Group Chapters in various cities. Those wishing information on forming a Chapter should write to: Technical Secretary of the IRE,1 East 79 St., New York City.

OBITUARY

Vernon B. Bagnall (A'30–M'40–SM'43) died recently. He had organized the Distant Early Warning line, now being built at the Arctic Circle. His company, a subsidiary of A. T. & T., is building the network. He joined A. T. & T. after graduating from the University of Wisconsin in 1927. He became general commercial manager of the Long Lines Department, later, general plant manager, and then, director of personnel. He was appointed general manager of the Western area in 1951. In January, 1956, he became assistant director of operations of the Long Lines Department in charge of engineering.

In World War II he took part in planning communications for D-Day invasion.

He was a member of the Armed Forces Communications and Electronics Association. He was a fellow of the A.I.E.E.

Speakers at Second Conference on Radio Interference Reduction in Chicago

Shown (*left to right*) are: A. L. Albin, Armour Research Foundation; J. Berliner, Rome Air Development Center; E. W. Wickert, ARF; L. W. Thomas, Department of the Navy, Bureau of Ships; V. H. Disney, ARF; J. W. Klotz, Office of the Assistant Secretary of Defense (Research and Development), Washington; H. A. Leedy, ARF; N. D. Flinn, Wright Air Development Center; E. H. Schulz, ARF; R. A. Schaller, Department of the Navy, Bureau of Aeronautics; S. I. Cohn, ARF; E. V. Kavanaugh, Signal Corps Engineering Laboratories; H. M. Sachs, ARF. The March conference on radio interference reduction was held in Chicago, Ill.

TECHNICAL COMMITTEE NOTES

Chairman D. E. Maxwell presided at a meeting of the **Audio Techniques** Committee at IRE Headquarters on March 20. It was reported that Subcommittee 3.3 on Methods of Measurement of Distortion was presently working on the Proposed Methods of Measurement of Intermodulation Distortion. The subcommittee hopes to have this ready shortly for submission to the committee.

The remainder of the meeting was devoted to the consideration of the Proposed Standard on Audio Techniques: Definitions of Terms being prepared by Subcommittee 3.1 on Audio Definitions.

The **Circuits** Committee met at IRE Headquarters on April 6 with Chairman W. R. Bennett presiding. A joint session was held with Subcommittee 4.1 on Transistor Circuitry for about one hour. Chairman T. R. Finch gave an account of activities since this subcommittee was first formed in November, 1952. The subcommittee helped organize the first Philadelphia Symposium on Transistor Circuits in February, 1954, and has continued to participate in what has come to be an annual event of outstanding importance in its field. The 1954 meeting drew an attendance of five hundred, the 1955 meeting drew seven hundred, and at the most recent one in February, 1956 there were over twelve hundred present.

Another activity has been the holding of an annual technical meeting of the subcommittee with about fifty invited guests who are able and willing to discuss selected topics on a more informal basis than would be possible with a larger audience.

The vigorous and stimulating activities in which the subcommittee has been engaged have made membership a sought-after prize by many in the transistor field. It has been found expedient to restrict membership to no more than one member from any one organization and no more than twelve on the whole subcommittee. No formal work on standards has been undertaken and it is the present feeling of the group none should be.

The subcommittee was commended by the members of the Circuits Committee for their spectacularly successful work.

The committee gave further consideration to the Proposed Standard on Definitions of Linear Active Circuits, and the Proposed Standard on Definitions of Linear Passive Circuits.

Chairman R. M. Showers presided at a meeting of the **Radio Frequency Interference** Committee on March 27, at IRE Headquarters. The major portion of this meeting was devoted to the discussion of the Proposed Supplement to IRE Standard 54 IRE 17. S1. The committee made minor revisions in the text of the proposed supplement and approved it for submission to the Standards Committee.

The **Radio Receivers** Committee met at IRE Headquarters on March 20 with Chairman D. E. Harnett presiding. The chairman opened the meeting with a proposal that the membership of this committee be enlarged and enriched by new members who are currently active in receivers work.

Mr. Harnett read a letter from A. V. Loughren which recommends areas of future work for the committee, such as: (1) standards on color receiver measurements, (2) test methods for receivers employing transistors, (3) non-entertainment receivers.

It was agreed that, in order to initiate transistor receiver standards, the chairman write to companies currently making transistor radios and ask that they recommend names for active membership.

Regarding non-entertainment receivers, it was agreed that this category was extremely broad (communications, radar, micro-wave, industrial and military television, etc.) and further discussion would be scheduled to delineate the various categories in terms of advisability and priority of action. F. R. Norton stated that one group which he felt could very profitably be standardized now was communications receivers.

In the absence of the chairman, the Vice-Chairman, H. Goldberg, presided at a meeting of the **Radio Transmitters** Committee at IRE Headquarters on March 23.

H. R. Butler announced that work has started on the revision of the 1948 Standards on Definitions of Transmitters Terms.

J. Ruston, Chairman of Subcommittee 15.1 on FM Transmitters, submitted the following proposed scope for the subcommittee: "The scope of the FM Transmitters Subcommittee is to recommend definitions and methods of test of all frequency modulated radio transmitters except those which operate at output frequencies above 890 mc. In addition, the subcommittee will review all proposed standards which are broadly applicable to fm transmitters." This scope was unanimously approved by the committee.

The committee reviewed the Proposed Standard on Double Sideband Transmitters: Methods of Test and referred it back to the originating subcommittee for further consideration.

The subcommittee on Single Sideband Transmitters under the chairmanship of A. Brown is preparing a Proposed Standard on Methods of Test for Single Sideband Transmitters for submission to the main committee before the summer vacation.

Ernst Weber presided at a meeting of the **Standards** Committee on March 20 at the Astor Gallery of the Waldorf-Astoria Hotel. Dr. Weber explained that traditionally the meeting of the Standards Committee held during the Convention was an informal meeting primarily for the purpose of familiarizing the members-elect with the work of the Standards Committee. A. G. Jensen gave a brief report on the standardization activities for 1955. M. W. Baldwin, chairman-elect, gave a report on the future standardization activities.

Dr. Weber stated that he had enjoyed serving as chairman of the Standards Committee for two terms and wished Mr. Baldwin good luck.

On behalf of all the members of the Standards Committee, Mr. Jensen thanked Dr. Weber for a job well done during the past two years.

Books

Nachrichtenübertragung Mittels Sehr Höher Frequenzen, by Gerhard Megla

Published (1954) by Fachbuchverlag, Leipzig W. 31, Germany. 266 pages+6 page index. 171 figures. 9¼×6¼. 17. DM.

The author, evidently well versed in both theory and practice, condenses an extensive art into a slim booklet whose English title is *Communication By Means Of Very High Frequencies.*

The first, larger part of the book discusses basic principles; the second, practical embodiments, including schematics and photos of actual installations and components.

Some of the many subjects discussed are: choice of wavelength in the quasi-optical range between 0.4 μ and 30 m, atmospheric absorption, fading, antenna gains, diversity reception, transposition of frequencies in extended radio relays, frequency and time division multiplex systems information theory, and gain and noise figure of triodes, klystrons and traveling wave tubes.

With minor exceptions the treatment is sound and in close agreement with American design principles. American readers will be interested in the extensive list of predominantly European and relatively unfamiliar references and in the great amount of international standardization—indispensable in a continent where communication lines cross many political boundaries.

The book is recommended as an introduction to engineers working in other fields and as a referesher manual to those active in the radio relay art.

W. J. ALBERSHEIM
Bell Telephone Labs.
Whippany, N. J.

Advances in Electronics and Electron Physics: Vol. VII, edited by L. Marton

Published (1956) by Academic Press, Inc., Publishers, 125 E. 23 Street, N. Y. 10, N. Y. 503 pages+23 page index+x pages. Illus. 9¼×6¼. $11.50.

For some years now the Academic Press has published an excellent series of review volumes in various fields. The titles of these books all begin with the words "Advances in." For example, there are series on the

Advances in Applied Mechanics, *Advances in Carbohydrate Chemistry*, and in the case of the volume being reviewed here *Advances in Electronics and Electron Physics*. All of these books serve the valuable purpose of keeping the specialist informed of advances in the broad field of his specialty. They consist generally of a collection of review articles relating to various branches of a general field. Different branches are covered in different years and thus a given review article written in some particular year may discuss advances in the art which have taken place during the preceding several years.

The field of electronics has been a rapidly expanding one during the past decade. This fact has been illustrated by the wide variety of topics included in this series in the preceding volumes. One important aspect of this growth during recent years has been the development of the transistor and the emphasis which it has focused upon solid state physics. The present volume recognizes this fact and in fact almost half of it is devoted to topics in a solid state. Some appreciation for the scope which this series is now attempting to cover can be had from a listing of the titles of the review articles in the present volume. These are: The Physics of Semiconductor Materials, Theory of the Electrical Properties of Germanium and Silicon, Characteristic Energy Losses of Electrons in Solids, Sputtering by Ion Bombardment, Observational Radio Astronomy, Analog Computers, and Electrical Discharge in Gases and Modern Electronics. These articles are all excellent in themselves. The chapter on theory of the electrical properties of germanium and silicon by Harvey Brooks of Harvard University seemed to this reviewer to be especially well done. The volume is therefore unhesitatingly recommended to those who have an interest in its subject matter.

This reviewer feels, however, that the field of electronics is becoming too large to be covered by one series of this kind. Transistor electronics and solid state physics are immense and growing subjects in themselves. Furthermore, transistor electronics and vacuum electronics are sufficiently diverse to have given rise to two separate bodies of specialists who are to some extent ignorant of and, sadly enough, fiercely competitive with one another's work. It would, therefore, seem advisable to have two separate series devoted to these two branches of electronics.

In the meantime, however, this series is doing an excellent job at a very difficult task. We should be grateful to the publishers for having brought together so much material into integrated form for ready reference.

G. C. DACEY
Bell Telephone Labs., Inc.
Murray Hill, N. J.

Vacuum Valves in Pulse Techniques, by P. A. Neeteson

Published (1955) by Elsevier Press, Inc., 2330 Holcombe Blvd., Houston 25, Texas. 165 pages+viii pages+5 page index. 147 figures. 6×9. $4.50.

This book is the latest addition to the Philips Technical Library series on vacuum tube techniques and applications. It deals with a method of analysis of networks containing vacuum tubes used as nonlinear elements.

The book can be divided into two sections. The first section deals with the basic theory of switching and the fundamental treatment of vacuum tubes used as switches. The second section deals entirely with an analysis of the large-signal nonlinear behavior of tubes used as a stable, bistable, and monostable multivibrators. In view of the fact that this book deals almost entirely with multivibrators, a more descriptive title would have been *Vacuum Valves as Multivibrators*.

The author first deals with the fundamentals of switches and switching, and then some principles in the solution of differential equations by the use of the operational calculus. He then applies these basic concepts to the study of the large signal behavior of the control-grid circuits and the plate circuits of tubes. This section is particularly interesting to engineers concerned with both tubes and transistors in that it suggests a method of analysis for transistor switching circuits.

The next section deals entirely with multivibrators, using the fundamental analysis developed in the first section. This section on multivibrators includes about two-thirds of the contents of the book and appears to be the reason the book was written. The analysis is first applied to the Eccles-Jordan flip-flop circuit, and then is developed for the monostable and astable multivibrators. The author presents experimental data throughout this section which agree very closely with the calculated data.

This book should be particularly interesting and useful to the engineer engaged in the design and development of pulse circuits. The reviewer found it easy to read as well as instructive and considers this book an excellent contribution to the field of electronic pulse techniques.

W. H. LAPHAM
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Modern Physics, by R. L. Sproull

Published (1956) by John Wiley & Sons, Inc., 440 4 Ave., N. Y. 16, N. Y. 457 pages+xii pages+11 page index+21 page appendix. Illus. 9¼×6. $7.75.

In many branches of engineering a working knowledge of modern physical principles is almost indispensable. Accordingly, engineering educators are forced to give modern physics more and more emphasis, not only on the graduate level, but on the undergraduate level as well. Judging from the preface, Sproull's book represents the contents of a one-semester course in atomic, molecular, nuclear, and crystal physics for engineering undergraduates, a course which has been taught for some years at Cornell, and which has also been taught to practicing engineers in nearby industries.

The book begins with an elementary discussion of the fundamental particles, considered both as individual entities and as members of a statistical aggregate. The reader is then prepared for quantum mechanics by a thoughtful summary of the experiments which highlighted the wave-particle dualism and could not receive a satisfactory explanation on classical grounds. After presenting the essentials of quantum mechanics, Sproull applies this information to atomic and molecular structure, atomic spectra, and crystals. He then goes on to treat such topics as the electrical, thermal, and magnetic properties of solids, crystal imperfections, semiconductors, and physical electronics. The book closes with a brief chapter on applied nuclear physics.

Generally speaking, the author succeeds admirably in getting rapidly to the point, stating the main ideas in their simplest form, and providing perspective and emphasis where necessary. Perhaps the most unique feature of the book is the brief but enlightening coverage of solid state physics and physical electronics. While much of the remaining material can be found in a number of other sources on a similar level, there are few places where these two topics are surveyed with such skill. Sproull's book should prove a valuable addition to the engineering education literature.

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Proceedings of the Symposium on Electromagnetic Wave Theory

Published in IRE TRANSACTIONS, vol. AP-4, no. 3, July, 1956 by the Professional Group on Antennas and Propagation, Institute of Radio Engineers, 1 E. 79 St., New York 21, N. Y. 402 pages. 8½×11 inches. $8.50 (free to members of the Professional Group on Antennas and Propagation).

In June, 1955 an international symposium on electromagnetic theory was held at the University of Michigan, sponsored by the university, Commission VI of URSI, the three branches of the Defense Department, and eleven industrial corporations. The purpose of the symposium was to assemble the leading scientists in the field of electromagnetic wave theory for the presentation of the latest developments in the field. The symposium was divided into seventeen sessions, held over a period of six days. This volume contains 44 out of the 45 invited papers, abstracts of the 53 contributed papers which were presented at the symposium, and summaries of the five panel discussions which were held on selected topics. The international character of this meeting is indicated by the fact that 23 out of the 45 invited papers presented were contributions from distinguished authors outside the United States.

As pointed out in the welcoming address by S. Silver, a symposium of such scope hardly could have been visualized fifteen years ago. Electromagnetic theory, which was originated by Maxwell, blossomed in half a century to the status of mature development, yielding the classical theory of light, including the theory of diffraction advanced by Fresnel, the theory dispersion of Brillouin and Sommerfeld, and many other brilliant achievements. The experiments of Marconi at the beginning of the century led to extensions of the theory to radio wave propagation, including the magneto-ionic theory. The subject of ground wave propagation, which had been in a somewhat undecided state because of mathematical difficulties, seemed to be settled by the papers of van der Pol and Bremmer in the late 1930's, and this led to a period of "all quiet on the electromagnetic front."

The tremendous impetus to research and technical progress initiated by World War II showed that many electromagnetic problems which had been considered as solved actually were not solved to the extent that solutions suitable for practical use were available. Mathematical developments led to physical interpretations which have given new insight to the complex phenomena taking place, such as the "creeping wave" of Franz and Depperman. The whole field of electromagnetic theory has been revitalized to the point where today progress is taking place on many fronts and at a vigorous pace. Contributions to this progress have been world-wide, so that the important papers are scattered through the world's scientific journals. In view of this fact, a collection of papers covering the latest developments in the broad field of electromagnetic theory and applications is of particular value at the present time. The *Proceedings* under review is indeed such a collection.

The scope of the fields covered is indicated by the titles of the sections, which include the papers presented at corresponding sessions. The complete papers are reproduced for the sessions on the following topics: boundary value problems of diffraction and scattering theory, forward and multiple scattering, antenna theory and microwave optics, propagation in double-refracting media. In addition, the volume contains the abstracts of the contributed papers on the following topics: scattering, diffraction, and general mathematical papers; multiple scattering, scattering from rough surfaces, and transmission and reflection problems; waveguides, propagation, and slow waves and surface waves; ferrites, plasma oscillations, and anisotropic media; antennas and microwave optics.

In addition to covering a wide range of topics, the papers themselves vary in character from highly mathematical expositions to reports of experimental measurement programs. The reviewer found several papers of an intermediate nature to be highly valuable, since they are descriptive summaries in easily understood terms of the results of complicated mathematical developments. Among these may be cited the paper by van de Hulst on "The Interpretation of Numerical Results Obtained by Rigorous Diffraction Theory for Cylinders and Spheres," and the survey by Kline of "Electromagnetic Research at the Institute of Mathematical Sciences of New York University." In addition, the paper by J. B. Keller on "Diffraction by a Convex Cylinder" is a good illustration of the way in which the rigorous solutions to certain idealized problems may be applied through physical reasoning to obtain approximate solutions to more complicated situations.

The quality of the printing is up to the usual high standards of the IRE. Although there are a number of typographical errors, these are generally of an obvious nature which should cause little inconvenience to the reader.

There is to be found between the covers of this volume a wealth of material of direct interest to research and development workers concerned with problems involving electromagnetic theory, such as wave propagation, antennas and waveguides, absorbing materials, and ferrite applications. In addition, the volume is recommended to the engineer or physicist who would know more about this field. The Professional Group on Antennas and Propagation is to be commended for undertaking the publication of this volume as a special issue of its TRANSACTIONS.

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Abstracts of IRE Transactions

The following issues of "Transactions" have recently been published, and are now available from the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, N. Y. at the following prices. The contents of each issue and, where available, abstracts of technical papers are given below.

Sponsoring Group	Publication	Group Members	IRE Members	Non-Members*
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*** Public libraries and colleges may purchase copies at IRE Member rates**

Audio

VOL. AU-4, NO. 2, MARCH–APRIL, 1956

PGA News

The Electrostatic Loudspeaker—An Objective Evaluation—R. J. Larson

The electrostatic loudspeaker, following development of new materials and methods, is now practical for high-frequency use in multichannel loudspeaker systems. Theoretical and mechanical design considerations illustrate the limitations at this stage of the art, including inherently high distortion at high output levels, and inability to withstand overloads. Principal advantages are low cost and efficient reproduction at extremely high frequencies.

A 3,000-Watt Audio Power Amplifier—A. B. Bereskin

A 3,000-watt audio power amplifier has been developed using the Bereskin power amplifier circuit described at the 1954 IRE National Convention and in the March–April 1954 issue of the IRE TRANSACTIONS on Audio. Solutions were found for some interesting problems that arose in this connection. A unit capable of delivering more than 3,000 watts with less than 2 per cent distortion over a 400–6,000 cycle frequency range was developed. The design procedure and test data on the final unit will be discussed.

Triode Cathode-Followers: A Graphical Analysis for Audio Frequencies—T. J. Schultz

Graphical methods are presented with which one may determine the operating path upon the plate-current characteristic curves for several commonly used feedback circuits. These include the ordinary RC-coupled triode stage without a cathode by-pass capacitor and two forms of the cathode follower: one in which the grid is returned to ground, the other in which it is returned to a tap on the cathode bias resistor. Once the operating path is established, the familiar computations which determine the gain, the 2nd and 3rd harmonic distortion, the dissipated and delivered power, etc. for the common triode stage may be used here. Excellent agreement is found between predicted and measured results.

Contributors

Broadcast Transmission Systems

PGBTS-4, MARCH, 1956

High Speed Duplication of Magnetic Tape Recordings—J. M. Leslie, Jr.

The high speed duplication of previously recorded magnetic tapes has made the tape radio network practical. For example, each o the two major radio networks in Mexico duplicates over 19,000 seven inch reels of taped programs per month for their several hundred affiliated stations. Since the tapes are erasabl and wire program circuits are seldom used these networks operate very economically, and the quality of their recorded programs is unimpaired by losses in transmission.

Likewise, the adoption of automatic programming systems for radio broadcasting will create a demand for syndicated magnetic tape programs and tape libraries.

High speed magnetic tape duplicators are also utilized for the mass production of tape recordings for entertainment, education, churches, libraries for the blind, for reviews of professional publications, and sales information for large field sales organizations.

The Ampex Model S-3200 tape duplicator with ten slaves will produce up to ten copies at one time of 15, 7½, or 3¾ ips master recordings at 60 ips. The copies can be recorded to be reproduced either at the speed of the master or at half speed; i.e., 3¾ ips copies from a 7½ ips master. The duplicates may be either half track, double track, full track, or two track stereophonic.

Comparisons are made of the degradation of the signal-to-noise ratio, frequency response, and distortion with respect to the number of generations of the duplicates. With optimum adjustment of the equipment, it is very difficult to identify the fourth generation copy from the master recording.

The Conversion of a Standard TV Mobile Unit for Greater Flexibility and Operating Convenience—H. F. Huntsman

Principles of the Harkins Multiplex System—W. N. Hershfield

The Subjective Sharpness of Simulated Color Television Pictures—M. W. Baldwin, Jr. and G. Nielsen, Jr.

This paper describes a visual experiment in which the observed variable is the subjective sharpness of a color picture. The picture is produced by the superposition of primary color images from three projectors. The test picture corresponds, in general sharpness, to the grade of picture that might be produced by existing or contemplated color television systems. The projectors are operated out of focus to achieve the moderate sharpness values required. The amount of defocus of each projector is expressed in equivalent television bandwidth as part of the calibration. Many different ways of dividing up bandwidth among the three primary colors are explored in determining the variation of picture sharpness.

Communications Systems

Vol. CS-4, No. 1, March, 1956

(Symposium on Communication by Scatter Techniques—George Washington University, Washington, D. C., November 14 and 15, 1955)

Keynote Address—E. M. Webster

Some Practical Aspects of Auroral Propagation—H. G. Booker

Progress of Tropospheric Propagation Research Related to Communications Beyond the Horizon—J. H. Chisholm

VHF Propagation by Ionospheric Scattering—A Survey of Experimental Results—R. C. Kirby

A brief survey is given of results from an experimental program extending over the last five years to investigate the nature and characteristics of high-loss regular vhf propagation by means of scattering and other mechanisms in the lower ionosphere. Short-term characteristics as well as diurnal, seasonal and geographical variation of the observed signals are described. The results of pulse-determination of height of scattering, spaced-antenna and polarization experiments, and observations of realized gain of directive antenna systems are given. The dependence of the strength of the signals on path length, scattering angle and frequency is described. Considerations for communication applications are summarized.

Practical Considerations for Forward Scatter Applications—J. R. McNitt

Some Meteorological Effects on Scattered Radio Waves—B. R. Bean

The long term variations of received scattered fields due to atmospheric effects are estimated for frequencies of 100 to 50,000 mc and over propagation paths of 100 to 1000 miles. The long term variations are presented in two parts: (1) empirically derived variations excluding absorption and (2) theoretically derived variations due to gaseous atmospheric absorption. The absorption effects are obtained by following a scattered radio wave through an actual atmosphere.

Point-to-Point Radio Relaying via the Scatter Mode of Tropospheric Propagation—K. A. Norton

Formulas are given for determining the transmitter power required to provide a specified grade of service in point-to-point radio relaying of the following types of signals: television, frequency modulation high fidelity music, frequency modulation voice, frequency shift telegraph, and a just measurable signal. Allowance is made for the antenna gains, the carrier frequency, the systems bandwidth, distance, the antenna heights above the ground and the effects of the terrain and the atmosphere along the transmission path. The formula for the transmission loss allows separately for the effects of the actual distance, the angular distance and the antenna heights, and this separation of the influence of these variables provides the basis for the development of rules for the efficient siting of the terminals of a tropospheric forward scatter relay circuit.

A Simplified Diversity Communication System for Beyond-the-Horizon Links—F. J. Altman and William Sichak

High-Gain Antennas for VHF Scatter Propagation—H. V. Cottony

Rhombic antennas were the first type employed in the study of propagation via ionospheric scatter. By the use of electrically long leg-lengths gains of the order of 20 decibels were obtained. Experimental measurements using model techniques indicated that assumptions usual in the design of rhombic antennas remained valid even for leg-lengths of 25 to 40 wavelengths.

In order to obtain a more compact antenna, while retaining the gain, experimental investigation was carried out on corner-reflector and Yagi-types of antennas. By the use of 60 degree corner-reflector and a collinear array, a corner reflector antenna having gain of 19.9 db. was constructed. By exercising care in adjusting the lengths of parasitic elements, a Yagi antenna, 4.2 wavelength, having a gain of 14.2 decibels, was designed. An array of four such Yagis, having a horizontal spacing of 1.8 wavelengths and a vertical separation of 1.6 wavelengths was measured to have a gain of 19.0 decibels.

Full scale corner-reflector antennas and Yagi antennas have been erected and have proved to be operationally satisfactory.

Transmitting Tubes for Scatter Communications—Theodore Moreno

Continuous wave klystron amplifiers have undergone considerable development in recent years, and a marked advance in the state of the art has resulted. The characteristics of these amplifiers that make them especially attractive for scatter communication will be reviewed. The design philosophy of some modern amplifiers will be reviewed, including the following tubes: 1) 10 kw output at 2000 mc, 50 db gain, 2) 2 kw output at 6000 mc, 50 db gain.

Power Amplifier Klystron for U.H.F. Transmission—F. A. Speaks

A review of design considerations and expected performance of external cavity klystrons is given. Information on availability of these power amplifier klystron tubes is presented along with comments on systems engineering considerations in klystron applications.

VHF Transhorizon Communication System Design—R. M. Ringoen

The basic properties of a signal received over a typical vhf transhorizon circuit are presented. The necessary parameters and features of a system designed to utilize efficiently this signal are then considered. These include modulation, diversity reception, teletype transmission, frequency control, equipment reliability, and duplex operation. In conclusion curves are presented showing system voice and data channel capacity and quality as a function of circuit length, reliability required, and frequency. It is concluded that available vhf equipment may be employed to provide reliable voice transmission and extremely reliable multi-channel teletype transmission for circuits in the 300 to 1200 mile range.

System Parameters Using Tropospheric Scatter Propagation—H. H. Beverage, E. A. Laport, and L. C. Simpson

Accumulated data from published sources and from unpublished research on tropospheric forward scatter propagation are reviewed and condensed for practical application to FM communication systems. Antennas suitable for use on scatter paths are reviewed and the limitations on usable gains are discussed. General design methods for FM systems are presented and reduced to a design chart that includes the relationship of all parameters in a frequency-division multiplexed FM telephone system. Then follow computed values of transmitter power as functions of distance, frequency and antenna size for a number of systems of practical interest using tropospheric forward scatter.

A Simple Picture of Tropospheric Radio Scattering—W. E. Gordon

Long Distance VHF-UHF Tropospheric Field Strengths and Certain of Their Implications for Radio Communications (Abstract)—L. A. Ames, E. J. Martin and T. F. Rogers

Results of Propagation Tests at 505 Mc and 4090 Mc on Beyond Horizon Paths—K. Bullington, A. L. Durkee, and W. J. Inkster

Some Ionosphere Scatter Techniques—D. A. Hedlund, L. C. Edwards and W. A. Whitcraft, Jr.

Signal Fluctuations in Long-Range Overwater Propagation—W. S. Ament and Martin Katzin

Component Parts

Vol. CP-3, No. 1, March, 1956

Proceedings or Transactions?—J. R. Pierce

Ferroelectrics and their Memory Applications—C. F. Pulvari

For information storage purposes, $BaTiO_3$ single crystals were grown, and typical data of the product are presented. Storage condensers using multidomain and *c*-domain crystals as a dielectric were produced.

Memory as well as switching properties were studied with particular reference to their application in a multicondenser memory matrix. A method for testing bistable storage condensers was developed; typical data are presented.

A gated, bidirectional pulse transformer circuit was developed, providing pulses of opposite polarity for writing and reading on the matrix leads. This circuit permits increase of the absolute ratio of matrix switching pulses from 2 to 1 to 3 to 1. Sequential, random or simultaneous sequential- and random-scanning of a multicondenser matrix are equally practical.

The Analysis and Design of Constant Voltage Regulators—I. B. Friedman

This paper is concerned with analysis and with the development of method for designing constant voltage regulators. A constant voltage regulator will give a more nearly constant output voltage despite a limited input variation.

This type of regulator consists of an input inductor, a transformer, and condenser connected as is then shown. The series inductor resonates with the capacitance and drives the voltage across the transformer into saturation. The current limiting effect of the series inductor plus the saturation of the transformer results in a measure of regulation.

A Proposed Current-Noise Index for Composition Resistors—G. T. Conrad, Jr.

A study of fluctuation voltage generated by dc current flowing in composition resistors has led to a convenient factor for expressing the noisiness of a resistor. This factor, or index, is named "conversion gain" and indicates the efficiency with which a resistor converts applied dc power to noise power, expressed in decibel units.

The method of measurement is described, and results are given for various commercial resistors including some film types.

The use of conversion gain for quality control testing is discussed. Also, examples are given of the use of conversion gain in computing interference in actual circuits.

Measurement of Parameters Controlling Pulse Front Response of Transformers—P. R. Gillette, K. Oshima, and R. M. Rowe

The two-element equivalent circuit commonly used in predicting the high-frequency or pulse-front response of a step-down or step-up transformer is not applicable to transformers with turns ratios near unity. Furthermore, the transformer leakage inductance (the series element in the circuit) may vary with frequency or time because of skin effects in the windings, and the distributed capacitance (the shunt element in the circuit) varies with frequency or time, source impedance, and load impedance because of variations in voltage distribution. These variations are difficult to take into account in measuring the element values and also in using the values in the prediction of transformer response.

A theoretical and experimental analysis has shown that a T circuit containing three inductances and one capacitance (or the mathematically equivalent π circuit, which contains seven elements) can be used to represent a transformer of any turns ratio, and element values obtained from appropriate measurements give reasonably accurate results over necessary frequency range. Measurements are easily made with an rf generator and a vacuum-tube voltmeter. Greater accuracy with which high-frequency response characteristics can be predicted by this T circuit indicates a marked improvement in accuracy will result when T circuit is used in predicting response of a transformer to fast-rising pulses.

Pulser Component Design for Proper Magnetron Operation—P. R. Gillette and K. Oshima

To obtain proper magnetron operation in a specified mode and reasonable life, it is necessary to control the rate that the applied voltage passes through the range within which magnetron oscillations can build up, and to control the amount of current available for this build-up.

A method will be suggested for determining the required pulse-forming network and pulse transformer characteristics, using appropriate equivalent circuits to represent the network, the transformer, and the nonconducting magnetron.

Studies based on this method indicate that, by proper choice of network and transformer characteristics, it should be possible to operate most types of magnetrons successfully without the use of despiking circuits.

Subminiature Toggle Switches—G. C. Jakubowski

PGCP News

Contributors

Electronic Computers

Vol. EC-5, No. 1, March, 1956

SEER, A Sequence Extrapolating Robot—D. W. Hagelbarger

The success of computers in doing routine work formerly done by people suggests that a computer capable of adjusting itself to a changing environment might be desirable. Such a characteristic might be especially valuable to the telephone industry which must service large numbers of people having changing needs and desires. As a step in this direction a relay machine which plays a penny-matching game with human opponents has been built. The machine is described and its behavior against people and other machines discussed.

Automatic Data-Accumulation System for Wind Tunnels—J. J. Wedel, A. Huntington, and M. B. Bain

A new high-speed data-accumulation system has been designed for a supersonic wind tunnel. The data are recorded on punched paper tape for direct input into an Electrodata digital computer. Extensive presentation of data is available to the wind-tunnel operators. All data are typed by an electric typewriter, and an automatic plotting machine plots several of the data words as functions of the independent-variable data word. Special codes to control the computer are automatically punched into the tape. The preliminary source of the data may be either manually operated keyboards or shaft-position digitizers. The new system increases the wind-tunnel pace, eliminates intermediate data handling before computation, and lowers the cost of data reduction.

Odd Binary Asynchronous Counters—J. E. Robertson

This paper describes a general method for modifying conventional binary asynchronous counters such that the counting register advances by any desired odd integer for each received count. The pertinent design features of conventional additive and subtractive asynchronous counters are reviewed. Simplification of the design of a counter which advances by an odd integer is achieved through use of a set of alternately additive and subtractive subcounters. An example of the logical design of a counter which advances by 13 is presented.

Complexity in Electronic Switching Circuits—D. E. Muller

The complexity of an electronic switching circuit is defined in a sufficiently general way so that most definitions which are presently used may be included. If $\phi(p, q)$ is the complexity of a p input q output circuit which has been minimized then we may define $E(p, q)$ as the maximum of $\phi(p, q)$ over all p input, q output circuits. In spite of the generality of the definition of complexity one may obtain the following inequality which gives upper and lower bounds on this maximum complexity:

$$C_1 2^r/r \leqq E(p, q) \leqq C_2 2^r/r$$

where $r = p + \log_2 q$. In this expression C_1 and C_2 are constants independent of p and q which depend upon the definition of complexity.

These theoretical bounds are compared with those obtained from a few known circuit designs.

On the Wiring of Two-Dimensional Multiple-Coincidence Magnetic Memories—N. M. Blachman

The application of Minnick and Ashenhurst's technique of p-fold multiple-coincidence magnetic storage in an $n \times n$ array of cores is shown to require finding $(p-2)$ orthogonal Latin squares of order n. The value of this technique lies in the reduction it effects in the disturbance of unselected cores. A method is suggested for reducing this disturbance to a level lower than that obtained by Minnick and Ashenhurst, by the application of reverse currents to the unselected interrogating wires during interrogation. The disturbance of unselected cores can be reduced to zero if $p = n + 1$. In this case, $(n+1)$ cores can be added to the store at the expense of a single additional interrogating wire. The resulting array of cores and interrogating wires is closely related to the finite projective geometry of order n.

A Programmed Variable-Rate Counter for Generating the Sine Function—J. N. Harris

The sine curve is approximated by a set of straight line segments whose slopes are chosen to be integral multiples of a binary fraction. A programmed counter counts up or down at a rate proportional to the slope, thus generating an approximate sine function. Using (360/256) $\approx$ 1.4 degree intervals and four integral slopes, $\pm 0(1/128)$, $\pm 1(1/128)$, $\pm 2(1/128)$, $\pm 3(1/128)$ the maximum difference between the true and the generated value is 0.014 and occurs at 36.6 degrees. The extension of this method to higher accuracy and to other functions is indicated.

A Time-Division Multiplier—M. L. Lilamand

A time-division multiplier for analog computers is described. Its features, for a switching pulse frequency of 2,000 cycles per second, are as follows: an accuracy of one part in a thousand, a pass band of 2 cycles per second, an input impedance of one megohm, and a very low output impedance (the output impedance of a feedback amplifier).

This multiplier has the following advantages when compared to two other types of analog multipliers: a) an accuracy limited solely by the stability of the components used and the fineness of the adjustments that can be made; b) a pass band greater than that of servomechanism multipliers; c) a much smaller amount of material than is necessary for diode multipliers with translators having parabolic characteristics and adjustments which can be made much more rapidly (although requiring a certain amount of practice); d) the possibility of changing the diodes without having to repeat all the adjustments.

These results have been obtained by the development of a precision electronic switch and by compensation of the stray capacities of the tubes.

Contributors

A Report on the International Analogy Computation Meeting—N. M. Blachman

PGEC News

Review of Electronic Computer Progress During 1955—J. P. Nash

Reviews of Current Literature

IRE Transactions on Electronic Computers—Index to Volume EC-4—1955

Nuclear Science

Vol. NS-3, No. 2, March, 1956

An Approximate Method for Obtaining the VSW on Cyclotron Dees—M. R. Donaldson

In the design of cyclotron resonant systems, the voltage distribution along the accelerating electrodes (dees) is frequently desired. This paper describes an approximate method for obtaining this vsw. An experimental check of the method is included. Data on Oak Ridge National Laboratory Cyclotrons are also given.

The "Hard-Bottoming" Technique in Nuclear Instrumentation Circuit Design—C. C. Harris

It is very desirable to operate vacuum tubes in such a manner that the operation of the overall circuit is essentially independent of large changes in tube characteristics. The technique of "hard-bottoming" of vacuum tubes in two-state circuits obtains operation that, in many cases, is unchanged until the vacuum tubes are almost completely inoperative by ordinary standards. Negative feedback has, of course, been used for many years to stabilize amplifier circuits, but the use of hard bottoming has not become as widespread.

The Physical Electronics Group of the Physics Division, ORNL, has, over the last few years, applied the hard-bottoming principle to many circuits used in nuclear instrumentation. In scaling circuits, it represents as large a step forward in design as did the addition of coupling diodes by Higinbotham. Precision timing circuits are made possible by use of this principle. These applications are described.

Proton Beam Study in a Fixed-Frequency Cyclotron—F. L. Green

Operational and theoretical experience with the ORNL 44-inch and 63-inch cyclotrons is used in estimating the time variation of proton beam current passing through the rf field between the dees of the ORNL 44-inch cyclotron. The proton current appears to have a significant reactive component. This result is probably typical of most fixed frequency cyclotrons whose ions make 30–100 orbits in being accelerated to maximum radius. The study is briefly related to problems which may be encountered in the design of a fixed-frequency rf system capable of accelerating hundreds of kilowatts of ions to be used for a purpose such as the production of radioisotopes.

Electronic Analog Devices for Design of Reactor Controls—E. R. Mann

Nuclear reactors for power production require essentially two control regimes—one for start-up and the other about design point power. The start-up regime requires controls and instrumentation for neutron flux. The power regime is one in which temperatures must be controlled.

The Bell-Strauss simulator has been used successfully for development of neutron flux control equipment. Nuclear power plant simulation requires a more elaborate analog computer such as the present ORNL nuclear plant simulator. This computer has been used successfully for designing servo mechanisms for rod control, temperature regulation and heat dump control for power reactor designs.

Some of these applications are described.

The Microtron, A Nuclear and Electronic Research Instrument—H. F. Kaiser

The microtron (electron cyclotron) originated about the same time, if not earlier, than the synchrotron, but because of limitations as well as assets, its development (reviewed here) has been slow. The potentialities of the microtron in various fields of nuclear and electronic research are discussed. Some of its desirable characteristics are: (a) a fixed magnetic field microwave accelerator capable of considerable reduction in size and weight for the energies attainable (30 mev or higher), (b) field or quasi field-emission electron source with possibility of yields comparable to those of linear accelerators, (c) electron output in small bunches with precise control of timing possible, (d) orbital distribution allowing easy extraction of electron beams for special experiments or for use of microtron as an injector to other accelerators, (e) simplified equipment with easy, stable, and reliable operation, (f) the special form "racetrack microtron" has further advantages for experimental work, (g) adaptation to F.F.A.G. magnet structures is a possibility still untouched, (h) modified for use with an auxillary magnetic field rising stepwise in time the "synchro-microtron" may attain high electron energies in very short times. Here the steady field structure may even be dispensed with, giving a compact microwave accelerator.

A Dual Function Gamma Monitor—R. E. Connally

A thallium-activated sodium iodide gamma monitor is described which utilizes both the ac and dc components of the anode current of a multiplier phototube. The dc component serves to monitor over a range of 10^4 the gross gamma activity of selected points in a solvent extraction plant for the processing of spent nuclear fuel. From the ac component a gamma energy analysis is obtained over an activity range of 10^3. The ac component also serves as a monitor on the multiplier phototube gain adjustment. The characteristics of the gamma monitor system are discussed.

News and Views

Telemetry & Remote Control

Vol. TRC-2, No. 1, March, 1956

A Message from the Chairman—C. H. Hoeppner

Some Methods of Error Signal Detection in PAM-Systems for Multiplex Transmission of Synchro Data—O. Carlstedt

It is often desirable to transmit synchro data over a two-wire line or radio link. This can be done by using time division multiplex. The amplitudes are then sampled and transmitted as pulse trains representing the sine and cosine of the shaft angles of the synchro transmitters. This paper discusses various methods of producing the servo error signals from the information in the received pulse trains.

The AN/AKT-14 Telemetry System

Part I—Introduction—G. S. Shaw

Part II—AKT-14 Airborne Telemeter—R. P. Bishop

Part III—UKR-7 Telemetric Data Receiving Set—D. C. Howard

Part IV—Quick-Look Recording System—J. A. Petersen

Part V—UKR-7 Ground Translator and Programmer—C. A. Campbell

Part VI—PWM and FM/FM Automatic Data Reduction With AKT-14 Telemetering Components—G. F. Anderson

Part VII—Appendix

A Program for an Airborne Digital Control System—S. I. Klein

The program to be described is one used in an advanced phase of the flight testing of the Digitac system, an airborne automatic control system utilizing a digital computer. The purpose of the system is summarized. The configuration of the system and some specific components are mentioned.

The computer and its order coding system are described briefly. The specific program and its code are presented in detail as far as permitted. Emphasis is placed on certain aspects which are interesting or unique and may be applicable to others in this field. Simplification of the program is made by means of block diagrams.

◆

Report of the Secretary—1955

To the Board of Directors,
The Institute of Radio Engineers, Inc.

Gentlemen:

The Annual Report for the year 1955 is herewith submitted.

Perhaps the most significant event of the year was the 118% increase in the Member Grade resulting mostly from the arrangements which made possible the up-grading of qualified Associate Grade members. This has brought the percentage of Professional Grade members to 42.1, whereas it was 29.1 at the beginning of the year.

It is interesting to note that the foreign member increase was 19.5% compared to 13% for the United States and Possessions.

Growth has taken place in the Professional Groups, in the output of editorial material, in the National Convention and in other activities. The affairs of the IRE continue in satisfactory condition.

Respectfully submitted,

Haraden Pratt

Haraden Pratt
Secretary

January 23, 1956

Membership

At the end of the year 1955, the membership of the Institute of Radio Engineers, including all grades, was 47,388, an increase of 5,610, or 13.4% over the previous year. The 5,610 member increase in 1955 was more than 4,644 and 4,260, the increases for 1954 and 1953 respectively. The percentage increase was 12½% in 1954 and 13% in 1953. The membership trend from 1912 to date is shown graphically in Fig. 1.

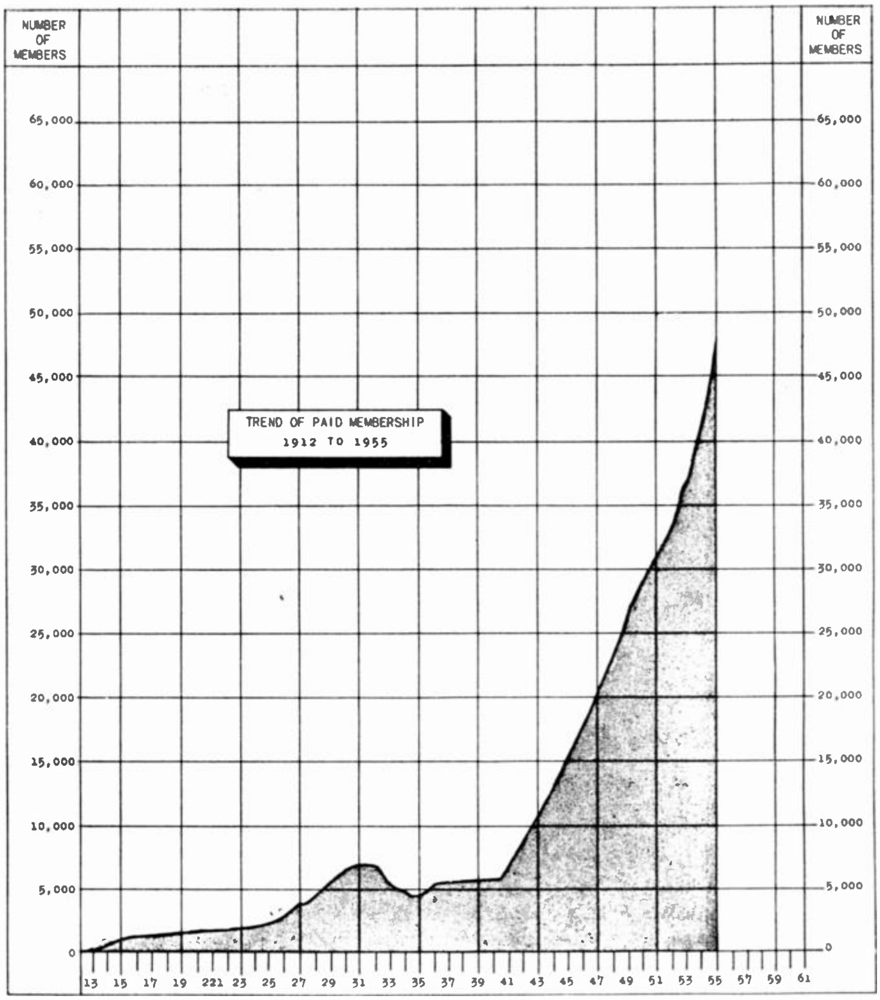

Fig. 1

Actual membership figures for 1953, 1954 and 1955 are shown in Table I. Of the 20,096 non-voting Associates, 4,833 have been in that grade for more than five years.

TABLE I

Total Membership Distribution By Grades, 1953–1955

Grade	As of Dec. 31, 1955		As of Dec. 31, 1954		As of Dec. 31, 1953	
	Number	Per Cent of Total	Number	Per Cent of Total	Number	Per Cent of Total
Fellow	565	1.2	489	1.2	425	1.2
Senior Member	5,643	11.9	4,780	11.4	4,170	11.2
Member	13,360	28.2	6,107	14.6	5,307	14.3
Associate	20,492‡	43.2	24,846†	59.5	22,702*	61.1
Student	7,328	15.5	5,556	13.3	4,530	12.2
Totals	47,388		41,778		37,134	

* Includes 856 Voting Associates. † Includes 803 Voting Associates. ‡ Includes 396 Voting Associates.

Following action taken by the Board of Directors on revisions to the qualifications for Member grade, the applications of all Associate grade members were re-examined and those qualified transferred to Member grade, with the result that the percentage of members in the grade of Member doubled in the year 1955.

It is with deep regret that this office records the death of the following members of the IRE during the year 1955.

Fellows

Clark, Alva B. (SM'46, F'56)
Nelson, Edward L. (A'19, M'25, F'38)
Pannill, Charles J. (M'13, F'16, L'48)
Shelby, Robert E. (A'29, M'36, SM'43, F'48)

Senior Members

Alba, Charles J. (A'43, SM'53)
Barger, George K. (A'43, SM'54)
Best, Nolan Rice (SM'53)
Beusman, Robert M. (A'29, SM'50)
Brittin, Frank Lewis (A'27, M'28, SM'43)
Brott, Francis J. (M'40, SM'43)
Brown, Walter N., Jr. (S'39, A'42, M'44, SM'45)
Cattell, Gilbert W. (A'25, SM'46)
Godsho, Albert P. (A'21, M'51, SM'51)
Lidbury, Frank Austin (A'27, SM'43)
Mead, Leo Roy (A'44, SM'46)
Odell, Newton Hays (A'43, SM'54)
Rockwell, Gaynor O. (SM'53)
Rothschild, Max (M'53, SM'53)
Schlesman, Carleton H. (SM'45)
Sharp, Hubert (A'48, SM'54)

Members

Berkey, William E. (M'47)
Brittain, Virgil M. (A'43, M'50)
Crawford, Bud (A'45, M'54)
Crossett, Edward C. (A'27, M'55)
Curtin, James N. (M'47)
Ekrem, T. C. (A'44, M'55)
Ellis, William C. (A'46, M'48)
Jacobs, Charles F. (A'41, M'53)
Jacques, Robert B. (M'45)
Jensen, George L. (A'29, M'47)

Johns, Lawrence T. (M'47)
Kadow, Arthur C. (A'30, M'55)
Luster, Eric W. (A'54, M'55)
Rodenhouse, Evert (M'46)
Sheppard, Harry S. (A'45, M'45)
Zimmer, H. Ward (M'54)

Voting Associates

Armagost, Harold C. (A'30, VA'39)
Hayes, Ralph S. (J'15, A'18, VA'39)
Nikirk, Thomas E. (A'35, VA'39)
Pierce, James F. (A'30, VA'39)
Tinney, Francis B. (A'24, VA'39)

Associates

Artkin, W. H., Jr. (A'52)
Bongiorno, Andrew (A'53)
Borders, James B. (A'54)
Cannon, Alan H. (A'49)
Carlson, David G. (A'52)
Carter, Harry S. (A'54)
Crosman, Loring P. (A'52)
Davies, Richard J. (A'41)
Fisher, Francis J. (A'44)
Glawson, Thomas J. (A'52)
Guettinger, Paul (A'45)
Holliday, William A. (A'54)
Jaccard, Ricardo H. (S'50, A'53)
Johnston, Hugh M. (A'42)
Mack, Edward J. (A'46)
Mattsen, Erling A. (A'53)
Nestlerode, Boyd W. (A'48)
Newhart, Edward L. (A'49)
Reitz, William H. (A'51)
Rolfe, Henry D. (S'52, A'52)
Shearer, Wayne G. (A'54)
Shirley, Queenie H. (A'45)
Taeschner, Lawrence (A'45)
Watson, A. J. (S'53, A'53)
Zaepfel, Charles G. (A'50)

Students

Berg, Frederick T., Jr. (S'52)
Grim, Robert L. (A'47, S'53)
Kornreich, Philipp G. (S'54)

Fiscal

A condensed summary of income and expenses for 1955 is shown in Table II, and a Balance Sheet for 1955 is shown in Table III.

TABLE II

SUMMARY OF INCOME AND EXPENSES, 1955

Income		
Advertising	$911,968.16	
Member Dues and Convention	964,742.87	
Subscriptions	105,820.90	
Sales Items—Binders, Emblems, etc.	64,046.30	
Investment Income	23,198.71	
Miscellaneous Income	1,461.96	
TOTAL INCOME		$2,071,238.90
Expense		
PROCEEDINGS Editorial Pages	$350,491.85	
Advertising Pages	485,202.24	
Directory	170,635.18	
Section and Student Branch Rebates	85,642.00	
Professional Group Expense	95,901.18	
Sales Items	47,653.11	
General Operations	367,279.73	
Convention Cost	328,298.64	
TOTAL EXPENSE		1,931,103.93
Reserve for Future Operations—Gross		$ 140,134.97
Depreciation		17,451.16
Reserve for Future Operations—Net		$ 122,683.81

TABLE III

BALANCE SHEET—DECEMBER 31, 1955

Assets		
Cash and Accounts Receivable	$ 323,831.77	
Inventory	20,533.48	
TOTAL CURRENT ASSETS		$ 344,365.25
Investments at Cost	1,002,000.31	
Buildings and Land at Cost	910,812.92	
Furniture and Fixtures at Cost	191,827.46	
Other Assets	31,708.67	
TOTAL		2,136,349.36
TOTAL ASSETS		$2,480,714.61
Liabilities and Surplus		
Accounts Payable		$ 35,129.77
Deferred Liabilities	$ 572,909.57	
Professional Group Funds on Deposit	120,319.20	693,228.77
TOTAL LIABILITIES		728,358.54
Reserve for Depreciation		76,949.06
Surplus Donated	595,286.61	
Surplus	1,080,120.40	
TOTAL SURPLUS		1,675,407.01
TOTAL LIABILITIES AND SURPLUS		$2,480,714.61

Editorial Department

IRE publication activities continued to increase substantially during 1955. The publication output for the year reached a new high of 88 issues totaling 11,146 pages, a 15% increase over the previous year.

The year was also marked by several noteworthy improvements in service and in the appearance of IRE publications. These included the issuance of an index to Abstracts and References, publication of review articles in PROCEEDINGS, a new cover for PROCEEDINGS and the adoption of letterpress printing by an increasing number of Professional Groups.

PROCEEDINGS OF THE IRE

The year was highlighted by the appearance of two special jumbo issues and two supplements. The October issue was devoted to Scatter Propagation, followed by the Solid-State Electronics issue in December. The April and November issues were accompanied by supplements containing indexes to Abstracts and References for 1954 and for 1946–1953, respectively, thus greatly enhancing the value of an already outstanding service.

Excluding the supplements, which totalled 248 pages, the number of PROCEEDINGS pages published during 1955 still showed a noticeable increase over the previous year, as can be seen in Table IV and Fig. 2. The number of papers, 170, was about the same as the previous year's total of 177. Eight IRE Standards also appeared.

TABLE IV

VOLUME OF PROCEEDINGS PAGES

	1955	1954	1953	1952
Editorial	2060	1884	1860	1804
Advertising	2372	2072	2146	1800
Total	4432	3956	4006	3604

The October issue displayed an entirely new, and more modern and attractive front cover, the first major change in PROCEEDINGS covers in sixteen years.

The program of review articles, begun at the end of 1954, began to bear fruit with the appearance of three papers during 1955 summarizing recent important developments in various fields of current interest.

The backlog and publication time of papers, which were greatly reduced the previous year, remained at a satisfactorily low point. The backlog of extra material awaiting publication amounted to about one-half an issue, and the speed with which papers were published averaged five to six months.

The volume of material reviewed for PROCEEDINGS and the disposition made was approximately the same as in the previous year. A total of 305 papers comprising 2006 pages was considered. Of the total, 40% of the papers were accepted, 29% were referred to the appropriate TRANSACTIONS for consideration, and 31% were rejected.

TRANSACTIONS

The year 1955 saw the TRANSACTIONS output of the Professional Groups continue to increase substantially. The year also saw an improvement in the TRANSACTIONS themselves, with 6 more Groups adopting letterpress composition for improved appearance, bringing the total to 12.

The Editorial Department published 56 issues of TRANSACTIONS totaling 3504 pages for 21 Groups during 1955, as compared with the 1954 totals of 51 issues totaling 3714 pages for 18 Groups. The apparent decline in total pages is due to space saved by the increased use of letterpress composition. Actually, there was a 20% increase in the amount of material published. A breakdown of TRANSACTIONS material published in 1954 and 1955 is given in Table V.

TABLE V

VOLUME OF TRANSACTIONS PAGES

	1955		1954	
	Issues	Pages	Issues	Pages
Aeronautical and Navigational Electronics	4	188	4	144
Antennas and Propagation	4	248	4	188
Audio	6	236	6	208
Broadcast and Television Receivers	4	196	4	312
Broadcast Transmission Systems	2	168	0	0
Circuit Theory	4	396	4	256
Communications Systems	1	96	3	414
Component Parts	2	144	2	172
Electron Devices	4	228	4	524
Electronic Computers	4	196	4	228
Engineering Management	1	56	2	132
Industrial Electronics	1	88	0	0
Information Theory	3	184	2	404
Instrumentation	1	188	1	60
Medical Electronics	2	104	0	0
Microwave Theory and Techniques	6	480	3	244
Nuclear Science	1	20	1	48
Reliability and Quality Control	1	60	2	104
Telemetry and Remote Control	3	72	2	56
Ultrasonics Engineering	1	76	2	116
Vehicular Communications	1	84	1	104
	56	3504	51	3714

IRE CONVENTION RECORD

The practice of publishing a CONVENTION RECORD containing papers presented at the IRE National Convention, begun in 1953, was continued. The 1955 CONVENTION RECORD, containing 236 papers and 31 abstracts totaling 1450 pages, was issued in ten Parts. Approximately 30,000 paid members of Professional Groups received free of charge a copy of that Part pertaining to the field of interest of his Group.

IRE STUDENT QUARTERLY

The IRE STUDENT QUARTERLY, begun in 1954, was issued 4 times in 1955 and totalled 156 pages. The publication is sent free to all IRE Student Members as part of a program of increased services to students.

IRE DIRECTORY

The 1955 IRE DIRECTORY was published in October, containing 976 pages including covers, of which 373 were membership listings and information, and 603 were advertisements and listings of manufacturers and products.

CONFERENCE PUBLICATIONS

Three conference publications, totaling 382 pages, were published by the Editorial Department for various Groups. These included the *Proceedings of the National Symposium on Quality Control and Reliability in Electronics*, *Proceedings of the Western Joint Computer Conference*, and *Proceedings of the Wescon Computer Sessions.*

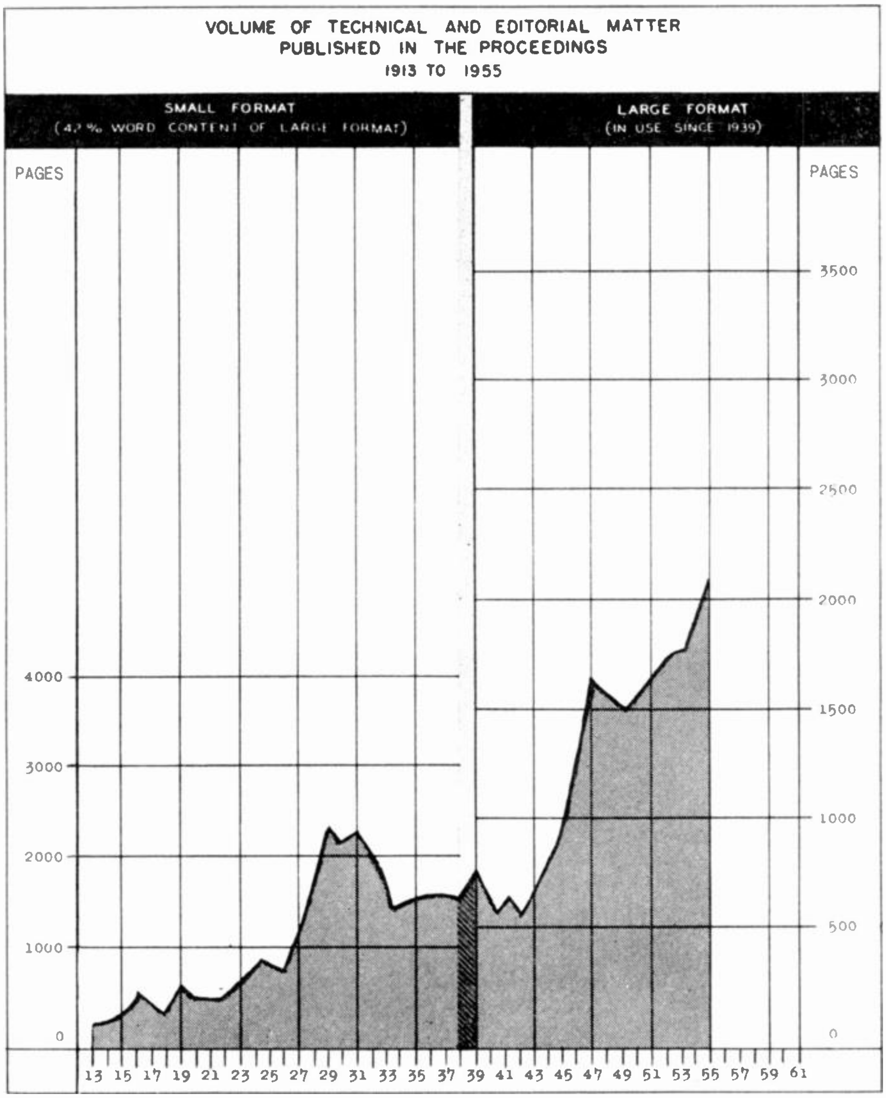

Fig. 2

Technical Activities

During the year 25 Technical Committees held 232 meetings, of which 215 were held at IRE Headquarters and 17 elsewhere.

The seven Standards listed herewith, having been approved by the Standards Committee and the IRE Board of Directors, were published in the PROCEEDINGS in 1955. Reprints are now available to the public.

May—

55 IRE 23. S1

Standards on Television: Definitions of Television Signal Measurement Terms, 1955.

June—

55 IRE 22. S1

Standards on Television: Definitions of Color Terms, 1955.

September—

55 IRE 2. S1

Standards on Antennas and Waveguides: Definitions for Waveguide Components, 1955.

September—

55 IRE 10. S1

Standards on Industrial Electronics: Definitions of Industrial Electronic Terms, 1955.

September—

55 IRE 17. S1

Standards on Radio Receivers: Methods of Testing Receivers Employing Ferrite Core Loop Antennas, 1955.

November—

55 IRE 26. S1

Standards on Graphical and Letter Symbols for Feedback Control Systems, 1955.

November—

55 IRE 15. S1

Standards on Pulses: Methods of Measurement of Pulse Quantities.

The following four Standards were approved by the Standards Committee in 1955 and will be published in the PROCEEDINGS early in 1956:

55 IRE 26. S2

Standard on Terminology for Feedback Control Systems

55 IRE 7. S1

Standards on Electron Devices: Definitions of Terms Related to Microwave Tubes (Klystrons, Magnetrons, and Traveling Wave Tubes).

55 IRE 7. S2

Standards on Electron Devices:

Definitions of Terms Related to Storage Tubes, 1955.
55 IRE 3. S1
Standards on Audio Systems and Components: Methods of Measurement: Gain Amplitude, Loss, Attenuation, Amplitude-Frequency Response.

IRE is directly represented on 29 committees of American Standards Association and sponsors two of them: the ASA Sectional Committee on Radio and Electronic Equipment, C16, and the ASA Sectional Committee on Sound Recording, Z57. One IRE Standard received approval of the American Standards Association as an American Standard in 1955, and is now available to international standards organizations.

IRE actively participated in international standardization in 1955 and was represented at the London meeting of the International Electrotechnical Commission in July, 1955.

Appointed IRE Delegates on Other Bodies

The IRE appointed delegates to a number of other bodies for a one-year period—May 1, 1955 to April 30, 1956 (as listed on page 845 of this issue).

The Annual Spring meeting of the International Scientific Radio Union (URSI) was held on May 2–5, 1955 at the National Bureau of Standards in Washington, D. C. It was co-sponsored by the following IRE Professional Groups: Antennas and Propagation, Circuit Theory, Instrumentation, and Microwave Theory and Techniques. The URSI Fall meeting was held on December 15–17, 1955 at the University of Florida, Gainesville.

Numerous responses to the questions under study by the various CCIR Study Groups have been received in IRE during 1955. A list of all material received from these organizations was distributed quarterly to the Chairmen of all Technical Committees, Professional Groups and Definitions and Measurement Subcommittees. During 1955 the Executive Committee of the U. S. Preparatory Committee of CCIR held 3 meetings and the 14 Study Groups held approximately 56 meetings.

The Joint Technical Advisory Committee

The Joint Technical Advisory Committee and its subcommittees held a total of 24 meetings in addition to the annual dinner.

Volume XII, the cumulative annual report of the JTAC Proceedings was published in 1955. This included in Section I—official correspondence between the Federal Communications Commission and the Joint Technical Advisory Committee (IRE-RETMA). Also included were other items of correspondence pertinent to the actions of the JTAC. Section II of the report contained approved Minutes of Meetings of the Joint Technical Advisory Committee for the period July 1, 1954 to June 30, 1955.

Two new subcommittees were formed by JTAC. The Subcommittee on Forward Scatter Propagation (55.1) was formed on February 24, 1955 for the purpose of reviewing and summarizing in form suitable for integrated publication, all available information relating to forward scatter propagation and to analyze the technical factors that relate to the most favorable integration of this form of propagation into the radio spectrum.

On May 26, 1955 a subcommittee on Spectrum Utilization (55.2) was formed to study the fundamental principles of frequency allocation with a view for better spectrum utilization.

The Study of Spurious Radio Emissions which the JTAC has been making since 1952 as a result of the Commission's request continued. Another report, "Spurious Radio Emission: the Technical Principles underlying Its Regulation in the Public Interest," prepared by the two JTAC Interference Subcommittees (52.2 and 54.1) was presented to the FCC Chairman. An analysis of a group of interference cases investigated by the Commission's staff was prepared by the JTAC Subcommittee. This report of the subcommittee, setting forth their conclusions, was approved by JTAC and transmitted to the FCC.

The JTAC Subcommittee on RF Interference from Arc Welders (54.2) submitted to JTAC an Interim Report on Consideration of Radiation from High Frequency Stabilized Arc Welders. This report was transmitted to the FCC Chairman. At the request of the FCC, JTAC also considered the FCC's Notice of Proposed Rule Making in the matter of the Commission's Docket No. 11467, FCC 55-835, 21512, and prepared comments to the questions in the docket. These comments were formulated on the basis of information received directly from representatives of the Joint Industry Committee on High Frequency Stabilized Arc Welders in several joint meetings. They resulted from several conferences in Washington, D. C. and at LaGuardia Airport, New York City. The latter meeting was attended by representatives of the FCC, the Civil Aeronautics Administration, the Air Transport Association, the American Airlines, as well as the electronic industry.

The International Electrotechnical Commission

IRE members were active in IEC Technical Committee 12 on Radio Communication, and Technical Subcommittee 12-1 on Measurements.

A list of all documents and material received in the Technical Department from the IEC was distributed to the Chairmen of all Professional Groups, Technical Committees and Subcommittees.

Professional Group System

General. There are 24 Professional Groups operating actively within the IRE. One new Group—the Professional Group on Military Electronics—was organized in 1955. Its scope covers the electronic sciences, systems, activities and services germane to the requirements of the Military. This Group has also undertaken to aid other Professional Groups in their liaison with and services to the Military through joint meetings and activities.

Approximately 50% of all IRE members have taken advantage of the Professional Group system which now has a total membership of 39,778. 2,074 Student Members of the IRE have joined the Groups at a special Student Member rate of $1 annually.

23 Groups have now levied publications assessments and 36,562 members have paid these assessments and are receiving the pertinent Group TRANSACTIONS regularly. In addition, a large number of company, university and public libraries have subscribed to the TRANSACTIONS of all the Groups and there is also a demand for individual Group subscriptions and individual copies of the TRANSACTIONS from outside sources.

In addition to supplementary financial and editorial assistance, the many services rendered by Headquarters to the Groups during 1955 included 763 mailings to Group members.

Symposiums. The procurement of papers and management of national symposia are now entirely in the hands of the Professional Groups. Each of the Groups had sponsored one or more technical meetings in the past year in addition to technical sessions at the IRE National Convention, the WESCON, the National Electronics Conference and other joint meetings, for a total of 91 meetings of national import in 1955.

Publications. 21 Groups are currently publishing IRE TRANSACTIONS covering their specific fields of interest and to date 167 issues (10,564 pages) have appeared. TRANSACTIONS were first published in 1951 when the Audio and Airborne Groups issued 6 TRANSACTIONS containing 98 pages. In 1952 10 Groups published 22 TRANSACTIONS containing 1474 pages. In 1953 15 Groups published 32 TRANSACTIONS containing 1798 pages. In 1954 20 Groups published 51 TRANSACTIONS containing 3714 pages. During the past year 21 Groups published 56 TRANSACTIONS containing approximately 3508 pages.

Twelve of the Groups are currently on a regularly stated publication schedule and the remaining Groups are working toward this goal. When this has been accomplished approximately 100 TRANSACTIONS issues per year will be published.

13 Groups' TRANSACTIONS are now printed by letterpress and the remaining Groups will follow this practice as soon as their circulation warrants it.

In addition to IRE TRANSACTIONS, several Groups are issuing Proceedings of meetings jointly sponsored with other societies, such as the Eastern and Western Joint Computer Conferences, the Electronic Components Conference, *et al.*

Professional Group Chapters. 146 Professional Group Chapters have been organized by Group members in 37 IRE Sections to date. Chapter growth is continuing at a healthy rate. The Chapters are meeting regularly and sponsoring meetings in the fields of interest of their associated Groups.

Section Activities

We were glad to welcome seven new Sections into the IRE during the past year. They are as follows: Alberta, Bay of Quinte, Egypt, Lubbock, Newfoundland, Northwest Florida, and Tokyo.

The total number of Sections is now 81. There has been a membership increase in 68 of the 81 Sections.

The Northwest Florida and Amarillo-Lubbock Subsections became full Sections in the year 1955. The Subsections of Sections now total 20. New ones in 1955: Fort Huachuca (Phoenix Section), Pasadena (Los Angeles Section), Piedmont (North Carolina-Virginia Section), Quebec (Montreal Section), and Westchester County (New York Section).

Student Branches, 1955

The number of Student Branches formed during 1955 was 9, 1 of which operates as an IRE Branch, and 8 of which operate as Joint IRE-AIEE Branches. The total number of Student Branches is now 130, 103 of which operate as Joint IRE-AIEE Branches.

Following is a list of the Student Branches formed during the year: Clemson College, University of Nevada, Norwich University, University of Oklahoma, Rice Institute, Rose Polytechnic Institute, Swarthmore College, U. S. Naval Postgraduate School, and State College of Washington.

IRE COMMITTEES—1956

Executive

A. V. Loughren, *Chairman*
W. R. G. Baker, *Vice-Chairman*
Haraden Pratt, *Secretary*

D. G. Fink
J. T. Henderson
A. G. Jensen
J. D. Ryder

Admissions

G. M. Rose, Jr., *Chairman*

H. S. Bennett
*T. M. Bloomer
*E. W. Borden
*H. A. Brown
C. M. Burrill
L. A. Byam, Jr.
L. J. Castriota
*W. E. Darnell
*E. T. Dickey
*J. S. Donal
E. E. Ecklund
*A. D. Emurian
*N. S. Freedman
*Jerome Fox
L. O. Goldstone
J. A. Hansen
F. S. Mabry
G. P. McCouch
*Andrew Mercier
H. G. Miller
*O. D. Perkins
*Harold Rapaport
W. L. Rehm
N. B. Ritchey
L. M. Rodgers
O. J. Sather
J. L. Sheldon
*W. B. Sullinger
*Richard Talpey
*Eugene Torgow
*J. G. Weissman

* Alternates.

Appointments

W. R. Hewlett, *Chairman*

C. R. Burrows
J. N. Dyer
J. J. Gershon
J. T. Henderson
A. V. Loughren
J. D. Ryder
D. J. Tucker

Awards

E. B. Ferrell, *Chairman*

Henri Busignies
R. M. Fano
L. R. Fink
D. E. Foster
A. V. Haeff
A. E. Harrison
H. E. Hartig
C. J. Hirsch
D. R. Hull
J. F. Jordan
J. E. Keto
C. N. Kimball
Urner Liddle
Garrard Mountjoy
A. B. Oxley
L. R. Quarles
George Sinclair
A. W. Straiton
W. L. Webb
H. W. Wells
E. M. Williams
Irving Wolff
H. A Zahl

Awards Coordination

W. M. Rust, Jr., *Chairman*

F. B. Llewellyn
A. V. Loughren

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F. J. Gaffney

25.2 DIELECTRIC MEASUREMENTS

J. L. Dalke, *Chairman*

C. A. Bieling
F. A. Muller

25.3 MAGNETIC MEASUREMENTS

C. D. Owens, *Chairman*

W. E. Cairnes
D. I. Gordon
P. H. Haas
R. C. Powell
J. H. Rowne
E. J. Smith

25.4 AUDIO-FREQUENCY MEASUREMENTS

A. P. G. Peterson, *Chairman*

R. Grim
R. A. Long

25.5 VIDEO FREQUENCY MEASUREMENTS

G. L. Fredendall, *Chairman*

J. F. Fisher
C. O. Marsh
H. A. Samulon
W. R. Thurston

25.6 HIGH FREQUENCY MEASUREMENTS

R. V. Lowman, *Chairman* Joint AIEE-IRE Committee High Frequency Measurements

G. B. Hoadley, *Chairman*, IRE Subcommittee 25.6

R. A. Braden
I. G. Easton
F. J. Gaffney
E. W. Houghton
D. Keim
B. M. Oliver
B. Parzen

25.8 INTERFERENCE MEASUREMENTS

R. M. Showers, *Chairman*

H. E. Dinger
C. W. Frick
F. M. Greene
A. W. Sullivan

25.9 MEASUREMENT OF RADIO ACTIVITY

G. A. Morton, *Chairman*

25.10 OSCILLOGRAPHY

M. J. Ackerman, *Chairman*

F. J. Bloom
W. G. Fockler
C. F. Fredericks
H. M. Joseph
G. R. Mezger (alternate)
T. B. Perkins
A. L. Stillwell
H. Vollum

25.13 TELEMETERING

W. J. Mayo-Wells, *Chairman*

J. L. Blackburn
J. F. Brinster
R. E. Colander
A. P. Bruer
R. L. Harding
C. H. Hoeppner
M. R. Kiebert
F. W. Lehan
E. E. Lynch
M. G. Pawley
W. E. Phillips
G. M. Thynell
F. L. Verwiebe
G. F. C. Weedon
W. A. Wildhack

25.14 ELECTRONIC COMPONENTS

J. G. Reid, Jr., *Chairman*

M. B. Carlton
G. B. Devey
J. W. Gruol
J. N. Hall
W. G. James
A. E. Javitz
J. H. Muncy
F. A. Paul
F. E. Wenger

16. MOBILE COMMUNICATION SYSTEMS

A. A. Macdonald, *Chairman*
W. A. Shipman, *Vice-Chairman*

N. Caplan
D. B. Harris
N. Monk
J. C. O'Brien
N. H. Shepherd
D. Talley
T. W. Tuttle
A. Whitney

12. NAVIGATION AIDS

H. R. Mimno, *Chairman*
W. Palmer, *Vice-Chairman*

C. M. Jansky, Jr.
H. I. Metz
A. G. Richardson
L. M. Sherer

12.2 STANDARD DF MEASUREMENTS

E. D. Blodgett, *Chairman*
J. Kaplan, *Vice-Chairman*
R. Silberstein, *Secretary*

A. D. Bailey
H. I. Butler
J. J. Kelleher
F. M. Kratokvil
A. A. Kunze
J. T. Lawrence
H. R. Mimno
W. M. Richardson
J. A. Solga
J. O. Spriggs
C. A. Strom, Jr.
S. R. Thrift
J. H. Trexler
H. W. von Dohlen

12.3 MEASUREMENT STANDARDS FOR NAVIGATION SYSTEMS

F. Moskowitz, *Chairman*
S. B. Fishbein, *Secretary*

P. Adams
R. Alexander
S. Anderson
R. Battle
S. D. Gurian
P. Hansel
G. Litchford
J. T. MacLemore
G. E. Merer
J. S. Pritchard
P. Ricketts
Abe Tatz
V. Weihe

13. NUCLEAR TECHNIQUES

G. A. Morton, *Chairman*

R. L. Butenhoff
D. L. Collins
D. C. Cook
Louis Costrell
T. R. Kohler
M. A. Schultz

14. PIEZOELECTRIC CRYSTALS

H. Jaffe, *Chairman*
P. L. Smith, *Vice-Chairman*

J. R. Anderson
H. G. Baerwald
R. Bechmann
W. G. Cady
A. I. Dranetz
W. A. Edson
I. E. Fair
W. D. George
E. Gerber
R. L. Harvey
E. D. Kennedy
W. P. Mason
R. A. Sykes
K. S. Van Dyke

27. RADIO FREQUENCY INTERFERENCE

R. M. Showers, *Chairman*
S. J. Burruano, *Vice-Chairman*

C. C. Chambers
J. F. Chappell
K. A. Chittick
L. E. Coffey
M. S. Corrington
E. W. Chapin
H. E. Dinger
E. C. Freeland
A. B. Glenn
J. A. Hansen
S. D. Hathaway
W. Mason
J. B. Minter
W. E. Pakala
D. W. Pugsley
D. Talley
H. G. Towlson
W. A. Shipman

27.1 BASIC MEASUREMENTS

M. S. Corrington, *Chairman*

S. J. Burruano
E. W. Chapin
H. E. Dinger
C. W. Frick
A. B. Glenn
F. M. Greene
W. R. Koch

TASK GROUP OF 27.1

E. O. Johnson, *Chairman*

E. W. Chapin
F. M. Greene
I. K. Munson

27.2 DEFINITIONS

W. Mason, *Chairman*

C. W. Frick

27.3 RADIO AND TV RECEIVERS

A. B. Glenn, *Chairman*

Z. Atlas
A. Augustine
D. L. Carpenter
E. W. Chapin
M. S. Corrington
T. Cuniff
R. J. Farber
A. M. Intrator
E. O. Johnson
W. R. Koch
P. Pan
C. G. Seright
P. Simpson
W. S. Skidmore
J. W. Stratman
D. Thomas
R. S. Yoder

27.4 RADIO TRANSMITTERS

27.5 INDUSTRIAL ELECTRONICS

S. J. Burruano, *Chairman*

27.6 RECORDING EQUIPMENT

M. S. Corrington, *Acting Chairman*

27.7 MOBILE COMMUNICATIONS EQUIPMENT

W. Shipman, *Chairman*

27.8 CARRIER CURRENT EQUIPMENT

27.9 COMMUNITY ANTENNAS

27.10 TEST EQUIPMENT

J. B. Minter, *Chairman*

27.11 ATMOSPHERICS

H. E. Dinger, *Chairman*

E. W. Chapin
W. O. Critchlow
F. H. Dickson
M. M. Newman
A. W. Sullivan

17. RADIO RECEIVERS

D. E. Harnett, *Chairman*
W. O. Swinyard, *Vice-Chairman*

K. A. Chittick
L. E. Closson
D. J. Healey III
K. W. Jarvis
J. K. Johnson
W. R. Koch
I. J. Melman
G. Mountjoy
F. R. Norton
L. Riebman
J. D. Reid
L. M. Rodgers
S. W. Seeley
F. B. Uphoff
R. S. Yoder

17.8 TELEVISION RECEIVERS

W. O. Swinyard, *Chairman*

W. R. Alexander
J. Avins
J. Bell
C. E. Dean
E. Floyd
E. C. Freeland
W. J. Gruen
W. R. Koch
C. O. Marsh
I. J. Melman
B. S. Parmet
E. Pufahl
G. F. Rogers
S. P. Ronzheimer

17.10 AUTOMATIC FREQUENCY AND PHASE CONTROL

F. B. Uphoff, *Chairman*

R. Davies
K. Farr
W. J. Gruen
W. R. Koch
R. N. Rhodes
D. Richman
L. Riebman

15. RADIO TRANSMITTERS

H. Goldberg, *Chairman*
A. E. Kerwien, *Vice-Chairman*

J. H. Battison
M. R. Briggs
A. Brown
H. R. Butler
T. Clark
W. R. Donsbach
L. K. Findley
H. E. Goldstine
F. B. Gunter
R. N. Harmon
J. B. Heffelfinger
P. J. Herbst
L. A. Looney
J. F. McDonald
S. M. Morrison
J. Ruston
G. W. Sellers
B. Sheffield
B. D. Smith
V. E. Trouant
I. R. Weir
V. Ziemelis
M. G. Staton

15.1 FM TRANSMITTERS

J. Ruston, *Chairman*

J. Bose
J. R. Boykin
N. Marchand
P. Osborne
H. P. Thomas

15.2 RADIO-TELEGRAPH TRANSMITTERS UP TO 50 MC

H. R. Butler, *Chairman*

J. L. Finch
J. F. McDonald
F. D. Webster
I. R. Weir

15.3 DOUBLE SIDEBAND AM TRANSMITTERS

J. B. Heffelfinger, *Chairman*

R. B. Beetham
W. T. Bishop, Jr.
L. K. Findley
D. H. Hax
L. A. Looney
E. J. Martin, Jr.

15.4 PULSE-MODULATED TRANSMITTERS

B. D. Smith, *Chairman*

R. Bateman
L. V. Blake
L. L. Bonham
H. Goldberg
G. F. Montgomery
W. K. Roberts

15.5 SINGLE SIDEBAND RADIO COMMUNICATION TRANSMITTERS

Adamant Brown, *Chairman*

W. B. Bruene
J. P. Costas
H. E. Goldstine
L. Kahn
A. E. Kerwien
E. A. Laport
J. B. Singel

15.6 TELEVISION BROADCAST TRANSMITTERS

R. N. Harmon, *Chairman*

E. Bradburd
W. F. Goetter
L. A. Looney
J. Ruston
F. E. Talmage

19. RECORDING AND REPRODUCING

D. E. Maxwell, *Chairman*

S. J. Begun
M. Camras
F. A. Comerci
E. W. D'Arcy
S. M. Fairchild
R. M. Fraser
A. W. Friend
C. J. LeBel
R. C. Moyer
C. B. Pear
H. E. Roys
L. Thompson
T. G. Veal
R. A. VonBehren
C. F. West

19.1 MAGNETIC RECORDING

R. C. Moyer, *Chairman*

J. S. Boyers
M. Camras
F. A. Comerci
E. W. D'Arcy
W. H. Ericson
O. Kornei
K. I. Lichti
C. B. Pear
E. Schmidt
W. T. Selsted
R. A. VonBehren

19.2 MECHANICAL RECORDING

L. Thompson, *Chairman*

W. S. Bachman
S. M. Fairchild
A. R. Morgan
R. C. Moyer
F. W. Roberts
M. F. Royston
R. A. Schlegel
A. S. R. Tobey

19.3 OPTICAL RECORDING

T. G. Veal, *Chairman*

P. Fish
R. M. Fraser
J. A. Maurer
E. Miller
C. Townsend

19.5 FLUTTER

H. E. Roys, *Chairman*

F. A. Comerci
S. M. Fairchild
U. Furst
C. J. LeBel

CCIR LIAISON GROUP OF IRE COMMITTEE 19

H. E. Roys, *Chairman* (*Representative*)
A. W. Friend (*Alternate*)

W. S. Bachman
R. M. Fraser
R. C. Moyer
L. Thompson

28. SOLID STATE DEVICES

H. L. Owens, *Chairman*
R. R. Law, *Vice-Chairman*
V. P. Mathis, *Secretary*

A. E. Anderson
J. B. Angell
S. J. Angello
Abraham Coblenz

L. Davis, Jr.
J. M. Early
J. J. Ebers
H. Epstein
R. S. Fallows
J. R. Flegal
H. Goldberg
J. R. Hyneman
J. P. Jordan
N. R. Kornfield
A. W. Lampe
J. R. MacDonald
L. T. MacGill
W. J. Mayo-Wells
C. W. Mueller
W. J. Pietenpol
R. L. Pritchard
J. R. Roeder
C. A. Rosen
B. J. Rothlein
R. M. Ryder
J. Saby
B. R. Shepard
S. Sherr
C. F. Spitzer
W. M. Webster

28.4 SEMICONDUCTOR DEVICES

S. J. Angello, *Chairman* (AIEE)
J. M. Early, *Chairman* (IRE)

J. B. Angell
R. L. Bright
A. C. Clarke
A. Coblenz
W. H. Lapham
R. M. LeLacheur
B. R. Lester
L. T. MacGill
H. T. Mooers
C. W. Mueller
R. L. Pritchard
K. A. Pullen, Jr.
B. J. Rothlein
J. Saby
H. N. Sachar
A. C. Sheckler
A. P. Stern
W. J. Mayo-Wells

28.4.1 DIODES

28.4.2 METHODS OF TEST FOR TRANSISTORS FOR LINEAR CW TRANSMISSION SERVICE

A. Coblenz, *Chairman*

28.4.3 DEFINITIONS OF SEMICONDUCTORS

B. J. Rothlein, *Chairman*

28.4.4 METHODS OF TEST FOR SEMICONDUCTOR DEVICES FOR LARGE-SIGNAL APPLICATIONS

W. H. Lapham, *Chairman*

A. W. Berger
C. Huang
R. M. LeLacheur
R. L. Trent
R. L. Wooley

28.4.5 METHODS OF TEST FOR BULK SEMICONDUCTORS

B. J. Rothlein, *Chairman*

E. N. Clarke
D. C. Cronemeyer
I. Drukaroff
J. R. Haynes
A. Kestenbaum
M. F. Lamorte
K. W. Uhler

28.4.6 PHOTO DEVICES

28.4.7 TRANSISTOR INTERNAL PARAMETERS

R. L. Pritchard, *Chairman*

J. B. Angell
J. M. Early
W. M. Webster

28.5 DIELECTRIC DEVICES

Dr. H. Epstein, *Co-Chairman* (AIEE)
C. A. Rosen, *Co-Chairman* (IRE)

J. H. Armstrong
H. Diamond
L. A. Finzi
F. P. Hall
S. R. Hoh
N. R. Kornfield
H. I. Oshry
C. Pulvari
N. Rudwick
E. A. Sack
B. R. Shepard
C. F. Spitzer

28.6 MAGNETIC DEVICES

J. A. Hornbeck, *Chairman* (IRE)

H. W. Welch, Jr., *Chairman* (AIEE)

A. Applebaum
D. R. Brown
T. H. Crowley
R. L. Harvey
M. L. Kales
C. A. Maynard
T. R. McGuire
J. A. Osborn
J. A. Rajchman
J. B. Russell
H. F. Storm
V. C. Wilson

21. SYMBOLS

H. R. Terhune, *Chairman*
R. T. Haviland, *Vice-Chairman*

E. W. Borden
D. C. Bowen
M. C. Cisler
W. A. Ford
I. L. Marin
C. D. Mitchell
C. Neitzert
M. B. Reed
A. C. Reynolds, Jr.
M. P. Robinson
M. S. Smith
R. M. Stern
H. P. Westman

21.3 FUNCTIONAL REPRESENTATION OF CONTROL, COMPUTING AND SWITCHING EQUIPMENT

A. C. Reynolds, Jr., *Chairman*

T. G. Cober
C. W. Frank
H. F. Herbig
W. S. Humphrey, Jr.
H. P. Kraatz
F. T. Meyer
E. W. Olcott
J. S. Osborne
T. J. Reilly

21.5 NEW PROPOSALS AND SPECIAL ASSIGNMENTS

M. P. Robinson, *Chairman*

21.7 LETTER SYMBOLS

C. Neitzert, *Chairman*

M. C. Cisler
G. A. Deschamps
D. C. Livingston
R. M. Stern
C. F. Rehberg

22. TELEVISION SYSTEMS

W. T. Wintringham, *Chairman*
W. F. Bailey, *Vice-Chairman*

M. W. Baldwin, Jr.
J. E. Brown
K. A. Chittick
C. G. Fick
D. G. Fink
P. C. Goldmark
R. N. Harmon
J. E. Hayes
J. L. Hollis
A. G. Jensen
I. J. Kaar
R. D. Kell
D. C. Livingston
H. T. Lyman
L. Mautner
J. Minter
A. F. Murray
D. W. Pugsley
D. B. Smith
M. E. Strieby

22.2 TELEVISION PICTURE ELEMENT

D. C. Livingston, *Chairman*

A. V. Bedford
J. B. Chatten
P. W. Howells
P. Mertz

23. VIDEO TECHNIQUES

J. L. Jones, *Chairman*
S. Doba, Jr., *Vice-Chairman*

S. W. Athey
A. J. Baracket
J. M. Barstow
J. H. Battison
E. E. Benham
K. B. Benson
E. M. Coan
J. R. DeBaun
V. J. Duke
G. L. Fredendall
J. R. Hefele
C. G. Pierce
W. J. Poch
H. O. Saunders

23.1 DEFINITIONS

G. L. Fredendall, *Chairman*

I. C. Abrham
R. F. Cotellessa
S. Deutsch
W. C. Espenlaub

23.2 UTILIZATION, INCLUDING VIDEO RECORDING: METHODS OF MEASUREMENT

S. W. Athey, *Chairman*

K. B. Benson
J. M. Brumbaugh
V. J. Duke
G. Gordon

23.3 VIDEO SYSTEMS AND COMPONENTS METHODS OF MEASUREMENT

J. R. Hefele, *Chairman*

I. C. Abrahams
G. M. Glassford
A. Lind
N. E. Sprecher
E. Stein
W. B. Whalley

23.4 VIDEO SIGNAL TRANSMISSION: METHODS OF MEASUREMENT

J. M. Barstow, *Chairman*

K. B. Benson
R. I. Brown
R. D. Chipp (Alternate for R. I. Brown)
M. H. Diehl
E. E. Gloystein
H. P. Kelly
R. S. O'Brien (Alternate for K. B. Benson)
R. M. Morris
J. R. Popkin-Clurman
E. B. Pores
E. H. Schreiber
L. Staschover
J. W. Wentworth

24. WAVE PROPAGATION

M. G. Morgan, *Chairman*

E. W. Allen, Jr.
H. G. Booker
K. Bullington
C. R. Burrows
T. J. Carroll
J. T. deBettencourt
J. H. Dellinger
F. H. Dickson
H. E. Dinger
I. H. Gerks
M. Katzin
R. C. Kirby
M. Kline
L. A. Manning
H. R. Mimno
R. K. Moore
K. A. Norton
H. O. Peterson
J. A. Pierce
G. Sinclair
J. C. W. Scott
R. J. Slutz
N. Smith
R. L. Smith-Rose
J. B. Smyth
H. Staras
A. W. Straiton
A. H. Waynick

24.1 STANDARD PRACTICES

H. O. Peterson, *Chairman*

24.2 THEORY AND APPLICATION OF TROPOSPHERIC PROPAGATION

T. Carroll, *Chairman*

24.3 THEORY AND APPLICATION OF IONOSPHERIC PROPAGATION

M. G. Morgan, *Chairman*

24.4 DEFINITIONS AND PUBLICATIONS

H. Staras, *Chairman*

24.6 RADIO ASTRONOMY

C. R. Burrows, *Chairman*

A. E. Covington
F. T. Haddock, Jr.
J. P. Hagen

24.7 TERRESTRIAL RADIO NOISE

H. Dinger, *Chairman*

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*Agricultural and Mechanical College of Texas: H. C. Dillingham
*Akron, Univ. of: P. C. Smith
*Alabama Polytechnic Institute: H. E. O'Kelley
Alabama, Univ. of: P. H. Nelson
Alaska, Univ. of: R. P. Merritt
*Alberta, Univ. of: J. W. Porteous
Arizona State College: C. H. Merritt
*Arizona, Univ. of: H. E. Stewart
*Arkansas, Univ. of: W. W. Cannon
Augustana College: V. R. Nelson
*British Columbia, Univ. of: A. D. Moore
*Polytech. Inst. of Bklyn. (Day Div.): M. V. Joyce
*Polytech. Inst. of Bklyn. (Eve. Div.): G. J. Kent
Brooklyn College: E. H. Green
*Brown Univ.: C. M. Angulo
*Bucknell Univ.: R. H. Young
Buffalo, Univ. of: W. Greatbatch
*Calif. Institute of Technology: H. C. Martel
*Calif. State Polytech. College: H. Hendriks
*Calif., University of: H. J. Scott
California, Univ. of at L.A.: W. L. Flock
Capitol Radio Eng's. Institute: L. M. Upchurch, Jr.
*Carnegie Institute of Technology: J. B. Woodford, Jr.
*Case Institute of Technology: J. R. Martin
Catholic University of America: G. E. McDuffie, Jr.
Central Technical Institute: J. E. Lovan
*Cincinnati, Univ. of: A. B. Bereskin
*Clarkson College of Tech.: R. J. Reich
*Clemson Agricultural College: L. C. Adams
*Colorado Agri. and Mech. College: C. C. Britton
*Colorado, Univ. of: W. G. Worchester
*Columbia University: P. Mauzey
*Connecticut, Univ. of: J. L. C. Lof
*Cooper Union School of Eng'g.: J. B. Sherman
*Cornell University: T. McLean
Dartmouth College: M. G. Morgan
*Dayton, Univ. of: L. H. Rose
*Delaware, Univ. of: H. S. Bueche
*Denver, Univ. of: R. C. Webb
*Detroit, Univ. of: G. M. Chute
Devry Technical Institute: W. B. McClelland
*Drexel Inst. of Technology: R. T. Zern
Duke University: H. A. Owen, Jr.
*Fenn College: K. S. Sherman
*Florida, Univ. of: M. H. Latour
*George Washington Univ.: G. Abraham
*Georgia Institute of Technology: B. J. Dasher
Gonzaga University: H. J. Webb
Harvard University: C. L. Hogan
Hofstra College: B. Zeines
Houston, Univ. of: T. N. Whitaker
Idaho, Univ. of: L. B. Craine
*Illinois Inst. of Technology: G. T. Flesher
*Illinois, Univ. of: P. F. Schwarzlose
Instituto Tecnologico de Aeronautica: D. K. Reynolds
*Iowa State College: G. A. Richardson
*Iowa, State Univ. of: E. M. Lonsdale
*John Carroll University: Appointment later
*Johns Hopkins University: W. H. Huggins
*Kansas State College: W. R. Ford
*Kansas, Univ. of: D. Rummer
*Kentucky, Univ. of: N. B. Allison
*Lafayette College: F. W. Smith
Lamar State College of Tech.: L. Cherry
*Laval University: J. E. Dumas
*Lehigh University: H. T. MacFarland
Louisiana Polytechnic Inst.: D. L. Johnson
*Louisiana State Univ.: L. V. McLean
*Louisville, Univ. of: S. T. Fife
Lowell Technological Inst.: C. A. Stevens
Loyola University: J. H. Battocletti
*Maine, Univ. of: C. Blake
*Manhattan College: C. J. Nisteruk
Manitoba, Univ. of: H. Haakonsen
*Marquette University: E. W. Kane
*Maryland, Univ. of: H. W. Price
*Mass. Institute of Technology: J. F. Reintjes
*Mass., University of: J. W. Langford
McGill University: F. S. Howes
*Miami, Univ. of: F. B. Lucas
*Michigan College of Mining and Tech.: R. J. Jones
*Michigan State University: I. O. Ebert
*Michigan, Univ. of: J. F. Cline
Milwaukee School of Eng'g: W. A. Van Zeeland
*Minnesota, Univ. of: L. Anderson
*Mississippi State College: D. E. Fisher
*Missouri School of Mines and Metallurgy, University of: R. E. Nolte
*Missouri, University of: J. C. Hogan
*Montana State College: R. C. Seibel
*Nebraska, Univ. of: C. W. Rook
*Nevada, Univ. of: W. Garrott
*Newark College of Eng'g.: D. W. Dickey
*New Hampshire, Univ. of: F. A. Blanchard
*New Mexico College of Agriculture and Mechanic Arts: H. A. Brown
*New Mexico, Univ. of: R. K. Moore
*New York, College of the City: H. Wolf
*New York University (Day Div.): S. Shamis
*New York University (Eve. Div.): S. Shamis
*North Carolina State College: E. G. Manning
*North Dakota Agricultural College: E. M. Anderson
*North Dakota, University of: C. Thomforde
*Northeastern University: J. S. Rochefort
*Northwestern University: C. W. McMullen
*Norwich University: R. F. Marsh
*Notre Dame, Univ. of: C. Hoffman
*Oberlin College: C. E. Howe
*Ohio State University: C. E. Warren
*Ohio University: D. B. Green
*Oklahoma Agri. and Mech. College: H. T. Fristoe
*Oklahoma Inst. of Technology: H. T. Fristoe
*Oklahoma, Univ. of: C. E. Harp
*Oregon State College: A. L. Albert
Ottawa University: L. A. Beauchesne
Pacific Union College: I. R. Neilsen
*Pennsylvania State University: H. J. Nearhoof
*Pennsylvania, University of: E. I. Hawthorne
*Pittsburgh, University of: J. Brinda, Jr.
*Pratt Institute: D. Vitrogan
*Princeton University: J. B. Thomas
Puerto Rico, Universidad de: J. L. Garcia de Quevedo
*Purdue University: W. H. Hayt, Jr.
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NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these pages, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, not to the IRE.

The Index to the Abstracts and References published in the PROC. IRE from February, 1955 through January, 1956 is published by the PROC. IRE, June, 1956, Part II. It is also published by *Wireless Engineer* and included in the March, 1956 issue of that journal. Included with the Index is a selected list of journals scanned for abstracting with publishers' addresses.

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ACOUSTICS AND AUDIO FREQUENCIES

534.014.5+538.56.029.1 **1269**

Subharmonic Oscillations in a Nonlinear System with Positive Damping—S. Lundquist. (*Quart. appl. Math.*, vol. 13, pp. 305–310; October, 1955.)

534.121.2 **1270**

Study of the Thin Layer of Air between a Circular Diaphragm and a Plane Electrode—C. Colin. (*J. Phys. Radium*, vol. 16, pp. 863–873; November, 1955.) An experimental investigation was made using an electromechanical system with the diaphragm arranged between two symmetrically placed electrodes. The frequency variation of the transfer function of the transfer function of the equivalent quadripole network is analyzed; a complex frequency is introduced.

534.13 **1271**

On Axi-symmetrical Vibrations of Shallow Spherical Shells—E. Reissner. (*Quart. appl. Math.*, vol. 13, pp. 279–290; October, 1955.)

534.2 **1272**

Do Sound Waves possess Momentum?—W. Brenig. (*Z. Phys.*, vol. 143, pp. 168–172; November 18, 1955.) Theory based on interaction with material indicates that sound waves have a momentum $p=\epsilon/C$, where ϵ is the energy and C the velocity of sound.

534.2 **1273**

Reflection and Transmission of Sound by a Moving Medium—J. B. Keller. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1044–1047; November, 1955.) Analysis shows that the reflection and transmission coefficients depend only on that component of the velocity of the medium which lies in the plane of incidence. Total reflection occurs over a range of values of this velocity.

534.2 **1274**

Propagation of Sound in Thin Elastic Shells—J. E. Young. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1061–1064; November, 1955.) Analysis leads to an expression for the axial propagation constant for a steel shell surrounding a column of air; only the lowest symmetric mode is discussed.

534.2 **1275**

Phase Velocities and Displacement Characteristics of Free Waves in a Thin Cylindrical Shell—P. W. Smith, Jr. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1065–1072; November, 1955.) Analysis is presented covering all possible modes of propagation of elastic waves in the shell. Standing, axially progressive, and helically progressive waves are identified.

534.2-14 **1276**

Notes on the Exact Equations governing the Propagation of Sound in Fluids—F. V. Hunt. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1019–1039; November, 1955.)

534.2-14 **1277**

Fluctuations in Intensity of Short Pulses of 14.5-kc/s Sound received from a Source in the Sea—F. H. Sagar. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1092–1106; November, 1955.) Report of an extensive experimental investigation carried out off the coast of New Zealand, in which resolution of pulses arriving by direct and indirect paths was achieved. The pulse duration was 1.3 ms and the transmission range was 70–500 yards. The observed fluctuation, expressed as a "variation coefficient" was 6.8 per cent–10.6 per cent for sea state 0 and 10.1 per cent–12.5 per cent for sea state 3.

534.2-8-14 **1278**

Swelling of a Liquid Surface under the influence of Ultrasonic Radiation—M. Kornfel'd and N. Molokhova. (*C.R. Acad. Sci. U.R.S.S.*, vol. 105, pp. 476–477; November 21, 1955. In Russian.) The experimentally determined relation between the ultrasonic energy density E, surface tension σ, the rise h of the liquid level, and the radius r of the swelling (equal to the quartz transducer) is given by $E=2\sigma h/r^2$.

534.213.4 **1279**

Heat Conduction Losses in the Acoustic Boundary Layer—J. E. Young. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1039–1043; November, 1955.) "The attenuation resulting from heat conduction of the quasi-plane mode in a cylindrical conduit is discussed in the high-frequency (narrow boundary layer) limit. The heat conduction part of the Kirchhoff losses is derived by means of a volume integral whose physical interpretation can be given."

534.232 **1280**

On the Efficiency of an Acoustic Line Source with Progressive Phase Shift—G. J. Thiessen. (*Canad. J. Phys.*, vol. 33, pp. 618–621; November, 1955.) Analysis indicates that the radiated energy is not reduced in consequence of a phase variation along a line source unless the rate of the variation is comparable to that in the propagated wave.

534.232 **1281**

Directional Properties of Continuous Plane Radiators with Bizonal Amplitude Shading—G. E. Martin and J. S. Hickman. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1120–1127; November, 1955.) The problem of reducing the levels of the minor lobes of linear, rectangular, and circular radiators is considered theoretically. The shading is accomplished by using equiphase normal-velocity distributions limited to two discrete amplitudes. Linear and rectangular radiators with such amplitude distributions can be designed so that minor-lobe levels are at least 21 db below the major-lobe level; the corresponding figure for the circular radiator is 25 db. The results are useful for the design of transducers.

534.232-8:549.514.51 **1282**

The Resonance Enhancement of Ultrasonic Quartz Crystals—G. Bolz. (*Z. angew. Phys.*, vol. 7, pp. 514–516; November, 1955.) The investigations described previously (2115 of 1950) are supplemented by measurements of the current generated by crystals of different thickness excited by an ultrasonic field of frequency constant at 2.04 mc. Values of radiation resistance deduced from these measurements are in good agreement with values derived from the approximate formula presented previously.

534.3+621.395.623.7 **1283**

Fundamental Acoustics of Electronic Organ Tone Radiation—D. W. Martin. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1113–1119; November, 1955.) The design of tone chambers and loudspeaker systems for electronic-organ installations in various types of auditoriums are discussed.

534.6 **1284**

Measurement of Correlation Coefficients in Reverberant Sound Fields—R. K. Cook, R. V. Waterhouse, R. D. Berendt, S. Edelman, and M. C. Thompson, Jr. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1072–1077; November, 1955.) A cross-correlation coefficient R is used as a criterion of randomness in the sound field; in a completely random field, $R=(\sin kr)/kr$, where $k=2\pi/\lambda$ and r is the distance between two points. An instrument for recording time variations of *R* is described and some measurements made in the 15,000-foot^3 reverberation chamber at the National Bureau of Standards are reported.

534.614–14 1285

Fixed Path, Variable Frequency Acoustic Interferometer—H. I. Leon. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1107–1112; November, 1955.) Equivalent-network analysis is presented for an interferometer comprising two crystals arranged parallel to one another, one serving as ultrasonic source and the other as fixed reflector. Measurements of the velocity of propagation in water over the frequency range 600–800 kc yield a value 1,496.8 ±0.3 mps at 25°C, with a temperature coefficient +2.7 mps per °C.

534.64+621.3.012.11:534 1286

Circle Diagram for Acoustics—B. Klimes. (Slab. Obz., Prague, vol. 16, pp. P37–P42; October, 1955.) An acoustic-impedance calculator based on a modified Smith chart is described in detail. Examples are given illustrating the applications and the method of using the calculator which comprises a specially graduated ruler and a Smith chart plotted partly on a base sheet and partly on a superposed transparent sheet. Six parameters are used.

534.75 1287

Improvements in Message Reception resulting from "sequencing" Competing Messages—J. C. Webster and L. Sharpe. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1194–1198; November, 1955.)

534.75 1288

Effects of Response Complexity upon listening to Competing Messages—J. C. Webster and L. N. Solomon. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1199–1203; November, 1955.)

534.75:534.78 1289

Relative Intelligibility of Speech Recorded Simultaneously at the Ear and Mouth—H. J. Oyer. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1207–1212; November, 1955.) "Monosyllabic words recorded at the lips and left ears of six speakers were fed to the headsets of 24 trained listeners at −12, −15, and −18 snr. Although the trend for intelligibility scores throughout the test is in the same direction for signals of both origins, decreasing snr is more destructive to the speech picked up at the lips."

534.75:534.78 1290

Effects of Training on Listeners in Intelligibility Studies—H. M. Moser and J. J. Dreher. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1213–1219; November, 1955.) Experimental evidence indicates that listener training has a great effect on the results in intelligibility studies.

534.781:621.376.5 1291

Laboratory Equipment for Quantizing Speech—Allen. (See 1540.)

534.79 1292

Rating Scale Method for Comparative Loudness Measurements—W. C. Michels and B. T. Doser. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1173–1180; November, 1955.)

534.84 1293

Study of Acoustical Requirements for Teaching Studios and Practice Rooms in Music School Buildings—R. N. Lane and E. E. Mikeska. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1087–1091; November, 1955.)

534.845:677.64 1294

Acoustical Properties of Carpet—C. M. Harris. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1077–1082; November, 1955.) Absorption measurements by the tube method were made on several hundred samples of different types of carpet; flow-resistance was also measured. Absorption measurements on some of the samples were also made by the reverberation-chamber method; no simple relation is found between the results by the two different methods.

534.861:621.396.712 1295

Design of Studios for Small Broadcasting Stations—R. F. Goodsman. (*J. Brit. IRE*, vol. 16, pp. 5–28; January, 1956.) "Practical considerations in the siting, design, and construction of studio buildings are given and methods of making studios and associated control rooms acoustically suitable are discussed. Reference is made to the studio building of the Trinidad Broadcasting Company, which incorporates one large, two medium, and two small studios. The equipment and circuit facilities provided in these studios and in the central control room are described."

621.395.616:534.61:621.3.089.6 1296

Probe Microphone Analysis and Testing at High Temperatures and High Intensities—K. W. Goff and D. M. A. Mercer. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1133–1141; November, 1955.) Description of methods for testing a microphone system for measuring sound fields inside wind tunnels etc.

621.395.623.64+534.833 1297

Design and Testing of Earmuffs—J. Zwislocki. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1154–1163; November, 1955.) An estimate is made of the greatest attenuation that can be obtained without sacrificing comfort. The desirability of incorporating Helmholtz resonators in the design is discussed. Some subjective experiments of the sound attenuation produced by two different designs are described and the results analyzed statistically.

621.395.623.743 1298

Design and Performance of a High-Frequency Electrostatic Speaker—L. Bobb, R. B. Goldman, and R. W. Roop. (*J. acoust. Soc. Amer.*, vol. 27, pp. 1128–1133; November, 1955.) The loudspeaker described has a diaphragm consisting of a thin polyester film covered with an evaporated gold layer, stretched around a semicylindrical ridged perforated electrode. The response varies $< \pm 2$ db over the frequency range 8–16 kc.

ANTENNAS AND TRANSMISSION LINES

621.372.5.029.6:535.5 1299

Polarization Filters and Polarization Correctors—G. Valensi. (*Ann. Télécommun.*, vol. 10, pp. 230–236; November, 1955.) Technique involving use of pleochroic crystals, familiar at optical frequencies, is adapted to the microwave region of the spectrum by using "artificial crystals" comprising metal bodies regularly spaced in low-loss dielectrics. Results are reported of experiments with wire dipoles embedded in polystyrol plates arranged in a stack between radiating and receiving horns; reflection/frequency characteristics are plotted for different dipole orientations. Applications are briefly indicated

621.372.8 1300

On Transients in Wave Guides—R. Gajewski. (*Bull. Acad. polon. Sci., Class* **4**, vol. 3, pp. 29–34; 1955. In English.) An analysis is made of the field variation during the interval between the arrival at a point in the waveguide of the forerunner and the main wave. The results are plotted as field-strength/time curves for a point 30 cm from the input of a waveguide with cutoff wavelength 6.28 cm and an applied signal of free-space wavelength 5 cm. During the interval examined, the "frequency" changes rapidly, and a small but not negligible amount of energy is transferred.

621.372.8 1301

Diaphragms in Waveguides—L. A. Vainshtein. (*Zh. tekh. Fiz.*, vol. 25, pp. 841–846; May, 1955.) A rigorous mathematical analysis is presented of the conditions in a rectangular waveguide, half of the cross section of which is occupied by an asymmetrical diaphragm (inductive or capacitative). The exact results so obtained are compared with previously published approximate data.

621.372.8 1302

On the Resonance Frequencies and the Field Configurations in Terminated Corrugated Waveguides—V. J. Vanhuyse. (*Physica*, vol. 21, pp. 829–838; October, 1955.) Generalization of analysis presented previously (2836 of 1955).

621.372.8:621.372.54 1303

The Polarguide—a Constant-Resistance Waveguide Filter—Klopfenstein and Epstein. (See 1330.)

621.396.67.029.53 1304

Standardised Transmitting Aerials for Medium-Frequency Broadcasting—S. F. Brownless. (*Proc. IRE, Aust.*, vol. 16, pp. 383–396; November, 1955.) "The [Australian] Postmaster-General's Department has developed a range of antenna systems suitable for National Broadcasting Service transmitting stations of powers from 200 watts to 50 kilowatts in the frequency range 540–1,600 kc. The antenna systems fall into two classes: "high" antennas having special antifading properties, usually near half-a-wavelength in height, and "low" antennas less than a quarter-wavelength in height. This paper traces the development of the designs, with special emphasis on low antenna systems suitable for construction by Departmental staff. Here the application of practices well-established at vhf leads to structures believed to be novel for mf broadcasting. Charts and diagrams are given from which antenna structures suitable for any particular application may be readily selected."

621.396.674.33 1305

Broadband Antenna for Field-Intensity Meters—E. N. Singer and H. R. Caler. (*Electronics*, vol. 29, pp. 130–131; February, 1956.) Brief details are given of a skeleton biconical closed-end antenna which can be used without readjustment over a 1:4.5 frequency range; *e.g.*, 88–400 mc. The design of the associated balun is also described.

621.396.677 1306

Endfire Slot Antennas—B. T. Stephenson and C. H. Walter. (TRANS. IRE, vol. AP-3, pp. 81–86; April, 1955.) Design theory is discussed. Discontinuities in the waveguide system are minimized by use of tapering sections and dielectric fillings; wide-band characteristics are obtained by the use of wide aperture slots. A flared slot antenna tested over the 3–6-cm band gave side lobes at least 20 db down, with a radiation efficiency ranging from 65 per cent at 3-cm λ to 55 per cent at 6-cm λ, the discontinuity minimizing device causing a 25 per cent drop in efficiency; the voltage swr was <1.4.

621.396.677.3.029.62 1307

Multiple Tuning in TV Antenna Design—J. F. Guernsey. (*Radio and Telev. News*, vol. 54, pp. 91–92, 94; October, 1955.) Use of the "wing" dipole in a Yagi array gives good performance over bands I and III. A typical array using three wing dipoles has ten parasitic and nine active elements stagger-tuned to give flat response throughout the ranges.

621.396.677.32 1308

A Nonresonant Endfire Array for V.H.F. and U.H.F.—W. A. Cummings. (TRANS. IRE, vol. AP-3, pp. 52–58; April, 1955.) A development of the helical antenna [1860 of 1949 (Kraus)] using rectilinear elements and giving linear polarization is described. A balanced array has been constructed which provides a gain of 6–10 db above a simple dipole over a 50 per cent frequency range and gives a voltage swr ⩾2.5:1 on a 300-Ω unscreened twin feeder.

621.396.677.71 1309

An Investigation of Slot Radiators in Rectangular Metal Plates—D. G. Frood and J. R. Wait. (PROC. IRE, Part B, vol. 103, pp. 103–109; January, 1956.) Measurements of the equatorial-plane radiation pattern of an axial $\lambda/2$ slot are compared with values calculated on the assumption that the plate can be represented by a thin elliptic cylinder or ribbon of infinite length. For a plate whose length is equal to or greater than its width the measured and calculated values agree to within a few per cent.

621.396.677.8 1310

Aerials with Reflectors and Conducting Disks for Decimetre Wavelengths—G. v. Trentini. (*Nachrichtentech. Z.*, vol. 8, pp. 569–577; November, 1955.) Dipole antennas combined with various arrangements of metal plates and strips are discussed. An arrangement relying on diffraction effects comprises a horizontal support carrying nine equally spaced parallel disks. Radiation patterns are calculated. The parallel-disk antenna has a higher gain than the reflector antenna of comparable dimensions, but the side-lobes are stronger; methods for overcoming this disadvantage are indicated.

AUTOMATIC COMPUTERS

681.142 1311

The Program-Controlled Electronic Computer at Munich (PERM)—H. Piloty, R. Piloty, H. O. Leilich, and W. E. Proebster. (*Nachrichtentech. Z.*, vol. 8, pp. 603–609; November and pp. 650–658; December, 1955.) Detailed illustrated description of a machine designed for calculations on scientific problems. A binary internal system is combined with a decimal external system. The word length is 50 binary digits. The magnetic-drum store rotates at 250 rps; mean access time is 2 ms and capacity is 8,192 words. Teleprinter tape is used for input and output, with photoelectric scanning also for the input. 2,400 tubes and 3,000 Ge diodes are used; the power consumption is <11 kw.

681.142 1312

An Accurate Electronic Multiplier—S. Sternberg. (*RCA Rev.*, vol. 16, pp. 618–634; December, 1955.) An account of developments of the time-division multiplier described by Goldberg (151 of 1953). A design giving long-term stability and increased speed of operation is described.

681.142:538.221 1313

Magnetic Core Circuits for Digital Data-Processing Systems—D. Loev, W. Miehle, J. Paivinen, and J. Wylen. (PROC. IRE, vol. 44, pp. 154–162; February, 1956.) Circuits for interconnecting toroidal cores used to perform various functions in digital computers are discussed. A single-diode loop permits unconditional transfer of information from one or more transmitting cores to one or more receiving cores. A split-winding loop permits conditional transfer and hence logical operations. An inhibit loop is also described. The operation of shift registers, cycle distributors, counters etc., is explained.

681.142:621.317.727 1314

A Digital Potentiometer—S. K. Dean and D. F. Nettell. (*Electronic Engng.*, vol. 28, pp. 66–69; February, 1956.) Description of an instrument developed for use with a teleprinter perforator for feeding measured voltage readings into an electronic computer. By comparing the input signal voltage with a series of reference voltages the former is represented in integers on a binary or decimal scale. Tests on a 10-stage instrument described indicate that a reliable 7-stage unit with a reading time under 3 seconds can be constructed with readily available components.

681.142:621.37 1315

The Isograph—an Electronic Root Finder—A. K. Choudhury. (*Indian J. Phys.*, vol. 29, pp. 468–473; October, 1955.) The instrument described is designed on the principle of harmonic synthesis, short-circuited and open-circuited delay lines fed from a matched frequency-sweep generator being used to produce the sine and cosine terms respectively. By controlling the amount of frequency sweep, any desired interval of the argument can be expanded and the accuracy of measurement thus increased.

681.142:621.383 1316

Character Recognition for Business Machines—M. H. Glauberman. (*Electronics*, vol. 29, pp. 132–136; February, 1956.) Arabic numerals are scanned by a column of photocells whose outputs modulate a pulse-generator system to give signals usable in computers. Characters are read at a maximum rate of 1,600 per second; operation is not critically dependent on style or size of type.

681.142:413.164 1317

Glossary of Terms relating to Automatic Digital Computers, B.S. 2641:1955 [Book Notice]—Publishers: British Standards Institution, London, 1955. (*B.S.I. Information Sheet*, p. 2; November, 1955.)

CIRCUITS AND CIRCUIT ELEMENTS

621.3.011.3/.4 1318

Formulas for computing Capacitance and Inductance—C. Snow. (*Nat. Bur. Stand. Circulars*, No. 544, 69 pp.; September 10, 1954) A collection of explicit formulas in terms of elementary functions, Legendre polynomials and functions, and elliptic functions. Formulas for mutual inductance and for the forces acting between current-carrying coils are also given.

621.318.57:621.373.1:537.312.8 1319

New Active Circuit Element using the Magnetoresistive Effect—A. Aharoni, E. H. Frei, and G. Horowitz. (*J. appl. Phys.*, vol. 26, pp. 1411–1415; December, 1955.) A basic circuit is considered comprising a bridge with resistance arms lying in the uniform field produced by current through a coil in the bridge diagonal. Analysis indicates that bistable operation is possible with reasonably short resolving time; it may be necessary to operate at low temperature. A design is described using Bi layers in the gaps of U-shaped electromagnets. Tristable operation is possible but not practical.

621.319.4:621.315.615 1320

Chlorinated Diphenyl Capacitors: a Survey of Production Technique—P. D. Wilmot. (*Elect. Rev., Lond.*, vol. 157, pp. 838–840; October 28, 1955.) Advantages of chlorinated diphenyls over mineral oil as impregnants for paper include a) higher dielectric strength, and b) higher permittivity. Applications include use in power-factor-correction capacitors.

621.372.011.1 1321

Generalization of Variation and Compensation Theorems for n Parameters of an Electrical Circuit—N. A. Brazma. (*C.R. Acad. Sci. U.R.S.S.*, vol. 105, pp. 271–274; November 11, 1955. In Russian.) The effect of impedance variations in one or more branches of a network on the current in one of the branches is calculated using matrices.

621.372.412 1322

Thickness-Shear and Flexural Vibrations of Rectangular Crystal Plates—R. D. Mindlin and H. Deresiewicz. (*J. appl. Phys.*, vol. 26, pp. 1435–1442; December, 1955.) Analysis is given for the infinite plate, the simply supported rectangular plate and the rectangular plate with one pair of parallel edges free and the other pair simply supported. For previous work see 1861 of 1951 and 2156 of 1952 (Mindlin).

621.372.412:549.514.51 1323

The Temperature Variation of the Frequency of AT- and BT-Cut Quartz Resonators—R. Bechmann. (*Arch. elekt. Übertragung*, vol. 9, pp. 513–518; November, 1955.) Measured frequency/temperature characteristics can be represented analytically as power series, three terms being sufficient to deal with the temperature range −60° to +100°C. The influence of the order of overtone on the temperature coefficient is discussed. See also 346 of 1956.

621.372.413.011.2 1324

Calculation of Shunt Resistances of Rhumbatron-Type Cavities—W. Chahid. (*C.R. Acad. Sci., Paris*, vol. 241, pp. 1733–1736; December 14, 1955.) The calculation is facilitated by deriving the expression for the shunt resistance in a form in which the axial electric field strength is the only independent variable.

621.372.414:621.372.8 1325

Traveling-Wave Resonator—P. J. Sferrazza. (*Tele-Tech & Electronic Ind.*, vol. 14, Section 1, pp. 84–85, 143; November, 1955.) A circuit comprising a directional coupler with the secondary arm ports connected to form a continuous loop is used for storing energy extracted from the primary in a wave which circulated around the loop. An *X*-band version used in testing for high-power breakdown is briefly described. (Presented at the 1955 National Electronics Conference.)

621.372.5:512.831 1326

An Expression for the Powers of a Matrix and its Application to Iterated Networks—A. Fekhikher. (*Ann. Télécommun.*, vol. 10, pp. 237–241; November, 1955.)

621.372.5:621.3.018.75 1327

Optimum Characteristics of Linear Pulse Systems—R. Kulikowski and J. Plebański. (*Bull. Acad. polon. Sci., Class* 4, vol. 3, pp. 23–28; 1955. In English.) General analysis is presented establishing the conditions for minimum distortion of pulses in linear systems. The analysis is applied to particular filter circuits. The results are embodied in three theorems.

621.372.54 1328

A General Theory of Reactive Non-dissipative L-Sections—A. Mogensen. (*Kungl. tek. Hogsk. Handl., Stockholm*, No. 95, 60 pp. 1955. In English.) Elementary theory is developed based on Foster's reactance theorem.

621.372.54 1329

The Design of Filters using only RC Sections and Gain Stages—A. N. Thiele. (*Electronic Engng.*, vol. 28, pp. 31–36, January, and pp. 80–82; February, 1956.) "A method is described of synthesizing filters, using RC sections within a feedback loop. Design information is given for high- and low-pass filters of 12, 18 and 24 db per octave slope and fixed cutoff frequency, and others of approximately 12 and 18 db per octave slope, whose cutoff frequency is variable continuously by the adjustment of a single element."

621.372.54:621.372.8 1330

The Polarguide—a Constant Resistance Waveguide Filter—R. W. Klopfenstein and J. Epstein. (PROC. IRE, vol. 44, pp. 210–218; February, 1956.) The filter described comprises a circular waveguide with spaced radial-line cavities by means of which a linearly polarized wave [see 25 of 1955 (Klopfenstein)] and subsequently reconverted. The device can handle high powers; a design for a television vestigial-sideband filter is described.

621.372.54:621.39.001.11 1331

Statistical Design and Evaluation of Filters for the Restoration of Sampled Data—R. M. Stewart. (Proc. IRE, vol. 44, pp. 253–257; February, 1956.)

621.372.54.029.62:621.372.2 1332

'T'-Stub Calculation for V.H.F. Transmission Line Filters—M. Telford. (*Marconi Rev.*, 4th Quarter, vol. 18, pp. 121–131; 1955.) A method is presented which has advantages over earlier methods in respect of flexibility and ease of calculation. It is applicable whether the stubs in a filter are true reciprocals or not and also in cases where another element, such as an isolating stub, is combined with a "T" stub to give a required frequency response.

621.373.42.029.42 1333

An Oscillator for Very Low Frequencies—(*Radio elect. Rev., Wellington, N. Z.*, vol. 10, pp. 31–32; October 1, 1955.) A circuit giving sinusoidal oscillations with periods of 35 seconds or more uses triodes connected as cathode followers as phase-shift elements.

621.373.52:621.314.7 1334

Frequency Stability of Point-Contact Transistor Oscillators—C. C. Cheng. (Proc. IRE, vol. 44, pp. 219–223; February, 1956.) The duality relation between circuits using the voltage-controlled negative-impedance base-input characteristic and those using the current-controlled negative-impedance emitter-input or collector-input characteristic is demonstrated. Stabilization criteria for both cases are derived analytically and are confirmed experimentally.

621.373.52.029.3 1335

A Frequency-Stable Transistor Audio Oscillator of Very Simple Design—W. D. Edwards. (*Canad. J. Technol.*, vol. 33, pp. 413–420; November, 1955.) A circuit is described in which a point-contact transistor maintains oscillations by supplying current pulses to a series LC circuit during half-cycle periods when the emitter is conducting. Frequency stability is improved by including a diode in the emitter circuit.

621.374.3:621.318.57 1336

High Sensitivity and Accuracy Pulse Trigger Circuit—S. Barabaschi. C. Cottini, and E. Gatti. (*Nuovo Cim.*, vol. 2, pp. 1042–1051; November, 1955. In English.) A pulse-height discriminator is described which incorporates a highly stable differential negative resistance provided by a Type-6CS6 multi-electrode tube, by virtue of current division between screen grid and anode. This circuit is compared with that of Kandiah (3486 of 1954), in which the negative resistance is provided by a cathode-coupled pair of tubes. The discriminator threshold can be set in the range 1–30 mv with stability within 1 per cent.

621.374.32:621.318.57:621.387.032.212 1337

Subtracting Counter using Dekatron Tubes—A. Coche. (*J. Phys. Radium*, vol. 16, pp. 861–863; November, 1955.)

621.375:621.372.57 1338

Active Quadripoles with Intermediate-Point Earthing—H Beneking. (*Arch. elekt. Übertragung*, vol. 9, pp. 519–527; November, 1955.) The discussion is based on a tube circuit described by Cantz (*Telefunken Röhre*, no. 30, p. 52; 1953) in which a point on a coil in the grid-cathode circuit is earthed. Generalized analysis is presented, using matrices. The treatment is suitable for any tube or transistor circuits that can be considered as series-parallel-series networks, and facilitates the development of some useful new circuits.

621.375.13 1339

Effect of Component Tolerances in Low-Frequency Selective Amplifiers—an Analysis—N. S. Nagaraja. (*J. Indian Inst Sci.*, Section B, vol. 37, pp. 324–337; October, 1955.) Amplifiers with Wien-bridge or twin-T selective feedback networks are considered. When the networks are designed for maximum selectivity, the Q factor of the amplifier is relatively sensitive to variation of network component values; this sensitivity can be reduced by suitable choice of component relative values, but a higher gain is then required to obtain the same selectivity.

621.375.2 1340

Amplifier Stage with Monotonically Rising Response to a Step Signal—J. Roorda. (*Tiedschr. ned. Radiogenoot.*, vol. 20, pp. 353–377; November, 1955.) The problem is to combine the monotonic response with the shortest possible rise time. Starting from consideration of a simple RC coupling, and using analysis based on Laplace transforms, the coupling circuit giving the required response is found in the form of a π network with parallel-RC vertical and series-LR horizontal arms.

621.375.2.024 1341

Valve Amplifiers for Very Low Frequencies—W. Ruppel. (*Nachrichtentech. Z.*, vol. 8, pp. 595–602; November, 1955.) DC amplifier circuits are briefly reviewed and descriptions are given of a high-gain voltage amplifier using two triodes and a low-output-impedance current amplifier using four triodes in a push-pull arrangement.

621.375.221.2:621.385.15 1342

Distributed Amplifier using Tubes with Secondary Emission—D. T. Jovanović and V. N. Kostić. (*Bull. Inst. Nuclear Sci. "Boris Kidrich,"* vol. 5, pp. 23–27; March, 1955. In English.) Description of a two-stage amplifier with three Type-EFP60 tubes in each stage, having a gain of 35 and a bandwidth of 160 mc.

621.375.3 1343

Magnetic-Amplifier Design—a Practical Approach—M. Lilienstein. (*Elect. Mfg.*, vol. 55, pp. 90–98; March, 1955.)

621.375.4:621.314.7 1344

Transistor Operating Conditions—W. T. Cocking. (*Wireless World*, vol. 62, pp. 109–111; March, 1956.) The use of the collector current /voltage characteristic curves in the design of earthed-base transistor amplifiers is discussed and numerical examples are given.

621.375.4:621.314.7 1345

Raising the Cut-Off Frequency of Transistors—H. Rühl. (*Nachrichtentech. Z.*, vol. 8, pp. 593–594; November, 1955.) Results of experiments with *n-p-n* and *p-n-p* transistors support Herzog's calculations (42 of 1955) of the rise of cutoff frequency attainable by connecting a neutralizing inductance in parallel with the capacitance between collector and emitter.

621.375.4.029.3:621.314.7 1346

High-Gain Transistor Amplifier—J. J. Davidson. (*Audio*, vol. 39, pp. 66–70; October, 1955.) The advantages of transistors over valves as low-level, high-gain, amplifiers with low noise properties are discussed and illustrated by a commercial application in a gramophone pre-amplifier, in which a single transistor stage takes the place of two or more tube stages.

621.375.43 1347

Broadband Transistor Feedback Amplifiers—J. Almond and A. R. Boothroyd. (*Proc. IEE*, Part B, vol. 103, pp. 93–101; January, 1956.) Negative-feedback amplifiers involving three cascaded common-emitter junction-transistor stages are discussed. With large feedback, stability conditions can be determined with sufficient accuracy by considering the forward and return paths of the feedback loop separately. The maximum feedback possible without instability depends on the frequency characteristic of the transistor current gain; this characteristic can be represented with adequate accuracy by a minimum-phase RC approximation. Amplifiers with over-all gain of 33 db and negative feedback of 30 db are described in which stability is secured by means of phase-advancing networks in the return path.

621.372 1348

Théorie des Réseaux de Kirchhoff. Régime Sinusoïdal et Synthèse [Book Review]—M. Bayard. Publishers: Editions de la Revue d'Optique, Paris, 408 pp., 1954. (*Tech. Mitt. schweiz. Telegr.-TelephVerw.* vol. 33, p. 476; November 1, 1955.) A comprehensive work on the analysis and synthesis of linear networks. forming one of a series presented by the Centre National d'Études des Télécommunications.

GENERAL PHYSICS

530.1 1349

The General Statistical Problem in Physics and the Theory of Probability—D. Bohm and W. Schützer. (*Nuovo Cim.*, supplement to vol. 2, pp. 1004–1047; 1955. In English.) An extended discussion leads to the conclusion that the problems of statistical physics in which the theory of probability does not apply may be more important than those in which it does.

530.145:621.396.822 1350

Quantum Theory of Fluctuations—H. Ekstein and N. Rostoker. (*Phys. Rev.*, vol. 100, pp. 1023–1029; November 15, 1955.) On the, basis of an analysis of method of measurement, an operator is constructed for the spectral density of a fluctuating variable; the classical dynamic variables are replaced by time-dependent Heisenberg operators. The theory is used to deduce Nyquist's law for a particular case, and to calculate the shot effect for free uncorrelated electrons.

530.152.15 1351

A General Approach to Hysteresis: Part 4—an Alternative Formulation of the Domain Model—D. H. Everett. (*Trans. Faraday Soc.*, vol. 51, pp. 1551–1557; November, 1955.) A comparison is made of various methods of formal representation of hysteresis phenomena in terms of a domain model. A symmetrical treatment is developed permitting the equations to scanning curves within a hysteresis loop to be written in a simple form. Part 3: *ibid*, vol. 50, p. 1077; 1954.

535.22 1352

Improved Value of the Velocity of Light derived from a Band-Spectrum Method—D. H. Rank, H. E. Bennett, and J. M. Bennett. (*Phys. Rev.*, vol. 100, p. 993; November 15, 1955.) A more accurate result than that reported previously [2619 of 1954 (Rank *et al.*)] has been obtained by using a new interferometric technique. The new value is 299,791.9 ±2.2 km.

535.43 1353

Theory of Scattering [of light] by an Inhomogeneous Solid possessing Fluctuations in Density and Anisotropy—M. Goldstein and E. R. Michalik. (*J. appl. Phys.*, vol. 26, pp. 1450–1457; December, 1955.)

537/538].081 1354

Memorandum on Electrical and Magnetic Units—O. Löbl. (*Bull. Soc. franç. Élect.*, vol. 5, pp. 804–808; November, 1955.) Digest of a paper presented to the Society. The various units systems in use are examined; disadvantages of the mks and cgs systems are indicated. A new system is proposed, called the "système paritaire de coefficients;" this is based on four fundamental units and retains the practical units such as the volt etc., together with unity values for the dielectric constant and permeability of vacuum.

537.311 1355

The Electron-Phonon Interaction, according to the Adiabatic Approximation—J. M. Ziman. (*Proc. Camb. phil. Soc.*, vol. 51, Part 4, pp. 707–712; October, 1955.)

537.312.62 1356

Superconductivity at Millimeter Wave Frequencies—G. S. Blevins, W. Gordy, and W. M. Fairbank. (*Phys. Rev.*, vol. 100, pp. 1215–1216; November 15, 1955.) Preliminary results of experiments on Sn at frequencies between 77 and 150 kmc are reported; residual resistivity is observed at these frequencies.

537.5:621.387 1357

The Electron Affinity of Hydrogen in a Microwave Gas Discharge—D. Walsh. (*J. Electronics*, vol. 1, pp. 444–448; January, 1956.) Experiments show that hydrogen in a microwave gas discharge is a much better electron captor than its calculated capture cross section would indicate, giving deionization times in tr switches comparable with those obtained with water vapor.

537.52 1358

Disappearance of Adsorbed Gases from Dielectric Surfaces under Electrodeless Discharge—S. R. Mohanti (Mohanty). (*Nuovo Cim.*, vol. 2, pp. 1107–1109; November 1, 1955. Addendum, *ibid.*, vol. 3, pp. 219–220; January 1, 1956. In English.)

537.525.5:621.385.132 1359

Studies of Externally Heated Hot-Cathode Arcs: Part 4—The Low-Voltage Form of the Ball-of-Fire Mode (the Low-Voltage Arc)—E. O. Johsnon. (*RCA Rev.*, vol. 16, pp. 498–532; December, 1955.) Discussion in terms of a model based on the observation that the stream of electrons entering the ball plasma from the cathode plasma is scattered so completely that the electrons within the ball have a Maxwellian energy distribution. Theoretical predictions are compared with probe measurements. Part 3: 2591 of 1955 (Johnson and Webster).

537.533/.534 1360

Ionization and Desorption due to Strong Electric Fields—F. Kirchner and H. Kirchner. (*Z. Naturf.*, vol. 10a, pp. 394–400; May, 1955.) Experimental investigations of the intensity distribution of field-type electron emission from single-crystal *W* points covered with thin films of other material are reported. Where surface compounds of *W* with *O* or *C* are present, a characteristic change of the emission distribution is observed after application of an opposing field. The change is attributed to local ionization, an electron being released into the interior of the metal and a positive ion being emitted into the vacuum if the field is strong enough to overcome the image force. The field ionization of physically adsorbed molecules or atoms required relatively strong fields. Quantitative estimates are made of the "pull-off" field strength and its temperature variation.

537.533 1361

A Method for the Systematic Calculation of an Electron—Optically Effective Field Distribution with Specified Imaging Properties—J. Picht. (*Optik, Stuttgart*, vol. 12, pp. 433–440; 1955.) Analysis is given for a purely magnetic field.

537.533:537.29 1362

High Field Electron Emission from Irregular Cathode Surfaces—T. J. Lewis. (*J. appl. Phys.*, vol. 26, pp. 1405–1410; December, 1955.) The enhancement of the field in front of an emitter due to surface irregularities (2631 of 1954) is studied in detail, with reference to mechanisms proposed by Schottky and by Fowler and Nordheim. The enhancement factor varies with distance from the surface and is also field dependent. The results provide explanations of anomalous conduction variations in liquids and gases.

537.533:621.385 1363

Space-Charge Effects in Electron Optical Systems—K. T. Dolder and O. Klemperer. (*J. appl. Phys.*, vol. 26, pp. 1461–1471; December, 1955.) A discussion of spherical aberration in beams exhibiting a waist. Conditions for transition from waist to crossover are examined. Experimental results support the theory.

537.533.7 1364

Mean Free Path for Discrete Electron Energy Losses in Metallic Foils—A. W. Blackstock, R. H. Ritchie, and R. D. Birkhoff. (*Phys. Rev.*, vol. 100, pp. 1078–1083; November 15, 1955.)

537.533.7:546.623-31:539.23 1365

Transmission of Electrons of Energies below 16 keV by Aluminium Oxide Films of Thickness 1000 to 3000 Å—O. Hoffmann. (*Z. Phys.*, vol. 143, pp. 147–152; November 18, 1955.)

537.56:537.311.37 1366

Critical Examination of the Theory of Plasmas based on Mean Free Path, in the Light of the Method based on the Distribution Function derived by solving Boltzmann's Equation—R. Jancel and T. Kahan. (*J. Phys. Radium*, vol. 16, pp. 824–828; November, 1955.) Discussion indicates that the distribution-function method is more suitable than the mean-free-path method for calculating the conductivity of anisotropic plasmas; (*e.g.*, plasmas subjected to electric and magnetic fields).

537.581:548.0:546.78 1367

Velocity Analysis of Thermionic Emission from Single-Crystal Tungsten—G. F. Smith. (*Phys. Rev.*, vol. 100, pp. 1115–1116; November 15, 1955.) It is suggested that the departure from a Maxwellian distribution observed by Hutson (3228 of 1955) is due to the finite resolution of the analyzer.

538.114 1368

Spin-Deviation Theory of Ferromagnetism: Part 1—General Theory—J. Van Kranendonk. (*Physica*, vol. 21, pp. 749–766; October, 1955.)

538.114 1369

The Origin of Ferromagnetism in Transition Metals—J. Friedel. (*J. Phys. Radium*, vol. 16, pp. 829–838; November, 1955.) Analysis of experimental evidence indicates that the energy-band concept consitututes a more satisfactory basis for the theory of ferromagnetism than the hypothesis that the magnetic carriers are bound to individual atoms. The occurrence of fractional numbers of carriers is explained on the basis of close-range interactions between carriers associated with the same atom. The absence of ferromagnetism in heavy elements such as Pd and Pt is a consequence of strong spin-orbit coupling.

538.114 1370

Influence of Crystalline Electric Fields on Antiferromagnetic Transitions—L. D. Roberts, R. B. Murray, and J. W. T. Dabbs. (*Phys. Rev.*, vol. 100, pp. 1100–1103; November 15, 1955.)

538.3 1371

On the Ampère Force—P. Moon and D. E. Spencer. (*J. Franklin Inst.*, vol. 260, pp. 295–311; October, 1955.) A re-examination of the expressions for the Ampère force (2923 of 1954) taking account of Warburton's comments (1321 of 1955).

538.312 1372

Source Representations for Debye's Electromagnetic Potentials—A. Nisbet. (*Physica*, vol. 21, pp. 799–802; October, 1955.) Theory of em radiation presented by Bouwkamp and Casimir (413 of 1955) is discussed; Debye potentials can be used for all points, even within the source distribution. This leads to an alternative method for the direct determination of multipole expansions.

538.56:537.56 1373

Electrodynamics of Turbulent Ionized Media—T. Kahan. (*C.R. Acad. Sci., Paris*, vol. 241, pp. 1726–1727; December 14, 1955.) The scattering of em power in a turbulent ionized medium is discussed. To be applicable for arbitrary values of electron density, analysis should take account of multiple scattering. Suitably modified forms of Navier's equations are indicated.

538.56.029.1+534.014.5 1374

Subharmonic Oscillations in a Nonlinear System with Positive Damping—S. Lundquist. (*Quart. appl. Math.*, vol. 13, pp. 305–310; October, 1955.)

538.566 1375

Theory of Total Reflection—F. I. Fedorov. (*C.R. Acad. Sci. U.R.S.S.*, vol. 105, pp. 465–468; November 21, 1955. In Russian.) The theory of total reflection of an elliptically polarized plane wave is developed from expressions for the energy density and the Poynting vector, using the notation of the earlier paper (3239 of 1955). Results indicate that at total reflection the mean flow of energy in the refracted wave contains a component normal to the plane of incidence; this component is zero in nontotal reflection and in two special cases; its magnitude is proportional to the wavelength in the first medium.

538.566 1376

Maximum Transmission of Electromagnetic Waves by a Pair of Wire Gratings—G. von Trentini. (*J. opt. Soc. Amer.*, vol. 45, pp. 883–885; October, 1955.) An experimental investigation was made of the transmission of 3.2-cm-λ waves through a pair of parallel wire gratings with various wire and grating spacings for various angles of incidence. Results are compared with values derived from theory.

538.566:535.42]+534.26 1377

Semiasymptotic Series for the Diffraction of a Plane Wave by a Cylinder—W. Franz and R. Galle. (*Z. Naturf.*, vol. 10a, pp. 374–378; May, 1955.) The technique described previously, involving Watson transforms [1955 of 1955 (Franz)] is used to develop series up to $(ka)^{-2}$, where $k = 2\pi/\lambda$ and a is the radius of the cylinder.

538.566:535.42 1378

Variational Formulation of Two-Dimensional Diffraction Problems with Application to Diffraction by a Slit—A. T. de Hoop. (*Proc. kon. ned. Akad. Wetensch. B.* vol. 58, pp. 401–411; 1955. In English.) Diffraction particularly of em waves is discussed. Analysis shows that for an incident plane wave the complex amplitude of the far-zone diffracted field can be expressed in a stationary form of the type indicated by Levine and Schwinger (83 of 1950). The case of a diffracting slit of infinite length and finite width is treated in detail. For normal incidence the results agree with those of Bouwkamp (2909 of 1954) and Müller and Westpfahl (1971 of 1953).

538.566:535.42 1379

On Integrals occurring in the Variational Formulation of Diffraction Problems—A. T.

de Hoop. (*Proc. kon. ned. Akad. Wetensch. B* vol. 58, pp. 325–330; 1955. In English.)

538.566:535.42 1380

The Diffraction of Electromagnetic Waves at a Grating consisting of Parallel Conducting Strips—L. A. Vainshtein. (*Zh. tekh. Fiz.*, vol. 25, pp. 847–852; May, 1955.) A rigorous solution is given for diffraction of a normally incident plane em wave, the width of the strips being equal to the spaces between them. Graphs show the reflection and transmission of the wave for various ratios of strip width to wavelength, and the amplitudes of the diffraction spectra.

538.566:535.42:621.372.8 1381

Diffraction of Centimetre Waves by a Conducting Sphere in a Waveguide—W. Chambron. (*J. Phys. Radium*, vol. 16, pp. 891–892; November, 1955.) Measurements were made at a frequency of 9.1 kmc using a magic-T arrangement. Results indicate that reflection coefficient is proportional to sphere volume; dispersion of results is attributed to small geometrical irregularities. The work is preliminary to a study of the diffraction of em waves by clouds.

538.566:535.43 1382

Scattering of Electromagnetic Waves from a Random Surface—W. C. Hoffman. (*Quart. appl. Math.*, vol. 13, pp. 291–304; October, 1955.) The medium below the surface is assumed to be perfectly conducting, so that the far-zone form of the Stratton-Chu solution can be used. The mean and covariance of the approximate expression for the scattered radiation are determined for both vertical and horizontal polarization.

538.566:537.562 1383

Interaction of Electromagnetic Waves of Radio-Frequency in Isothermal Plasmas: Collision Cross Section of Helium Atoms and Ions for Electrons—J. M. Anderson and L. Goldstein. (*Phys. Rev.*, vol. 100, pp. 1037–1046; November 15, 1955.) Theoretical and practical aspects of the laboratory experiments described previously [2637 and 2970 of 1953 (Goldstein *et al.*)] are discussed and results of measurements using He gas are presented. The ratio of the effective cross sections of ions and atoms for electron collisions is about 3×10^5 at an ion density of $10^{11}/\text{cm}^3$ at room temperature.

538.566:538.221:621.318.134 1384

Nonlinearity of Propagation in Ferrite Media—A. Clavin. (PROC. IRE, vol. 44, p. 259; February, 1956.) Measurements are briefly reported. Both losses and phase shift varied with temperature at constant power level. The results are compared with those of Sakiotis *et al.* (3240 of 1955).

538.566.2.029.6:537.226 1385

Investigations on Artificial Dielectrics at Microwave Frequencies: Part 1—S. K. Chatterjee and B. V. Rao. (*J. Indian Inst. Sci.*, Section B, vol. 37, pp. 304–323; October, 1955. The transmission of H_{01} wave through a parallel-plate array was studied experimentally. The observed variation of phase change with angle of incidence is in fair agreement with that calculated from the formula given by Carlson and Heins (2756 and 3504 of 1947); the difference between them is attributed to diffraction effects and the presence of higher-order modes inside the array. Values are deduced for the minimum dimensions required to avoid diffraction effects.

538.569.4 1386

Resonance Transitions induced by Perturbations at Two or More Different Frequencies—N. F. Ramsey. (*Phys. Rev.*, vol. 100, pp. 1191–1194; November 15, 1955.) Expressions are derived for the alteration of magnetic resonance frequency due to the presence of a second oscillation at a nonresonance frequency. Applications of the formulas to nuclear-resonance and molecular-beam experiments are discussed.

538.569.4:535.33/.34:621.385.029.6 1387

Improvement in a Paramagnetic-Electron-Resonance Spectrograph. Application to the Study of Diphenylpicrylhydrazyl—G. Berthet. (*C.R. Acad. Sci., Paris*, vol. 241, pp. 1730–1733; December 14, 1955.) The sensitivity of apparatus operating in the 3-cm band (*Onde élect.*, vol. 338, p. 489; 1955) is greatly increased when the klystron source of nominal power 30–40 mw is replaced by one of much higher power; *e.g.*, 3 w.

538.569.4:535.34 1388

Relaxation Times in Magnetic Resonance—D. Pines and C. P. Slichter. (*Phys. Rev.*, vol. 100, pp. 1014–1020; November 15, 1955.) The effect of motion of the absorption centers on the width of resonance lines is discussed on the basis of a random-walk model, and a simple picture is presented of the electron relaxation processes.

538.569.4:535.34 1389

Some Devices for the Stark Modulation Millimeter-Wave Spectrograph—A. Okaya. (*Rev. sci. Instrum.*, vol. 26, pp. 1024–1028; November, 1955.) An over-all sensitivity of about $5\times10^{-8}\text{cm}^{-1}$ in the 6-mm wave range is attained as a result of appropriate design of Stark cell, frequency multiplier, lock-in detector, and square-wave generator.

538.6:536.7 1390

Thermodynamical Theory of Galvanomagnetic and Thermomagnetic Phenomena—R. Fieschi. (*Nuovo Cim.*, supplement to vol. 2, pp. 1168–1170; 1955. In English.) Addendum to paper noted previously (1961 of 1955).

539.378.3 1391

The Optical Investigation of the Interdiffusion of Metals—H. Schopper. (*Z. Phys.*, vol. 143, pp. 93–117; November, 1955.) The technique used involves the preparation of very thin films of known thickness.

53.023 1392

Fundamental Formulas of Physics [Book Review]—D. H. Menzel (Ed.). Publishers: Prentice-Hall, Inc., New York, 765 pp., 1955. (*Science*, vol. 122, p. 976; November 18, 1955.) " . . . a valuable reference book for every physicist. . . . "

538.569.4:535.33/.34 1393

Spectroscopy at Radio and Microwave Frequencies [Book Review]—D. J. E. Ingram. Publishers: Butterworths Scientific Publications, London, 332 pp., (*J. Electronics*, vol. 1, pp. 457–458; January, 1956.)

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.16 1394

The Identification of Radio Stars—A. M. Naqvi and J. N. Tandon. (*Proc. nat. Inst. Sci. India*, Part A, vol. 21, pp. 244–251; July 26, 1955.) An examination is made of the possibility that the fainter radio stars, classified by Mills (333 of 1954) as Class II, are within our galaxy. The observed coincidences in position of radio stars and *M* dwarfs appear to be significant.

523.16 1395

Absorption of 3.5-m Radiation in the Optical Emission Nebula, NGC 6357—B. Y. Mills, A. G. Little, and K. V. Sheridan. (*Nature, Lond.*, vol. 177, p. 178; January 28, 1956.) This is the first reported case of absorption of radio waves by an emission nebula; it leads to an estimated electron temperature of 6,500°K for the nebula.

523.7 1396

East/West Asymmetry in the Formation of New Sunspots—M. d'Azambuja. (*C.R. Acad. Sci., Paris*, vol. 241, pp. 1712–1714; December 14, 1955.) Analysis of records covering many years indicates that about twice as many centers of activity are observed on the eastern half of the solar disk as on the western half.

523.74:551.510.535 1397

A New Index of Solar Activity based on Ionospheric Measurements—C. M. Minnis. (*J. atmos. terr. Phys.*, vol. 7, pp. 310–321; December, 1955.) The monthly mean relative sunspot number R_M is assumed to contain a component constituting a direct index of solar activity R_v, together with an error component R_x having a standard deviation of about 20 per cent. A new index I_{f_2}, based on an analysis of the critical frequency of the F_2 layer over the period 1938–1954, has been constructed whose residual error component is only one tenth that of R_x. The magnitude of I_{f_2} for a given month is computed from the mean noon F_2-layer critical frequencies at Slough, Huancayo and Watheroo and is based, in effect, on a calibration of the F_2-layer critical frequencies in terms of R_v.

523.75 1398

Accuracy of Solar-Flare Observations—L. W. Ross. (*J. atmos. terr. Phys.*, vol. 7, pp. 344–345; December, 1955.) The division of observed solar flares into more than three classes is not statistically justifiable; more uniform and detailed reporting is required.

523.75:550.385 1399

Solar H_α Filaments and Geomagnetic Disturbances—H. I. Leighton and D. E. Billings. (*J. atmos. terr. Phys.*, vol. 7, pp. 349–350; December, 1955.) Experiments to test Kiepenheuer's suggestion (3877 of 1947), identifying the solar M-regions causing geomagnetic disturbances with dark filaments on the solar disk, gave negative results.

523.78:551.594.6:621.396.11 1400

The Influence of the Solar Eclipse on the Propagation of Atmospherics in the Frequency Range 5–30 kc—G. Skeib. (*Veröff. met. hydrol. Dienst., Potsdam*, pp. 24–27; 1955.) A map shows the position of sources of atmospherics in Europe at the time of the eclipse; records of measurements over a two-hour period show a marked eclipse effect on 30 kc with a 15-minute delay, but little effect on 10 kc. An anomalous increase of field strength on 5 kc is related to the reduction of the ionosphere /earth-duct cutoff frequency resulting from the eclipse.

550.38+523.746:538.65 1401

The Stability of a Homopolar Dynamo—E. Bullard. (*Proc. Camb. phil. Soc.*, vol. 51, Part 4, pp. 744–760; October, 1955.) The stability of the self-exciting disk dynamo is considered, taking into account the friction at the axle and the effect of an external electrical load in parallel with the field coils. Possible analogies between the results obtained and the motion of an electrically conducting fluid in a magnetic field are discussed; the theory may be useful in explaining the magnetic field of the earth and of sunspots.

550.380.87:550.385 1402

A Method for the Elimination of Slow Variations in the Recording of Pulsations of the Geomagnetic Field—P. A. Blum and A. Lebeau. (*C.R. Acad. Sci., Paris*, vol. 241, pp. 1807–1809; December 14, 1955.)

550.385:551.510.535 1403

The Diurnal Variation of Irregular Geomagnetic Fluctuations—S. B. Nisholson and O. R. Wulf. (*J. geophys. Res.*, vol. 60, pp. 389–394; December, 1955.) The diurnal variation of the fluctuations, showing a maximum in late evening for middle latitudes, is correlated with atmospheric turbulence in the ionosphere, which is assumed to be hindered in daytime by electromagnetic damping. There is also a pronounced seasonal effect; this may be connected with the large-scale circulation of the atmosphere.

551.51 1404

Thermal and Gravitational Excitation of Atmospheric Oscillations—H. K. Sen and M. L. White. (*J. geophys. Res.*, vol. 60, pp. 483–495; December, 1955.) Previous work is extended to include a unified treatment for both gravitational and thermal forcing functions. From consideration of various atmospheric models it appears that thermal effects are far more important than gravitational ones in producing the solar semidiurnal pressure variation; this is not confirmed by observation, but the disagreement may be eliminated by assuming the possibility of heating other than by ground eddy currents.

551.510.53 1405

Nitrogen Oxides and the Airglow—M. Nicolet. (*J. atmos. terr. Phys.*, vol. 7, pp. 297–309; December, 1955.) Possible chemical and photochemical reactions which would account for the formation of nitrogen oxides in the upper atmosphere are discussed and are shown to provide a possible explanation of the airglow.

551.510.535 1406

On the Cooling of the Upper Atmosphere after Sunset—A. N. Lowan. (*J. geophys. Res.*, vol. 60, pp. 421–429; December, 1955.) Cooling in the *E* and *F* regions of the ionosphere is investigated theoretically, assuming that heat transfer takes place only by conduction. At a time 2½ hours after sunset the temperature is unchanged at altitudes below 160 km; at a height of 380 km the maximum drop is 440°K. There should be an appreciable increase of ion density in the *F* layer, but this will be offset, except in equatorial regions, by downward diffusion.

551.510.535 1407

Formation of the Lower Ionosphere—K. Watanabe, F. F. Marmo, and J. Pressman. (*J. geophys. Res.*, vol. 60, pp. 513–519; December, 1955.) The available evidence suggests that ions in the *D* layer are mainly produced by photo-ionization of NO; photo-ionization of O_2, at its first ionization potential, should occur in the *E* layer and further data are required to decide whether this layer is caused by such a process or by ionization by soft X rays.

551.510.535 1408

The Measurement of Normal *E*-layer Critical Frequencies at Night—W. R. Piggott. (*J. atmos. terr. Phys.*, vol. 7, pp. 341–342; December, 1955.) The normal *E*-layer critical frequency at night is best determined from absorption/frequency curves, plotted as -log ρ/log f. Results of typical measurements taken with standard DSIR absorption measuring equipment (2301 of 1955) are shown. From the trend of foE variation it was possible to identify the associated absorption band on a few of the routine night-time $h'f$ curves obtained at Slough, in spite of the presence of E_s and other irregularities. From the variation of foE with time a recombination coefficient of about 10^{-8} was deduced, but, owing to the low transmitter power, measurements of foE<0.7 mc could not be made; further work with higher power is needed.

551.510.535 1409

Night-Time Measurement of Positive and Negative Ion Composition to 120 km by Rocket-Borne Spectrometer—C. Y. Johnson and J. P. Heppner. (*J. geophys. Res.*, vol. 60, p. 533; December, 1955.) During a flight on July 8, 1955, only positive ions of mass number 28 were detected in the *E* region. These are identified as N_2^+. Ionospheric records for the same period and region show the existence of E_s clouds.

551.510.535 1410

Viscosity in the *F* Region—J. W. Dungey and A. J. Willson. (*J. geophys. Res.*, vol. 60, pp. 521–523; December, 1955.) It is shown that viscosity is of primary importance for disturbances whose scale is smaller than the mean free path, λ, and cannot be described by an effective coefficient; any initial disturbance on such a small scale will disappear very rapidly. Assuming normally accepted values for λ at 400 km altitude, it follows that patches of ionization causing the twinkling of radio stars cannot be due to turbulence in the neutral gas as suggested by Maxwell (1649 of 1955).

551.510.535 1411

Changes in the Absorption of Cosmic Noise observed during Two Ionospheric Disturbances—C. A. Shain. (*J. atmos. terr. Phys.*, vol. 7, pp. 347–348; December, 1955.) Curves are given showing the observed time variation of total absorption at Hornsby (34° S, 151° E) and of f_0F_2 at Canberra (35° S, 149° E) and Brisbane (28° S, 153° E), at the period of ionospheric disturbances on November 25, 1950 and August 20, 1950. Following the suggestions of Mitra and Shain (1426 of 1954), increased absorption is shown to be correlated with increased f_0F_2 and is presumably due to *F*-region attenuation. Deductions are made as to the path and speed of the disturbances.

551.510.535:523.78 1412

Interpretation of Ionospheric Results during Eclipses—J. Hunaerts and M. Nicolet. (*J. geophys. Res.*, vol. 60, pp. 537–538; December, 1955.) Accounts published by various workers of the solar eclipse of February 25, 1952 have been analyzed using the scale-height variation concept introduced by Nicolet (1644 of 1951). The vertical distribution of terrestrial atmospheric temperature varies with latitude, and the recombination coefficient in the *E* layer is $\nless 4\times10^{-8}$ cm^3 per second.

551.510.535:551.594.5 1413

The Recombination Coefficient in the *E*-layer during Aurorae—A. Omholt. (*J. atmos. terr. Phys.*, vol. 7, pp. 345–346; December, 1955.) In an earlier paper (710 of 1955) a mechanism involving variations in positive-ion concentrations was suggested to explain the abnormally high values of recombination coefficient during auroras. An alternative explanation assuming a high value of the negative-ion/electron ratio (in the range 0.5–3) is shown to be in accordance with observed data.

551.510.535:621.317.799 1414

Variable-Frequency Echo Sounding of the Ionosphere at Oblique Incidence—W. Dieminger, K. H. Geisweid, and H. G. Möller. (*Nachrichtentech. Z.*, vol. 8, pp. 578–586; November, 1955.) The development of the technique described by Dieminger (674 of 1952) is discussed with particular attention to synchronizing arrangements. Records obtained over two paths are compared with records of vertical-incidence soundings at points on the paths.

551.510.535:621.396.11 1415

Heights of Irregularities giving Rise to the Fading of 150-kcs Waves—R. B. Banerji. (*J. geophys. Res.*, vol. 60, pp. 431–439; December, 1955.) A calculation is made of the relation between phase and amplitude for a wave propagated through a region of random absorption below the reflection level; results agree with those obtained experimentally. A method for estimating particle collision frequency in the absorbing region is presented, based on that of Jones *et al.* (2311 of 1953), from which data regarding the region may be deduced.

551.510.535:621.396.11 1416

Polarization of Electromagnetic Waves for Vertical Propagation in the Ionosphere—Roy and Verma. (See 1526.)

551.510.535:621.396.11 1417

Some Remarks concerning Ionospheric Absorption-Work—K. Rawer. (*J. geophys. Res.*, vol. 60, pp. 534–535; December, 1955.) Irregularities in the frequency dependence of observed absorption decrements are attributed to focusing effects due to curvature of the layers involved. In the *F* layer these effects occur particularly with third-order echoes. Account should be taken of the effect in the analysis of absorption observations made during conditions of rapid fading.

551.510.535:621.396.812.3 1418

Ionospheric Wind Determination from Spaced Radio Receiver Fading Records—G. W. G. Court. (*J. atmos. terr. Phys.*, vol. 7, pp. 333–340; December, 1955.) Direct analysis of the fading patterns of reflected signals at three spaced receivers [96 of 1950 (Mitra)] can indicate the true ionospheric wind and changes in orientation of the patterns without assuming any particular distribution of orientation. A new method of analysis of the fading records is proposed, together with an alternative method of observation in which a single fixed receiver is used in conjunction with a second one which is moved in a circle round the first.

551.510.535"1955":621.396.11 1419

Ionosphere Review 1955—T. W. Bennington. (*Wireless World*, vol. 62, pp. 145–146; March, 1956.) Consideration of the records of sunspot numbers and ionosphere data indicates that solar activity may increase rapidly to reach a maximum in the middle of 1957, with the monthly mean daytime muf reaching 34 mc for east-west transmissions and 38 mc for southerly paths by November, 1956.

551.594.5 1420

Vertical Extent of Auroral Arcs and Bands—B. W. Currie and J. T. Weaver. (*Canad. J. Phys.*, vol. 33, pp. 611–617; November, 1955.) Measurements on 181 photographs taken from three stations indicate that quiet arcs and bands are confined to a narrow layer just about the 100-km level. The thickness of this layer is most often between 20 and 40 km, and rarely >50 km. From the ratio of the number of arcs and bands to the total number of observed forms it is inferred that the percentage of auroral time during which the luminosity is restricted to this layer is 60 per cent.

551.594.6:621.396.821 1421

The Effect of Atmospherics on Tuned Circuits—Edwards. (See 1538.)

LOCATION AND AIDS TO NAVIGATION

621.396.93 1422

The Theoretical Design of Direction-Finding Systems for High Frequencies—W. C. Bain. (*Proc. IEE*, Part B, vol. 103, pp. 113–119; January, 1956.) "The problem of finding the bearing of a distant hf transmitter in conditions of wave interference is examined for the simplified case of noninteracting antennas on a plane earth and with no pick-up of horizontally polarized radiation. Two methods of approach are considered—solution of the field equations for a number of incident plane waves from a knowledge of the field at the antennas, and the fitting of rectilinear constant-phase lines to observed values by a *least squares* process. It is shown that the cyclical system of Earp and Godfrey [1059 of 1949] is a *least squares* system of the latter type. Systems of the Wullenwever kind bear a close resemblance to a least-squares system with weighting according to the signal amplitude at each antenna; the difference lies in the fact that they operate with sinusoidal functions of phase instead of linear functions."

621.396.93 1423

Spacing-Error Analysis of the Eight-Element Two-Phase Adcock Direction Finder—D. N. Travers. (Trans. IRE, vol. AP-3, pp. 63–65; April, 1955.) In the array described the elements are arranged on a circle, with alternate angular separations of 54° and 36°; the operating frequency range is 20:1. Element-spacing values $>\lambda$ may be used; bandwidth is limited by other factors, such as antenna impedance or vertical pattern, rather than spacing error.

621.396.933 1424

Air Safety Service at the Zurich Intercontinental Airport—A. Fischer. (*Tech. Mitt. schweiz. Telegr.-Teleph Verw.*, vol. 33, pp. 449–470; November 1, 1955. In German and French.) An account of the navigation aids, air traffic control and communication systems used, and of the interrelation between these services.

621.396.96 1425

Radar Polarization Power Scattering Matrix—C. D. Graves. (Proc. IRE, vol. 44, pp. 248–252; February, 1956.) An improved method is described for calculating the amount and polarization of the energy reflected from the target for arbitrary polarization of the incident wave from measurements with any one polarization.

621.396.96:551.578 1426

Airborne Weather Radar uses Isoecho Circuit—F. W. Ruppert and J. M. Smith. (*Electronics*, vol. 29, pp. 147–149; February, 1956.) A light-weight equipment suitable for use in commercial aircraft is described. Return signals stronger than a preset level cause blacking out on the ppi display, so that storm centers appear as dark areas surrounded by illumination.

621.396.962.3 1427

Prediction of Pulse Radar Performance—W. M. Hall. (Proc. IRE, vol. 44, pp. 224–231; February, 1956.) Improved range-calculation procedure is described, based on detailed reconsideration of all the terms entering into the radar equation. The procedure is particularly useful for comparisons of performance.

MATERIALS AND SUBSIDIARY TECHNIQUES

533.583:546.82 1428

Gettering of Gas by Titanium—V. L. Stout and M. D. Gibbons. (*J. appl. Phys.*, vol. 26, pp. 1488–1492; December, 1955.) Experiments are described which indicate that Ti can be used as a getter for O_2, N_2 and CO_2 at temperatures above 700°C, for H_2 in the temperature range 25°–400°C, and for water vapor and methane at high or low temperature. Only H_2 is released by Ti on heating subsequent to sorbtion.

535.215+537.533.8 1429

Effect of Electron Bombardment on Secondary and Photoelectric Emission of Cesium-Antimonide—K. Miyake. (*J. phys. Soc. Japan*, vol. 10, pp. 912–913; October, 1955.) Continuation of experiments described previously (2968 of 1955). Photoelectric fatigue effects are also discussed in a separate paper (*ibid.*, pp. 913–915).

535.215:546.24:537.311.33 1430

Recombination Processes in Tellurium—D. Redfield. (*Phys. Rev.*, vol. 100, pp. 1094–1100; November 15, 1955.) Studies were made on single crystals with acceptor densities of about 10^{16}/cm^3, using photoconductivity techniques with pulsed illumination. The results indicate that at 100°K direct recombination dominates over recombination through localized traps at all illumination levels. It is deduced that small-energy-gap materials should have long lifetimes and should be sensitive photoconductors, and that there should be an optimum value of energy gap, probably near 0.5 ev, giving maximum lifetime.

535.37:546.472.21 1431

On the Spectral Distribution of Infrared-Stimulated Phosphorescence of Pb-Activated ZnS-Type Phosphors—S. Asano. (*J. phys. Soc. Japan*, vol. 10, pp. 903–905; October, 1955.)

535.376:546.472.21 1432

Electroluminescence of Zinc Sulfide Single Crystals—D. R. Frankl. (*Phys. Rev.*, vol. 100, pp. 1105–1111; November 15, 1955.) Measurements made using half-wave 60-cps excitation are reported and the results are compared with those of other workers, the intensity and phase of the electroluminescence peaks being examined in detail. It is deduced that excitation occurs by impact of conduction electrons accelerated through internal barriers, that the two electroluminescence peaks in each cycle result respectively from immediate recombination and from recombination delayed by electron trapping, and that the applied field tends to hold the electron in the trap.

535.376:546.681.18 1433

Electroluminescence of GaP—G. A. Wolff, R. A. Herbert, and J. D. Broder. (*Phys. Rev.*, vol. 100, pp. 1144–1145; November 15, 1955.) Experimental observations are reported; the phenomena are consistent with the impact-excitation mechanism suggested by Piper and Williams (3439 of 1952).

537.226/.228.1:546.431.824–31 1434

Effect of Firing Cycle on Structure and some Dielectric and Piezoelectric Properties of Barium Titanate Ceramics—L. Egerton and S. E. Koonce. (*J. Amer. ceram. Soc.*, vol. 38, pp. 412–418; November 1, 1955.) Experimental results indicate the existence of particular conditions for firing time and temperature leading to optimum grain size, as evidenced by the corresponding values of dielectric constant, piezoelectric constants and coupling coefficients. Firing cycles should be modified to suit the particular purpose for which the material is to be used. By using a special technique involving rapid heating and cooling, it is possible to prepare specimens with dielectric constants as high as 3,000 accompanied by low piezoelectric constants.

537.226/.227:546.431.824–31 1435

Phase Equilibria in the System $BaTiO_3$-SiO_2—D. E. Rase and R. Roy. (*J. Amer. ceram. Soc.*, vol. 38, pp. 389–395; November 1, 1955.) A comprehensive experimental investigation is reported. The existence of three intermediate compounds was established and three simple eutectics were determined. Glasses with high refractive indices were obtained over a limited range of compositions. The dependence of the cubic-hexagonal transition temperature on the SiO_2 content is discussed.

537.226 1436

Artificial Dielectrics utilizing Cylindrical and Spherical Voids—H. T. Ward, W. O. Puro, and D. M. Bowie. (Proc. IRE, vol. 44, pp. 171–174; February, 1956.) Artificial dielectrics are investigated comprising three-dimensional arrays of holes in polystyrene, teflon, and other materials with relatively high mechanical strength. A theoretical expression is derived for the over-all dielectric constant when the holes are spherical or cylindrical with nearly equal length and diameter; for cylindrical holes with large length/diameter ratios the dielectric constant depends on the orientation with respect to the electric field. Values of 1.1–2.6 are obtained by measurements at 5 kmc.

537.226:621.315.621.4 1437

X-Ray Investigation of Solid Solutions of $BaTiO_3$-$PbZrO_3$—E. A. Porai-Koshits, N. Ya. Karasik, and G. O. Gomon. (*Zh. tekh. Fiz.*, vol. 25, pp. 945–946; May, 1955.)

537.227:546.431.824–31 1438

Ferroelectric Hysteresis in Barium Titanate Single Crystals—H. H. Wieder. (*J. appl. Phys.*, vol. 26, pp. 1479–1482; December, 1955.) An experimental and theoretical investigation has been made of the hysteresis loop of crystals with antiparallel domains only. Measurements were made over the temperature range −100° to +100°C. Coercivity and losses decrease sharply as the crystal passes through the phase transitions from tetragonal to orthorhombic at −10°C and from orthorhombic to trigonal at −90°C but the loop retains rectangularity. It may be possible by controlling the crystal growth to shift the orthorhombic phase to room temperature.

537.311.33 1439

The Transport of Injected Electrons and Holes in a Semiconductor—R. Gevers. (*Physics*, vol. 21, pp. 888–896; November, 1955.) Laplace-transformation technique is used to solve differential equations describing the transport of added current carriers in a homogeneous semi-conductor. For time intervals much greater than the relaxation time, the result agrees with that derived by Keilson (753 of 1954) using a different method. An effective diffusion coefficient and a mobility value applicable to the establishment of charge neutrality during the relaxation time are introduced. The value of the small local space charge occurring during the transport period is calculated. The polarizability of the injected pairs if the applied field is alternating is discussed.

537.311.33:546.23/.24:539.26 1440

Soft X-Ray Absorption of Tellurium and Vitreous and Metallic Selenium—M. P. Givens, C. J. Koester, and W. L. Goffe. (*Phys. Rev.*, vol. 100, pp. 1112–1115; November 15, 1955.) Measurements are reported and the results are discussed in relation to the density of states in the conduction band.

537.311.33:[546.28+546.289 1441

Crystal Cutting—T. H. Kinman and C. Hayward. (*B. T.-H. Activ.*, vol. 26, pp. 137–139; September/October, 1955.) A method of slicing and dicing Ge and Si crystals is described, using a multiple tungsten-wire cutter.

537.311.33:546.28 1442

Electrical Properties of Near-Degenerate Boron-Doped Silicon—R. O. Carlson. (*Phys. Rev.*, vol. 100, pp. 1075–1078; November 15, 1955.) Measurements have been made of resistivity and Hall effect in single-crystal Si specimens with B content in the range 10^{18}–10^{19} atoms/cm^3. The anomalous Hall mobility effect previously observed by Morin and Maita (750 of 1955) was studied over the temperature range 25°–300°K. For degenerate samples the Hall mobility is about 46 cmps per v/cm at 300°K.

537.311.33:546.289 1443

Minority Carrier Extraction in Germanium—R. Bray. (*Phys. Rev.*, vol. 100, pp. 1047–1055; November 15, 1955.) A method of carrier extraction is discussed in which special contacts are used to limit the entry of minority carriers into the specimen while offering no barrier to majority carriers. Almost complete depletion of minority carriers was obtained with electric fields of strength well under 50 v/cm using samples 1–2 cm long with minority-carrier lifetime of the order of 100 µs. Resistance at 65°C was increased as much as 13-fold, corresponding to extraction of about 90 per cent of all the carriers, for a specimen with room-temperature resistivity of 32 Ω/cm. This method of extraction has been termed "exclusion" by Low (3296 of 1955).

537.311.33:546.289 1444

Removal of Copper from Germanium—K. B. Blodgett. (*J. appl. Phys.*, vol. 26, pp. 1520–1521; December, 1955.) Samples of *n*-type Ge were first coated with Cu which was allowed to diffuse into the interior. Experiments were then made on removing the Cu by heating the samples at 700°C a) in O_2 atmosphere, b) in H_2 atmosphere, or c) in H_2, the samples being coated with an iron salt. The results indicate that the coating in method c) serves as a "sink" for the Cu; by cleaning off the surface and applying a fresh coating the Cu content can be reduced repeatedly.

537.311.33:546.289 1445

A Study of the Etching Rate of Single-Crystal Germanium—P. R. Camp. (*J. electrochem. Soc.*, vol. 102, pp. 586–593; October, 1955.) Experiments were made using etchants composed mainly of H_2O_2, HF, and water. The temperature variation of the etching rate is consistent with the assumption that two surface reactions take place in sequence. Crystal orientation is significant. From the etching data, the thickness of the surface layer disturbed by abrasive grinding was estimated to be 2–10 μ.

537.311.33:546.289 1446

Electrolytic Etching at Small-Angle Grain Boundaries in Germanium—S. G. Ellis. (*Phys. Rev.*, vol. 100, pp. 1140–1141; November 15, 1955.) "There is a difference of appearance between *n*-type and *p*-type germanium crystals which have been anodically etched. This can be explained if only the hole current contributes to the etching. An *n*-type crystal can be made to etch in the same way as a *p*-type crystal if injected holes reach the crystal-electrolyte interface. Hole-electron recombination within the crystal can then reduce the rate of etching. Such recombination at small-angle grain boundaries has been demonstrated."

537.311.33:546.289 1447

Electron Microscopy of Etched Germanium Surfaces—J. W. Allen and K. C. A. Smith. (*J. Electronics*, vol. 1, pp. 439–443; January, 1956.) Examination of Ge surfaces, etched by a reagent whose activity depends on the presence of free carriers, reveals raised areas which may mark the emergence of edge dislocations.

537.311.33:546.289 1448

Variation of the Conductivity of Germanium by an External Electric Field—S. G. Kalashnikov and A. E. Yunovich. (*Zh. tekh. Fiz.*, vol. 25, pp. 952–954; May, 1955.) Negative charges were induced on thin plates of Ge, and the conductivity of the plates was measured. Considerable variation was observed, depending on the type of Ge used and on the previous surface treatment (polishing or etching). These experiments show that surface treatment considerably alters the surface states, and also that the normally observed hole conductivity of the surface layer is changed into electronic conductivity when paraffin wax is present at the surface.

537.311.33:546.289:535.215 1449

Longitudinal Photomagnetoelectric Effect in Germanium—J. Aron and G. Groetzinger. (*Phys. Rev.*, vol. 100, pp. 1128–1129; November 15, 1955.) "The emf developed parallel to the gradient of light absorption (Dember emf) in a germanium crystal is reduced by the application of a transverse magnetic field, the diminution being about 10 per cent for a field of 5,000 gauss. The size of the effect is approximately quadratic in the field up to about 2,000 gauss, is then linear to 4,000 gauss, and subsequently saturates."

537.311.33:546.289:537.228 1450

Temperature Dependence of the Elastoresistance in *n*-Type Germanium—R. W. Keyes. (*Phys. Rev.*, vol. 100, pp. 1104–1105; November 15, 1955.) A more extensive study of the temperature dependence of the elastoresistance of *n*-type Ge than that reported by Smith (2418 of 1954) indicates that the elastoresistance is inversely proportional to absolute temperature, in agreement with theory developed; *e.g.*, by Herring (2642 of 1955).

537.311.33:546.289:538.214 1451

Magnetic Susceptibility of Germanium—D. K. Stevens, J. W. Cleland, J. H. Crawford, Jr., and H. C. Schweinler. (*Phys. Rev.*, vol. 100, pp. 1084–1093; November 15, 1955.) An experimental investigation covering the frequency range 70°–300°K is reported. High-purity specimens exhibit decreasing diamagnetism with increasing temperature. The charge-carrier susceptibility for *n*- and *p*-type specimens is found by comparing the observations with those for the pure Ge at the same temperature. Deductions are made regarding the charge-carrier masses and the nature of the energy surfaces. The specimens examined included one of *n* type which had been bombarded by fast neutrons.

537.311.33:546.289:539.89 1452

Conductivity, Hall Effect, and Magnetoresistance in *n*-Type Germanium, and their Dependence on Pressure—G. B. Benedek, W. Paul, and H. Brooks. (*Phys. Rev.*, vol. 100, pp. 1129–1139; November 15, 1955.) Measurements have been made over the pressure range 1–10,000 kg/cm². The results are interpreted in terms of a low-field theory based on a shape parameter of the energy ellipsoids and on the dependence of collision time on energy. Effects due to impurities are considered.

537.311.33:546.289:621.314.7 1453

Transistor Fabrication by the Melt-Quench Process—J. I. Pankove. (PROC. IRE, vol. 44, pp. 185–188; February, 1956.) A method is described for forming *p-n* junctions close to one another in a bar of impurity-doped Ge by partly melting the material and resolidifying it. The method is distinguished from that described by Pfann (2125 of 1954) by the high speed of the solidifying process, which may be >0.85 cmps.

537.311.33:546.289:621.396.822 1454

Noise in Germanium—S. Okazaki and H. Oki. (*J. phys. Soc. Japan*, vol. 10, pp. 910–912; October, 1955.) Observations were made on thin single-crystal specimens over the frequency range 100 kcps–100 mc, using a heterodyne circuit with square-law detector and cro. The excess current noise varies with frequency according to a $1/f^{\beta}$ law, where β is always >1 and most often about 2. The noise figure at 100 kc is 10–20 db when the current passed is 5 ma.

537.311.33:546.3-1-28-289 1455

Magnetoresistance of Germanium-Silicon Alloys—M. Glicksman. (*Phys. Rev.*, vol. 100, pp. 1146–1147; November 15, 1955.) Measurements have been made on *n*-type crystals with various compositions. The results are consistent with the energy-band structure suggested by Herman (460 of 1955).

537.311.33:546-3-1-28-289:538.569.4 1456

Cyclotron Resonance in Ge-Si Alloys—G. Dresselhaus, A. F. Kip, Han-Ying Ku, G. Wagoner, and S. M. Christian. (*Phys. Rev.*, vol. 100, pp. 1218–1219; November 15, 1955.)

537.311.33:547 1457

The Semiconductivity of Organic Substances: Part 2—D. D. Eley and G. D. Parfitt. (*Trans. Faraday Soc.*, vol. 51, pp. 1529–1539; November, 1955.) The resistance of crystalline organic substances in vacuo has been determined by an ac method. The results are used to determine the energy gaps for intrinsic semiconductivity in *iso*dibenzanthrone (0.96 ev), α:α-diphenyl β-picryl hydrazyl (0.26 ev) and metal-free phthalocyanine (1.49 ev). An impurity conductivity has been detected in phthalocyanine at temperatures up to about 150°C. Possible conduction mechanisms are discussed. Part 1: *ibid.*, vol. 49, pp. 79–86 (Eley *et al.*) 1953.

537.311.33:621.314.7 1458

Transistor Physics—W. Shockley. (*Proc. IEE*, Part B, vol. 103, pp. 23–41; January, 1956.) Text of the 46th Kelvin lecture. Crystal imperfections basic to transistor operation are indicated and the technology of controlling these imperfections to produce desired properties is discussed.

538.221 1459

On the Origin of Magnetic Anisotropy induced by Magnetic Annealing—S. Chikazumi and T. Oomura. (*J. phys. Soc. Japan*, vol. 10, pp. 842–849; October, 1955.) The anisotropy induced by annealing was measured as a function of the composition of Fe-Ni alloys for various cooling rates. The results are not compatible with theories of "strain in directional order" or of "elongated order phase," but are consistent with a theory of dipole-dipole interaction differing with different sorts of atomic pairs.

538.221 1460

Effect of Shape Anisotropy on the Coercive Force of Elongated Single-Magnetic-Domain Iron Particles—T. O. Paine, L. I. Mendelsohn, and F. E. Luborsky. (*Phys. Rev.*, vol. 100, pp. 1055–1059; November 15, 1955.) Experiments have been made on elongated particles with diameters around 150 Å, produced by an electrodeposition method. Direct correlation was observed between the coercive force and the length/diameter ratio of the particles.

538.221 1461

An Approach to Elongated Fine-Particle Magnets—I. S. Jacobs and C. P. Bean. (*Phys. Rev.*, vol. 100. pp. 1060–1067; November 15, 1955.) The relation between the coercive force and the shape of elongated single-domain particles is examined in the light of experimental results obtained by Paine *et al.* (1460 above). A "chain-of-spheres" model is presented by means of which the processes involved can be explained.

538.221 1462

The Fluctuating Field Model of Ferromagnetism with Particular Reference to Nickel—F. D. Stacey. (*Canad. J. Phys.*, vol. 33, pp. 661–667; November, 1955.)

538.221 1463

Influence of Carbon in Solution on the Magnetic Properties of Soft Iron and 3.5% Si Iron Alloys—A. Ferro and G. Montalenti. (*Ricerca sci.*, vol. 25, pp. 2828–2833; October, 1955.) Armco and other alloys were investigated. The percentage of free carbon is deduced from magnetic relaxation measurements. The differences in behavior are related to the different mobility of free carbon in the Si-Fe matrix.

538.221 1464

Investigation of Nucleation Centres of Reverse Magnetization in Silicon Iron Crystals—Ya. S. Shur and V. R. Abel's. (*C.R. Acad. Sci. U.R.S.S.*, vol. 105, pp. 469–471; November 21, 1955. In Russian.) An experimental study, by the powder-pattern method, of domain formation on reverse magnetization. Specimens of 4 per cent Si iron 0.1–0.2 mm thick were used. See also 470 of 1955 (Goodenough) and Bates and Martin, *Proc. phys. Soc.*, vol. 66, pp. 162–166; February 1, 1953.

538.221:538.632 **1465**
The Spontaneous Hall Effect in Ferromagnetics: Part 1—J. Smit. (*Physica*, vol. 21, pp. 877–887; November, 1955.) The effect is investigated analytically and experimentally; measurements at different temperatures suggest that it is closely related to the resistivity of the material. An explanation of the effect is advanced based on an isotropic scattering of conduction electrons by lattice imperfections.

538.221:546.74 **1466**
Influence of the Internal State on the Position of the Poles in Magnetized Nickel Wires—C. Schwink. (*Z. Phys.*, vol. 143, pp. 205–218; November 18, 1955.) The influence of stresses and texture on the position of magnetic poles was investigated using an electron-optical method [2465 of 1954 (Marten *et al.*)] The results in the region of plastic deformation can be explained on present-day theories of the behavior of polycrystalline metals; in the region of mixed plastic-elastic deformations results are explained by assuming an easily deformable surface layer of thickness about 0.03 mm.

538.221:621.318.134 **1467**
Origin of the Uniaxial Anisotropy in Iron-Cobalt Ferrites—S. Iida, H. Sekizawa, and Y. Aiyama. (*J. phys. Soc. Japan*, vol. 10, p. 907; October, 1955.)

538.221:621.318.134 **1468**
Note on an Investigation of the Anomalous Time-Constant of Certain Iron-Deficient Magnesium Manganese Ferrites—L. C. F. Blackman and N. P. R. Sherry. (*J. Electronics*, vol. 1, pp. 385–388; January, 1956.) Experiments on MgMn ferrites having Fe deficiencies of 10 per cent–40 per cent show that the dielectric constant, and possibly also the resistivity, of the material is critically dependent on firing temperature, showing a pronounced peak corresponding to temperatures between 1,330° and 1,380°C. The effect diminishes as the Fe content is increased and is not present in the stoichiometric material.

538.221:621.376.32 **1469**
Measurements of Reversible Permeability and their Theoretical Interpretation—H. Wilde. (*Z. angew. Phys.*, vol. 7, pp. 509–513; November, 1955.) A variometer having a ferrite core and a magnetizing coil with high-μ core was used as an oscillator at a mean frequency of 75 mc in experiments to determine how useful such an arrangement would be as an usw frequency modulator. The frequency/excitation-current characteristic is of "butterfly" form, the splitting being due to hysteresis. The relation between the main curve and the modulation loops obtained at different values of bias current is investigated. The field-strength variation of the over-all reversible permeability determined by calculating the contributions from the elementary domains before and after wall movements is in good agreement with measured values.

538.569.3.029.63/.64 **1470**
Broadband Absorbing Materials—W. H. Emerson, A. G. Sands, and M. V. McDowell. (*Tele-Tech & Electronic Ind.*, vol. 14, Section 1, pp. 74–75, 137; November, 1955.) An experimental investigation of microwave absorption by spun mats of animal hair impregnated with a special rubber solution is reported. A typical value of the reflection factor for an 8-in.-thick mat on a metal base is <2 per cent at 500 mc. Percentage-reflection curves are given for two specimens at frequencies up to >10 kmc.

538.569.4:546.87 **1471**
Cyclotron Absorption in Bismuth—R. N. Dexter and B. Lax. (*Phys. Rev.*, vol. 100, pp. 1216–1218; November 15, 1955.)

538.639:546.87:537.311.31 **1472**
Effect of Small Admixtures on Galvanomagnetic Properties of Bismuth—N. E. Alekseevski., N. B. Brandt, and T. I. Kostina. (*C.R. Acad. Sci. U.R.S.S.*, vol. 105, pp. 46–49; November 1, 1955.. In Russian.) The magnetoresistance effect in Bi with traces of Sn and Te impurities was investigated experimentally at zero and at 1,750 atm pressure, at low temperatures. Results are presented graphically. See also 3632 of 1955 (Alekseevski and Brandt).

549.514.51 **1473**
Investigation of Pieozelectric Oscillations of Quartz by X-Ray Diffraction—R. Mermod. (*Helv. phys. Acta*, vol. 28, pp. 543–562; November 15, 1955. In French.)

549.514.51:537.226 **1474**
Dielectric Constant of Quartz as a Function of Frequency and Temperature—M. R. Stuart. (*J. appl. Phys.*, vol. 26, pp. 1399–1404; December, 1955.) Measurements were made over the temperature range 20°–400°C, at frequencies from 1 to 90 kc, with the electric field directed along the optic axis. Results are presented graphically and discussed in relation to the hypothesis that ions are displaced in "tunnels" parallel to the optic axis.

621.315.61 **1475**
Dielectric Absorption due to Water of Crystallization in Pinacol Hydrate—J. S. Cook and R. J. Meakins. (*Trans. Faraday Soc.*, vol. 51, pp. 1483–1488; November, 1955.) Results are reported of dielectric measurements made at frequencies between 5 cps and 50 mc, at various temperatures. The dielectric absorption and dispersion decrease rapidly with decreas-water content.

621.315.61:546.287 **1476**
Silicone Insulants—J. D. Hayden. (*Electronic Engng*, vol. 28, pp. 58–63, February and pp. 115–119; March, 1956.) An illustrated review of properties and applications.

621.315.616 **1477**
An Investigation into the Relaxation Processes in Polyvinyl Acetate at Temperatures below the Softening Temperature—P. F. Veselovski and A. I. Slutsker. (*Zh. tekh. Fiz.*, vol. 25, pp. 939–942; May, 1955.) Measurements of the dielectric properties of the material were carried out over a temperature range from −150° to +20°C and a frequency range from 50 to 10^{10} cps. Experimental curves are shown.

621.318.22:538.221 **1478**
A Method of preparing Iron Powder for Permanent Magnets—E. H. Carman. (*Metallurgia, Manchr*, vol. 52, pp. 165–168; October, 1955.)

621.791.3 **1479**
The Significance of Contact-Angle Measurements in Soldering—N. R. Srinivasan and H. S. Aswath. (*J. Indian Inst. Sci.*, Section B, vol. 37, pp. 293–303; October, 1955.)

MATHEMATICS

517.93 **1480**
Uniformly Almost Periodic Solutions of Nonlinear Differential Equations of the Second Order: Part 1—General Exposition—C. Obi. (*Proc. Camb. phil. Soc.*, vol. 51, Part 4, pp. 604–613; October, 1955.

MEASUREMENTS AND TEST GEAR

621.3.018.41(083.74)+529.786 **1481**
The Unit for Frequency—J. Hers. (PROC. IRE, vol. 44, pp. 260–261; February, 1956.) Bullard's suggestion to adopt a new definition of the second (3686 of 1955) is deprecated. It is suggested that the unit of frequency, to be termed the hertz, should be defined independently of the second as the 9 192 632th part of Cs frequency. A more precise value could be adopted later by international agreement; the value should be such that one hertz would equal one cycle per second at some convenient date.

621.3.018.41(083.74):621.396.9 **1482**
Frequency Variations in New Zealand of 16-kc/s Transmissions from GBR Rugby—A. H. Allan, D. D. Crombie, and W. A. Penton. (*Nature, Lond.*, vol. 177, pp. 178–179; January 28, 1956.) The frequency of the received signal has been compared with that of a local standard crystal oscillator adjusted to be about 3 parts in 10^7 fast; the beats were recorded continuously. Specimen records illustrate the diurnal distribution of the apparent frequency variation of the transmitted signals. The frequency of WWVH was measured at the same site [*J. Instn. elect. Engrs.*, vol. 1, pp. 650–651; October, 1955 (Allan)] shows variations at least one order greater than those of GBR.

621.317.3:621.314.7 **1483**
Measuring R.F. Parameters of Junction Transistors—W. N. Coffey. (*Electronics*, vol. 29, pp. 152–155; February, 1956.) "Equipment and techniques for measuring small-signal *h* parameters of triode and tetrode junction transistors in the range from 1 to 24 mc are described."

621.317.3:621.396.822 **1484**
Measurement of Electrical Fluctuations with the Aid of Thermoelectric Devices—V. I. Tikhonov. (*Zh. tekh. Fiz.*, vol. 25, pp. 817–822; May, 1955.) It is suggested that thermocouples and thermistors may be used as standard noise sources for measurement of noise spectra. The theory of the method is discussed and a formula (16) is derived determining the accuracy of the measurements. A brief report is also given on an experiment.

621.317.312 **1485**
The Exact Measurement of Alternating Currents—G. Trautner. (*Arch. Elektrotech.*, vol. 42, pp. 94–99; August 30, 1955.) An arrangement is described using a Wheatstone bridge with one load-dependent resistance and an ordinary vibration galvanometer as null indicator. After initial calibration with dc, an ac of, *e.g.*, 170 ma can be determined to within 0.04 per cent.

621.317.32 **1486**
Time-Voltage Pulse Discriminator—C. E. Lowe. (*Electronics*, vol. 29, pp. 178, 186; February, 1956.) A circuit is described whose sensitivity is not affected by the absolute magnitude of the compared voltages. The difference component is detected as a series of pulses by the use of an alternating reference voltage in a bridge network.

621.317.32:621.385.032.216 **1487**
Arrangement of the Measurement of Low Alternating Voltages by the Compensation Method—A. Vanavermaete. (*Helv. phys. Acta*, vol. 28, pp. 522–524; November 15, 1955. In French.) A description is given of a circuit designed primarily for measuring the conduction properties of oxide cathode coatings.

621.317.382.029.6:538.632 **1488**
The Hall Effect and its Application to Power Measurement at Microwave Frequencies—H. E. M. Barlow and L. M. Stephenson. (*Proc. IEE*, Part B, vol. 103, pp. 110–112; January, 1956.) Experiments were made on a crystal of *n*-type Ge mounted in a cavity resonator magnetically coupled to a rectangular waveguide, so that the crystal was immersed in a microwave field; a current proportional to the microwave electric field was passed through the crystal at right angles to the microwave magnetic field. The time average of the Hall emf observed under these conditions was approxi-

mately proportional to the power in the waveguide. The method can be used under any conditions of load without absorbing more than a small fraction of the power being transmitted.

621.317.7:621.397.6 1489

A Test-Signal Generator for Measurements on Television Transmission Systems—O. Macek. (*Frequenz*, vol. 9, pp. 380–386; November, 1955.) The signals provided by the equipment discussed are those recommended by the German Funk-Betriebs-Kommission; these are compared with those recommended by the CCIF.

621.317.7.089.6:621.311.6 1490

An Electronic Supply for Use in the Calibration of Instruments—Wilkins and Harkness. (See 1554.)

621.317.727:681.142 1491

A Digital Potentiometer—Dean and Nettell. (See 1314.)

621.317.729 1492

The Rubber Membrane and Resistance Paper Analogies—J. H. O. Harries. (Proc. IRE, vol. 44, pp. 236–248; February, 1956.) Methods of investigating fields by means of rubber-membrane and resistance-paper models are reviewed; precautions necessary to avoid errors are indicated.

621.317.742 1493

Standing-Wave Detector with a Helix-Line Element—F. J. Tischer. (*Tele-Tech & Electronic Ind.*, vol. 14, Section 1, pp. 70–71, 134; November, 1955.) The detector comprises an insulated helix wound on a metal cylinder. This reduces the wave velocity by a factor of 10, resulting in an extension of the useful range to below 500 mc.

621.317.755 1494

The Recording of High-Speed Single-Stroke Electrical Transients—D. R. Hardy, B. Jackson, and R. Feinberg. (*Electronic Engng.*, vol. 28, pp. 8–12, January and pp. 75–79; February, 1956.) A review of developments during the last 20 years, covering cr tubes, auxiliary circuits and photographic techniques. 81 references.

621.317.755:621.385.832 1495

A Precision Cathode-Ray Oscillograph with a Spot Diameter of a few μ—M. von Ardenne. (*NachrTech.*, vol. 5, pp. 481–489; November, 1955.) Detailed description of an instrument in which the oscillograms are photographed at normal size; the area of the spot is about 10^{-9} times that of the screen. A reduced image of the first crossover is produced by an auxiliary magnetic lens, and a slightly magnified image of this second crossover is produced by the main magnetic lens. Reproduced oscillograms of various phenomena indicate the degree of detail attainable.

621.317.761:538.569.4 1496

Broadband Microwave Frequency Meter—P. H. Vartanian and J. L. Melchor. (Proc. IRE, vol. 44, pp. 175–178; February, 1956.) An arrangement is described depending on paramagnetic resonance in α,α-diphenyl β-picryl hydrazyl; its operating range is from 600 mc upwards through the X band. The hydrazyl is contained in a 2-inch section of coaxial line placed in a longitudinal magnetic field. A cro indication of resonance is obtained as the magnetic field is swept up to 4 kg. Frequencies 8 mc apart in the S band can be resolved, and single frequencies can be determined to within ±1 mc.

621.317.761.029.51/.63 1497

Wide-Range Heterodyne Frequency Meter—W. C. Richard. (*Tele-Tech & Electronic Ind.*, vol. 14, Section 1, pp. 86–87, 149; November, 1955.) A description is given of a meter for the range 10 kc–1.040 kmc developed for the U.S. Signal Corps. The range is covered by using the harmonic output of a modified Hartley oscillator with fundamental ranges 125–250 kc and 2.5–5 mc and of a particular version of the Colpitts circuit with fundamental range 65–130 mc. Schematic and block diagrams are given.

621.317.79:621.396.822 1498

Automatic Noise-Factor Meter—H. Wallman. (*Chalmers tek. Högsk. Handl.*, no. 161, 17 pp.; 1955.) A null method is described based on the principle of balancing amplifier noise against ½ (amplifier noise+noise-diode noise); the advantage over other standard methods is that the only source of systematic error lies in the calibration of the 3-db attenuator used.

621.317.794 1499

Metal-Resistance Bolometers at Low Temperatures—K. Bischoff, E. Justi, M. Kohler, and G. Lautz. (*Z. Naturf.*, vol. 10a, pp. 401–412; May, 1955.) Sensitivity can be improved by operating at an appropriate low temperature; using a Ni-foil element, the sensitivity at 90°K is ten times as great as at room temperature. The problem is discussed in relation to measurements of long-wave infrared radiation, and the effect of interrupting the radiation is considered.

621.319.4(083.74) 1500

An Adjustable Absolute Capacitance Standard—G. Zickner. (*Arch. Elektrotech.*, vol. 42, pp. 71–93; August 30, 1955.) Description of the cylindrical capacitance standard of the Physikalisch-Technische Bundesanstalt. The capacitance is about 100 pf and the setting accuracy about 0.001 pf per scale division. The absolute value can be estimated to within 0.15 per cent in the least favorable circumstances.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

550.8:534.2–8 1501

The Scientific Bases for the Use of Ultrasonics in Mining and Geology—I. Malecki. (*Acta tech. Acad. Sci., hungaricae*, vol. 13, pp. 397–407; 1955. In German.)

621.3–52:621.9 1502

Electronic Controls for Machine Tools—D. A. Findlay. (*Electronics*, vol. 29, pp. 122–129; February, 1956.)

621.3.012.8:621–52:628.8 1503

Electrical Analogues for Heat Exchangers—R. L. Ford. (*Proc. IEE*, Part B, vol. 103, pp. 65–82; January, 1956.) Equivalent circuits for heat exchangers are discussed in relation to problems of automatic control. Circuits composed entirely of passive elements and circuits including amplifiers are considered.

621.317.39:538.221 1504

A High-Frequency Method for Metallurgical Investigations of Magnetic Alloys—F. Fraunberger. (*Z. Metallkde*, vol. 46, pp. 749–751; October, 1955.) The method described is based on the marked dependence of the alloy resistivity on its crystal structure at frequencies above those at which irreversible processes play a part.

621.317.39:620.1.08 1505

The Phase Comparator—J. C. Anderson. (*Electronic Engng.*, vol. 28, pp. 63–65; February, 1956.) Description of a nondestructive method of testing steel springs by measuring the L/R ratio for a coil within which the spring is compressed.

621.384.6 1506

Cascade Generators for Particle Acceleration up to 4 MeV—W. Heilpern. (*Helv. phys. Acta*, vol. 28, pp. 485–491; November 15, 1955. In German.) Circuit modifications leading to reduced ripple and internal resistance are described.

621.384.6+621.387.4]:539.1(44) 1507

Nuclear Energy and its Industrial Applications: Part 2—Particle Accelerators and Nuclear-Physics Apparatus—(*Onde élect.*, vol. 35, pp. 955–1115; November, 1955.) This issue comprises a further group of papers on subjects including particle counters and other electronic apparatus and techniques involved in nuclear physics. Part 1: 958 of 1956.

621.384.611/.612 1508

Nonlinear Regenerative Extraction of Synchrocyclotron Beams—K. J. Le Couteur and S. Lipton. (*Phil. Mag.*, vol. 46, pp. 1265–1280; December, 1955.) Analysis indicates that a nonlinear deflector can extract the beam with higher energy and perhaps greater theoretical efficiency than the linear one used hitherto in the Liverpool machine. See also 873 of 1956.

621.384.612 1509

The Influence of Magnetic-Field Errors on Betatron Oscillators in the Strong-Focusing Synchrotron—G. Luders. (*Nuovo Cim.*, supplement to vol. 2, pp. 1075–1146; 1955. In German.) Summarized report of research carried out for the European Organization for Nuclear Research up to the autumn of 1953.

621.385.833 1510

Investigation of Focusing Properties of Cylindrical Magnetic Lenses and Systems comprising such Lenses—S. Ya. Yavor. (*Zh. tekh. Fiz.*, vol. 25, pp. 779–790; May, 1955.)

621.385.833 1511

Determination of the Magnetic Field for focusing Electron Beams of a Given Type—I. I. Tsukkerman. (*Zh. tekh. Fiz.*, vol. 25, pp. 853–860; May, 1955.) The limitations are established which are imposed on the magnetic field of a curvilinear electron-optical system when the axial trajectory of the beam and the electric field adjacent to this trajectory are given, and also when it is required to obtain a real similar image in a given normal plane. Examples are given of the design of some purely magnetic electron-optical systems (systems with spiral, circular and straight-line axes).

621.385.833 1512

Variable-Magnification Magnetic Electron-Optical Systems free from Image Rotation—Tsukkerman. (See 1598.)

621.385.833 1513

Numerical Calculation of the Induction in a Magnetic Electron Lens causing No Image Rotation—M. Laudet. (*C.R. Acad. Sci., Paris*, vol. 241, pp. 1728–1730; December 14, 1955.)

621.385.833 1514

100-keV Electrons in the Electrostatic Electron Microscope (Intermediate Accelerator)—G. Möllenstedt. (*Optik, Stuttgart*, vol. 12, pp. 441–466; 1955.) Description of an instrument in which the cathode potential is −50 kv and the object potential is +50 kv, so that the electrons are incident on the object with an energy of 100 kev, while the energy of electrons striking the viewing screen is arranged to be only 50 kev.

621.385.833 1515

New Quantitative Methods in Electron-Optical Shadow Technique—C. Schwink. (*Optik, Stuttgart*, vol. 12, pp. 481–496; 1955.) Continuation of previous work [1536 of 1954 (Rollwagen and Schwink)]. The finite divergence of the illuminating beam is taken into account. Possible methods of improving the sensitivity are discussed.

621.387.464 1516

Characteristics of the Optical Arrangement of a Scintillation Counter—Y. Koechlin. (*J. Phys. Radium*, vol. 16, pp. 849–853; November, 1955.) An investigation is made of the possibility of increasing the fraction of the scintillation light reaching the cathode of the photomultiplier cell by providing the scintillator with a diffusing coating; the influence of geometric factors is also studied.

621.398:631.3 1517

Radio-Controlled Tractor—(*Engineer, Lond.*, vol. 200, pp. 518–519; October 7, 1955.) A system demonstrated near London used a battery-operated 27.12-mc transmitter with six nonsimultaneous channels, provided by tone modulation, respectively controlling the steering left and right, clutch release, implement raising and lowering, and engine stop. The receiver has tuned-reed relays.

621.398:681.142 **1518**

A Transducer for Digital Data-Transmission Systems—R. H. Barker. (*Proc. IEE*, Part B, vol. 103, pp. 42–51; January, 1956.) Transducers for target-coordinate representation, for weapon control systems, have been constructed to represent the angular position of a shaft as a 14-digit binary number; *i.e.*, to an accuracy of rather better than one minute of arc. Photoelectric scanning is used. Possible errors are discussed.

537.228.1:621.317.39 1519

Einführung in die piezoelektrische Messtechnik [Book Review]—W. Gohlke. Publishers: Akademische Verlagsgesellschaft Geest and Portig, Leipzig, 241 pp., 1954. (*Z. angew. Phys.*, vol. 7, pp. 555; November, 1955.) This introduction to piezoelectric measurements consitutes the eighth volume of a series of technical-physical monographs, and provides a detailed treatment of the fundamentals and applications of the subject.

PROPAGATION OF WAVES

621.396.11 1520

The Shielding of Radio Waves by Conductive Coatings—E. L. Hill. (TRANS. IRE, vol. AP-3, pp. 72–76; April, 1955.) The subject is discussed with particular reference to shielding effects experienced in aircraft where conducting coatings are provided on external surfaces to prevent charge accumulation; wavelengths considered are long compared with openings in the aircraft skin.

621.396.11:551.510.535 1521

The Interaction of Pulsed Radio Waves in the Ionosphere—J. A. Fejer. (*J. atmos. terr. Phys.*, vol. 7, pp. 322–332; December, 1955.) Preliminary daytime measurements using low-power transmitters and a receiver on a common site are discussed. The electron and collision frequency density and the energy-loss coefficient are deduced from the theory of Bailey and Martyn (2168 of 1935 and back references). The resulting collision-frequency values agree with laboratory determinations by Crompton *et al.* (106 of 1954) and with a value obtained from work on partial reflections by Gardner and Pawsey (132 of 1954). The electron densities are near those obtained by Gardner and Pawsey. The energy-loss coefficient, obtained in the present case for electrons of low excess energy, is much higher than the values found by Crompton *et al.* working with electrons having high excess energies. The results appear to agree better with the original Bailey-Martyn theory than with the alternative form suggested by Huxley (231 of 1954).

621.396.11:551.510.535 1522

On the Level at which Fading is imposed on Waves Reflected Vertically from the Ionosphere—H. G. Booker. (*J. atmos. terr. Phys.*, vol. 7, pp. 343–344; December, 1955.) By comparing theoretical with experimental autocorrelation functions for plane waves incident normally upon a diffracting screen, it is shown that fading is imposed upon the wave within, or near, the reflecting stratum; scattering by irregularities in this region plays an important part in the propagation of the wave.

621.396.11:551.510.535 1523

Some Results of a Sweep-Frequency Propagation Experiment over an 1150-km East-West Path—B. Wieder. (*J. geophys. Res.*, vol. 60, pp. 395–409; December, 1955.) Experiments using a pulsed sweep-frequency ionosphere recorder at each of the end points and another at the midpoint of the great-circle path show that the transmission-curve-derived F_2-layer muf is up to 5 per cent too low, depending on time of day and season.

621.396.11:551.510.535 1524

Sweep-Frequency Pulse-Transmission Measurements over a 2400-km Path—P. G. Sulzer. (*J. geophys. Res.*, vol. 60, pp. 411–420; December, 1955.) Analysis of results of experiments similar to those detailed by Wieder (1523 above) shows propagation on numerous occasions during the winter of 1953–54 at frequencies considerably above the muf calculated from vertical-incidence observations at the midpoint of the path.

621.396.11:551.510.535 1525

Heights of Irregularities giving Rise to the Fading of 150-kc/s Waves—Banerji. (See 1415.)

621.396.11:551.510.535 1526

Polarization of Electromagnetic Waves for Vertical Propagation in the Ionosphere—R. Roy and J. K. D. Verma. (*J. geophys. Res.*, vol. 60, pp. 457–482; December, 1955.) A solution is given of the wave equations obtained; *e.g.*, by Saha *et al.* (1442 of 1948), and the orientation of the polarization ellipses is deduced. Electron density and collision frequency in the ionized layers are deduced from the value of the tilt angle and the ratio of the ellipse axes. Applied to experimentally obtained patterns, the theory gives a value of 1.7×10^6 per second for the collision frequency in the *E* layer.

621.396.11:551.510.535 1527

Regularly-Observable Aspect-Sensitive Radio Reflections from Ionization aligned with the Earth's Magnetic Field and located within the Ionospheric Layers at Middle Latitudes—A. M. Peterson, O. G. Villard, Jr., R. L. Leadabrand, and P. B. Gallagher. (*J. geophys. Res.*, vol. 60, pp. 497–512; December, 1955.) The reflection geometry and the characteristics of echoes received at frequencies between 6 and 30 mc suggest that the phenomenon is caused by a type of particle bombardment generally similar to that which is believed to cause the aurora.

621.396.11:551.594.6:523.78 1528

The Influence of the Solar Eclipse on the Propagation of Atmospherics in the Frequency Range 5–30 kc/s—Skeib. (See 1400.)

621.396.11.029.51:551.510.535 1529

Long-Range Propagation of Low-Frequency Radio Waves between the Earth and the Ionosphere—J. Shmoys. (PROC. IRE, vol. 44, pp. 163–170; February, 1956.) "The problem of modes of propagation of electromagnetic waves between a perfectly conducting earth and a gradually varying ionosphere is considered. The case of exponentially varying ionospheric parameters is solved in terms of Bessel functions. The propagation constant, the angle of arrival and the group velocity are calculated for the first few modes of propagation."

621.396.11.029.6 1530

Synthesis of Radio Signals on Overwater Paths—A. H. LaGrone, A. W. Straiton, and H. W. Smith. (TRANS. IRE, vol. AP-3, pp. 48–52; April, 1955.) The fluctuations of microwave radio signals on overwater paths are correlated with variations in water level. The signal-strength variations will contain the first, second and third harmonics of the water-level cycles. An expression is derived relating the cross-correlation function of signal-strength variations at two vertically spaced antennas with variations of spacing.

621.396.11.029.62 1531

Radio Transmission Loss vs Distance and Antenna Height at 100 Mc/s—P. L. Rice and F. T. Daniel. (TRANS. IRE, vol. AP-3, pp. 59–62; April, 1955.) Curves based on extensive observations are given which are considered to be more precise than those published in 1949 by the FCC Ad Hoc committee [see 3524 of 1949 (Lewis)].

621.396.11.029.62 1532

Coverage Conditions for TV and F.M. Stations elucidated by Field-Strength Charts—K. Steen-Andersen. (*Teleteknik, Copenhagen*, vol. 6, pp. 205–221; November, 1955.) The preparation and method of use of field-strength charts is described. Statistical information gathered by the Danish Post Office is used as basis for a discussion of field-strength distribution inside and outside buildings. Interference of various types is considered. The field-strength values and interference protection conditions laid down at the 1952 Stockholm conference are given for comparison.

621.396.11.029.62:551.594.5 1533

V.H.F. Auroral and Sporadic-E Propagation from Cedar Rapids, Iowa, to Ithaca, New York—R. Dyce. (TRANS. IRE, vol. AP-3, pp. 76–80; April, 1955.) Analysis of continuous records, taken over the period April, 1952 to May, 1954, of reception of a 50-mc transmission show that auroral propagation occurred during 4.77 per cent of the time and propagation by E_s during 0.82 per cent of the time.

RECEPTION

621.396.621:621.376.33 1534

A Locked-Oscillator Quadrature-Grid F.M. Sound Detector—J. Avins and T. Brady. (*RCA Rev.*, vol. 16, pp. 648–655; December, 1955.) The circuit described uses a pentode valve with sharp-cutoff suppressor characteristic. AM rejection and static limiting are provided at high signal level by grid damping and degeneration, and at low signal level by operation of the circuit as a locked oscillator.

621.396.621:621.376.5:621.396.41 1535

Electrical Pulse Communication Systems: Part 3—Transmission and Reception Problems in Pulse Systems—Filipowsky. (See 1546.)

621.396.722 1536

Extendible Long-Distance Receiver Installations for Telegraph Services—W. Hasselbeck. (*Telefunken Ztg.*, vol. 28, pp. 162–171; September, 1955. English summary, p. 196.) A series of rack-mounted units is described including the sw receivers Type E127, Type E104, and Type E305, receiver Type E108 (10 kc–1.8 mc), a teleprinter keying unit, dual-diversity combining unit, double-current power supply unit, etc. Racks are cabled for the maximum number of units, switches in the rack cabling being actuated automatically on inserting a unit. The build-up of installations for reception of various types of transmission is illustrated.

621.396.82.029.51:621.317.729:621.314.7 1537

A Radio Interference Measuring Set using Point-Contact Transistors—J. N. Barry and G. W. Secker. (*Electronic Engng.*, vol. 28, pp. 53–57; February, 1956.) Circuit and detailed description of a portable battery-operated unit designed to measure interference in the long-wave band due to harmonic radiation from television line timebase circuits. The instrument is essentially a superheterodyne receiver with IF 90 kc. The minimum input signal for reliable readings is one giving an output signal/noise ratio of 10 db, *viz.* 1 μv in 75Ω or 15 μv in 15 kΩ.

621.396.821:551.594.6 **1538**
The Effect of Atmospherics on Tuned Circuits—A. G. Edwards. (*J. Brit. IRE*, vol. 16, pp. 31–39; January, 1956.) From a general analysis of the effect of an aperiodic signal on a tuned system the Fourier compoennt at the resonance frequency is determined. Available information on the lightning discharge is summarized, and an estimate is made of the spectrum of the waveform radiated from the main return stroke and its variation at different distances from the source. Experiments are described in which atmospherics received from distant and close sources were recorded simultaneously in tuned and untuned channels. The results are consistent with predictions from earlier work when allowance is made for scatter in source distance.

621.396.828 **1539**
Radio Interference Control in Aircraft—A. L. Albin and J. McManus. (*Tele-Tech & Electronic Ind.*, vol. 14, Section 1, pp. 76–77, 124; November, 1955.) Methods of interference control at frequencies up to several kmc are discussed. The importance of proper bonding and screening of openings by copper mesh is stressed. The use is suggested of waveguide attenuators for holes for control shafts and other openings up to 1-inch diameter. 11 references to U.S. military standards and special reports.

STATIONS AND COMMUNICATION SYSTEMS

621.376.5:534.781 **1540**
Laboratory Equipment for Quantizing Speech—V. H. Allen. (*Electronic Engng.*, vol. 28, pp. 48–52; February, 1956.) Details are given of a trigger unit and quantitizing unit used in investigating the fine structure of speech waveforms and the effect of distortion on intelligibility. The operation of the units in a delta-modulation system is described; with this system, good intelligibility was preserved with quantizing frequencies down to 5 kc.

621.39 **1541**
A Review of Line and Radio-Relay Communication Systems—H. Stanesby. (*Proc. IEE*, Part B, vol. 103, pp. 11–17; January, 1956.) The evolution of long-distance communication systems is outlined and the work on international standardization carried out by the CCIF and the CCIR is mentioned.

621.39.001.11 **1542**
Methods of sampling Band-Limited Functions—R. S. Berkowitz. (Proc. IRE, vol. 44, pp. 231–235; February, 1956.) "A family of signals is considered which lie within a bandwidth of cps. Methods are discussed of experimentally obtaining suitable discrete numbers at the rate of 2 w per second to describe completely any given members of the family. An ***Educated Direct*** sampling method is presented and compared with previously known sampling methods."

621.391.1:621.376.23:621.397.2 **1543**
Transient Response of Detectors in Symmetric and Asymmetric Sideband Systems—Murakami and Sonnenfeldt. (See 1566.)

621.394.14 **1544**
Investigation of a Special Transformation of the Teleprinter Alphabet as a Transformation of Vectors—E. Henze. (*Arch. elekt. Übertragung*, vol. 9, pp. 528–532; November, 1955.) A simple method of privacy coding is discussed.

621.396.41 **1545**
A New Low-Power Single-Sideband Communication System—E. A. Laport and K. L. Neumann. (*RCA Rev.*, vol. 16, pp. 635–647; December, 1955.) Description of a simple system, Type SSB-1, for simplex or duplex operation on telephony or telegraphy over short or medium distances.

621.396.41:621.376.5:621.396.621 **1546**
Electrical Pulse Communication Systems: Part 3—Transmission and Reception Problems in Pulse Systems—R. Filipowsky. (*J. Brit. IRE*, vol. 16, pp. 40–58; January, 1956.) Various time-division multiplex systems are discussed, synchronous and asynchronous systems being compared. The use of functional multiplexing (CODEP) to reduce redundancy is described. When choosing a system for a particular purpose, limitations in power radiation must be considered. Effects due to various types of noise are discussed; regenerative repeating is the most important method for overcoming these effects in long-range systems. Special detection methods and frequency- and time-selection methods for separating the signal from the noise are reviewed. 56 references. Part 2: 562 of 1956.

621.396.41.029.6:621.3.018.78 **1547**
R.F. Bandwidth of Frequency-Division Multiplex Systems using Frequency Modulation—R. G. Medhurst. (Proc. IRE, vol. 44, pp. 189–199; February, 1956.) The frequency distribution of energy in fm microwave multiplex systems is analyzed and an examination is made of the extent of intermodulation distortion caused by limiting the bandwidths of the rf networks in the system. The results are used to determine the minimum filter bandwidths for given permissible distortion.

621.396.65.029.6+621.397.26 **1548**
The Australian Radio-Link Network for Television and U.S.W. Broadcasting—(*Radio Tech., Vienna*, vol. 31, pp. 335–340; October/November, 1955.) The special planning problems encountered in Austria are discussed and a brief account is given of the equipment so far installed. The system operates mainly in the 2-kmc band.

621.396.712:534.861 **1549**
Design of Studios for Small Broadcasting Stations—Goodsman. (See 1295.)

621.396.73:621.396.61/.62 **1550**
Portable Radiotelephone Sets—H. Muth and G. Ulbricht. (*Telefunken Ztg*, vol. 28, pp. 143–149; September, 1955. English summary, p. 194.) Sets are generally designed for eight hours continuous service (transmission time 20 per cent), using phm in the 80-mc or 160-mc band, with up to 12 switch-selected channels. Operating costs are lowest using a vibrator power pack with lead-acid accumulators. Details are given of two recently developed sets. Applications are described in the following papers:

"Teleport" Portable F.M. U.S.W. Radiotelephone Sets in Industry—W. Leisner (pp. 150–153. English summary, pp. 194–195).

Portable Radiotelephone Sets in the Operation of Railways—A. Schepp and F. Pepping (pp. 154–159. English summary, p. 195).

Use of Portable Radiotelephone Sets on Airfields (pp. 159–161. English summary, pp. 195–196).

621.396.931 **1551**
Multichannel Networks in the Public Mobile Radiotelephone Service—K. H. Deutsch. (*Funk-Technik, Berlin*, vol. 10, pp. 556–557; October, 1955.) A discussion of the maximum number of mobile stations which can conveniently share one or two channels. The number, which varies between 45 and 70 per channel in the U.S.A., is likely to be smaller in Germany; limited experience on one network indicates a maximum of about 35. Use of two channels and suitable switching nearly trebles this maximum for the same average delay time.

SUBSIDIARY APPARATUS

621–52:621.375.3 **1552**
Magnetic-Amplifier Two-Speed Servo System—J. J. Suozzi. (*Electronics*, vol. 29, pp. 140–143; February, 1956.) A system is described in which two half-wave bridge-type magnetic-amplifier stages drive a full-wave slave-type output stage. Design data are presented for a number of systems.

621–526 **1553**
A Servo System for Digital Data Transmission—R. H. Barker. (*Proc. IEE*, Part B, vol. 103, pp. 52–64; January, 1956). The stability of the servo system is affected by the quantized nature of the digital data and by time delays inherent in the transmission and digital systems. A method of synthesis is discussed enabling a degree of prediction to be incorporated which insures that the regenerated data do not lag on the original data under steady-state conditions.

621.311.6:621.317.7.089.6 **1554**
An Electronic Supply for Use in the Calibration of Instruments—F. J. Wilkins and S. Harkness. (*Proc. IEE*, Part B, vol. 103, pp. 83–92; January, 1956.) Description of a high-power oscillator/amplifier set, with phase-shift unit, giving an output of at least 700 va at unity power factor within the range 30 cps–5 kc from each of two amplifiers. The output voltage does not vary by more than 0.01 per cent during the time taken to calibrate a point on an instrument scale.

621.311.6:621.373.52 **1555**
Transistor Power Converter Capable of 250 Watts D.C. Output—G. G. Uchrin. (Proc. IRE, vol. 44, pp. 261–262; February, 1956.) A unit based on the circuit described previously [974 of 1955 (Uchrin and Taylor)] has been developed giving 250 w output from a 24-v input. Experimental performance figures are given.

621.314.5:621.387 **1556**
Thyratron Inverter uses Controlled Firing Time—F. Lawn. (*Electronics*, vol 29, pp. 164–167; February, 1956.) The circuit described permits control of ac output voltage without saturable reactor, with improved regulation, efficiency and response speed. One thyratron serves as control tube for extinguishing the conducting power tube at any desired phase.

TELEVISION AND PHOTOTELEGRAPHY

621.397.26+621.396.65.029.6 **1557**
The Austrian Radio-Link Network for Television and U.S.W. Broadcasting—(See 1548.)

621.397.5:535.623 **1558**
A New Look at Colorimetry—D. L. MacAdam. (*J. Soc. Mot. Pict. Telev. Engrs.*, vol. 64, pp. 629–630; November, 1955. Discussion, pp. 630–631.) An account of the proceedings at the meeting of the International Commission on Illumination (CIE) in June, 1955, at which the revision of colorimetry standards was discussed. The relevance of the problem to color television is briefly indicated.

621.397.5:535.623 **1559**
Survey of the Various Colour-Television Systems—E. Schwartz. (*Arch. elekt. Übertragung*, vol. 9, pp. 487–504; November, 1955.) The systems discussed include the NTSC, the two-color-subcarrier, and the coding method [1815 of 1953 (Valensi)]. 185 references.

621.397.5:535.623 1560

The Moscow Colour-Television Experiments—A. M. Warbanski (Varbanski). (*Nachr-Tech.*, vol. 5, pp. 490–492; November, 1955.) German adaptation of paper noted previously (582 of 1956). The standards used are 525 lines, 25 complete pictures per second, corresponding to 150 frames of each color per second. The picture-carrier frequency is 78 mc and the width of the video channel 8.4 mc.

621.397.5:778.5 1561

Television Signal Recording—W. Woods-Hill. (*Wireless World*, vol. 62, pp. 127–130; March, 1956.) A recording system using 35-mm microfilm moving at normal or twice-normal film speed is outlined. The recording is made via a cr tube in which the timebase applied to the X plates is synchronized with the line pulses and a 15-mc voltage applied to the Y plates is modulated by the picture signal. The image is projected with its height optically reduced so as to occupy $<1/200$ of the height of the film frame and the sweep is adjusted to occupy the total usable width. Reproduction is effected by means of a photoelectric pick-up system.

621.397.6:621.317.7 1562

A Test-Signal Generator for Measurements on Television Transmission Systems—Macek. (See 1489.)

621.397.62 1563

Television Receiver with Continuously Variable Tuning—A. V. J. Martin. (*Télévision*, pp. 271–272; November, 1955.) A Belgian version of the Boncourt all-standards receiver is described. The layout follows normal practice except for the timebase system, in which two thyratron relaxation oscillators are used which can be tuned to synchronization according to the relevant standards, and the continuous-tuning feature. The television bands I (40–70 mc) and III (164–220 mc) are covered, alternative receiver bandwidths of about 4 and 8 mc being provided.

621.397.62:621.314.26.029.62 1564

Simplified Band-III Convertor—O. E. Dzierzynski. (*Wireless World*, vol. 62, pp. 134–139; March, 1956.) A single-stage converter using a triode-pentode frequency changer, designed for use in areas of high signal-strength, is described in detail.

621.397.62:621.314.7 1565

Transistorized Sync Separator Circuits for Television Receivers—H. C. Goodrich. (*RCA Rev.*, vol. 16, pp. 533–550; December, 1955.) Double clipping of synchronizing signals can be achieved in a circuit using only one junction transistor as a result of the low-voltage knee in the characteristic. The immunity of the circuit to impulse noise can be improved by including a diode to control the circuit time constant. The performance is satisfactory for ordinary commercial receivers.

621.397.62:621.391.1:621.376.23 1566

Transient Response of Detectors in Symmetric and Asymmetric Sideband Systems—T. Murakami and R. W. Sonnenfeldt. (*RCA Rev.*, vol. 16, pp. 580–611; December, 1955.) Analysis is presented indicating the advantages of the synchronous detector over the envelope detector, with special reference to asymmetric-sideband systems for television. General formulas are particularized for the triple-stagger-tuned band-pass filter for different modulation levels. Observations of the transient performance of synchronous detectors are described.

621.397.621.2:535.623:621.385.832 1567

Improvement in Color Kinescopes through Optical Analogy—D. W. Epstein, P. Kaus, and D. D. VanOrmer. (*RCA Rev.*, vol. 16, pp. 491–497; December, 1955.) "In color kinescopes wherein the phosphor dots are deposited by the conventional optical exposure, the movement of the deflection center with deflection angle causes a radial misregister between the phosphor dots and electron spots. This misregister has been eliminated by interposing a thin aspheric lens between the light source and the aperture mask during exposure of the phosphor screen in the manufacture of the tube."

621.397.7 1568

Low-Power Telecasting—M. E. Williamson and S. E. Rodby. (*J. Soc. Mot. Pict. Telev. Engrs.*, vol. 64, pp. 618–621; November, 1955.) Short account of the development of inexpensive television stations for the U. S. armed forces. An area of radius about 5 miles can be served using equipment with about 30 w effective radiated power.

621.397.7 1569

Copenhagen Television Station—J. Hansen and I. L. Nielsen. (*Teleteknik, Copenhagen*, vol. 6, pp. 197–204; November, 1955.) A description is given of the station arrangement; some details are included on the transmitters and antenna.

621.397.8 1570

Image Gradation, Graininess and Sharpness in Television and Motion-Picture Systems: Part 4 A & B—Image Analysis in Photographic and Television Systems (Definition and Sharpness)—O. H. Schade. (*J. Soc. Mot. Pict. Telev. Engrs.*, vol. 64, pp. 593–617; November, 1955.) "Aperture theory" is developed. The properties and combination of "apertures" (point images) can be described in the space domain by transmittance functions and in the frequency domain by their Fourier spectra (sine-wave response). The basic operation of image formation and analysis is the convolution of two functions. The "equivalent pass band" is a significant parameter. Part 3: 1233 of 1954.

TRANSMISSION

621.376.222 1571

Why Fight Grid Current in Class B Modulators?—J. L. Hollis. (*Proc. IRE, Aust.*, vol. 16, pp. 397–401; November, 1955.) Reprint. See 3249 of 1953.

621.376.32:538.221 1572

Measurements of Reversible Permeability and their Theoretical Interpretation—Wilde. (See 1469.)

621.396.61.004 1573

Unattended Broadcasting Transmitters—W. J. Baker. (*Brit. Commun. Electronics*, vol. 2, pp. 64–68; November, 1955.) Techniques developed for unattended operation are briefly reviewed. Important aspects are use of air-cooled tubes, automatic monitoring, and devices for protection against failure.

TUBES AND THERMIONICS

621.314.63 1574

A Note on the Small-Amplitude Transient Response of *P-N* Junctions—B. R. Gossick. (PROC. IRE, vol. 44, p. 259; February, 1956.) Analysis indicates that when the forward bias is sufficient to make the barrier RC time constant small compared with the average recombination time, the response is very fast.

621.314.63:546.289 1575

Capacitance Measurements on Alloyed Indium—Germanium Junction Diodes—D. R. Muss. (*J. appl. Phys.*, vol. 26, pp. 1514–1517; December 1, 1955.) "Donor densities in the base material of fused junction diodes, inferred from capacitance data, are used to calculate majority carrier mobilities. The dependence of capacitance on reverse bias at very low biases is found to be given by the sum of two terms, a space charge capacitance and a capacitance due to the flow of holes as given by Shockley's low level *p-n* junction theory."

621.314.63:621.396.822 1576

Spectral Analysis of Flicker Noise of Ge Diodes at Low Frequencies—J. P. Borel, C. Manus, and R. Mercier. (*Helv. phys. Acta*, vol. 28, pp. 454–458; Novemebr 15, 1955. In French.) Noise measurements were made at 10 kc, 1.7 kc, 167 cps, and 16.6 cps; calibration was performed using a resistor noise source. The apparatus gave a direct reading of the mean-square value of noise current. Results indicate that this mean-square value varies with the diode reverse current according to a power law which depends on the frequency; consequently the spectral distribution of the noise depends on the diode current.

621.314.7 1577

The Frequency Response of Bipolar Transistors with Drift Fields—L. B. Vales. (PROC. IRE, vol. 44, pp. 178–184; February, 1956.) Details of charge-carrier transport in point-contact transistors are discussed. The frequency variation of current multiplication is calculated taking account of the distribution of transit time of minority carriers between emitter and collector. The absolute transit time depends on both drift and diffusion effects, but the distribution depends only on diffusion. Calculated results are compared with measurements.

621.314.7:537.311.33 1578

Transistor Physics—Shockley. (See 1458.)

621.314.7:621.317.3 1579

Measuring R.F. Parameters of Junction Transistors—Coffey. (See 1483.)

621.383.27 1580

Feedback in Photoelectron Multipliers—L. G. Leiteizen and N. S. Khlebnikov. (*Zh. tekh. Fiz.*, vol. 25, pp. 943–944; May, 1955.) It was found that a photoelectron multiplier with a semitransparent Sb-Cs cathode had a low noise level and an amplification factor of the order of 10^6–10^7 at a voltage of 1–1.2 kv. Attempts to increase secondary emission by raising the voltage were ineffective owing to optical feedback. By making certain constructional improvements the amplification factor was raised to 10^8.

621.385:621.396.822 1581

Theory of Shot Effect—M. E. Gertsenshtein. (*Zh. tekh. Fiz.*, vol. 25, pp. 827–833; May, 1955.) Mean values of noise current in a tube are evaluated from the local fluctuations of the convection current.

621.385:621.396.822 1582

Correlation of Fluctuations in an Electron Gas—M. E. Gertsenshtein. (*Zh. tekh. Fiz.*, vol. 25, pp. 834–840; May, 1955.) Continuation of analysis (1581 above). Methods are indicated for calculating the correlation tensor (1) for an electron gas with arbitrary electron-velocity distribution; this is required for determining the shot-noise intensity.

621.385.029.6 1583

Space-Charge Waves in Accelerated and Decelerated Unidimensional Electron Streams—R. Müller. (*Arch. elekt. Übertragung*, vol. 9, pp. 505–512; November, 1955.) Analysis is given for a system in which the potential distribution along the electron stream can be represented by a simple power law. For practical conditions the space-charge waves can be considered as distorted sine waves.

621.385.029.6 1584

Space-Charge Distribution in a Static Magnetron—H. C. Nedderman. (*J. appl. Phys.*, vol. 26, pp. 1420–1430; December, 1955.) A method of investigation is described based on photoelectric measurement of the radiation intensity from gas atoms in the interaction space excited by electron collisions. The results indicate that space charge extends to the anode under all conditions. A considerable fraction of the space charge consists of electrons trapped for long times.

621.385.029.6 **1585**
Space-Charge Waves in Crossed Electric and Magnetic Fields—S. S. Solomon. (*J. appl. Phys.*, vol. 26, pp. 1443–1449; December, 1955.) Analysis shows that growing waves can be propagated along a neutralized beam in crossed fields by converting either the kinetic or the potential energy of the electrons into wave energy. In the former case the TE and TM modes are coupled in general, but the coupling coefficient is negligible for electron velocities much smaller than the velocity of light. In the latter case, which is that of the traveling-wave magnetron, the TE and TM modes are uncoupled even when the electron velocity is comparable with the velocity of light.

621.385.029.6 **1586**
Magnetron Theory—D. Gabor and G. D. Sims: R. Q. Twiss. (*J. Electronics*, vol. 1, pp. 449–452, 454–456; January, 1956.) Buneman's criticisms (939 of 1956) of previous papers by the authors (3787 and 3785 of 1955) are answered.

621.385.029.6 **1587**
Self-Sustained Electronic Spokes in Magnetrons—A. Raev, I. Uzunov, and A. Angelov. (*J. Electronics*, vol. 1, pp. 452–454; January, 1956.) Conditions are described in which oscillations occurring in two- and four-segment magnetrons appear to be due to a rotating electronic "spoke" which is self-sustained without a tuned circuit. Similar oscillations have also been found with a single-anode magnetron.

621.385.029.6 **1588**
X-Band Klystrons for High-Power C. W. Operation—H. S. Cockroft and J. R. Pickin. (*J. Electronics*, vol. 1, pp. 359–372; January, 1956.) Description of the construction and performance of amplifiers with up to 2 kw output and oscillators with 500 w output.

621.385.029.6 **1589**
Design Information on Large-Signal Traveling-Wave Amplifiers—J. E. Rowe. (Proc. IRE, vol. 44, pp. 200–210; February, 1956.) Formulas are derived for high-power operation of traveling-wave valves taking account of space charge. The parameters considered are the relative injection velocity, the gain parameter, the input level, the space-charge parameter and the space-charge-range parameter. Results are presented graphically.

621.385.029.6 **1590**
E and C Type Traveling-Wave Devices—P. Guénard and O. Doehler. (Proc. IRE, vol. 44, p. 261; February, 1956.) Comment on 3436 of 1955 (Heffner and Watkins).

621.385.029.6:621.373.4 **1591**
Generation of Electromagnetic Oscillations by means of a Travelling-Wave Valve with an External Helix—V. S. Mikhalevski and D. N. Venerovski. (*Zh. tekh. Fiz.*, vol. 25, pp. 812–816; May, 1955.) An experimental investigation was conducted, to establish the conditions for excitation of oscillations as determined by the pitch of the helix, the mean velocity of electrons and the intensity of the magnetic focusing field, for an assumed electron-velocity distribution. The experimental results are in agreement with the conclusions of theory.

621.385.029.6:621.376 **1592**
Klystron Modulation and Schlömilch Series—J. R. M. Vaughan. (*J. Electronics*, vol. 1, pp. 430–438; January, 1956.) Amplitude modulation of the output of a klystron oscillator, whose frequency is varied by modulation of the reflector voltage, is investigated theoretically by use of the Schlömilch series of Bessel functions; the conclusions are verified by experiment.

621.385.029.6:621.396.822 **1593**
Analysis of Noise in Electron Beams—F. N. H. Robinson and H. A. Haus. (*J. Electronics*, vol. 1, pp. 373–384; January, 1956.) Extension of analysis presented previously [3443 of 1955 (Haus and Robinson)]. Linear systems, including amplifiers with lossy circuits and those with beams involving more than two modes of propagation, are discussed. The minimum noise figure of any beam type amplifier can be calculated from a knowledge of the propagation modes and associated power flow.

621.385.029.6:621.396.822 **1594**
Interception Noise in Electron Beams at Microwave Frequencies—W. R. Beam. (*RCA Rev.*, vol. 16, pp. 551–579; December, 1955.) Theory is developed particularly for pencil beams and intercepting elements with round apertures, on the basis of an assumed transverse distribution of probability of electron interception. Results of experiments support the assumptions made. Partial interception of the beam gives rise to two noise components, due respectively to velocity and current fluctuations.

621.385.029.6.032.213 **1595**
A High-Temperature Cantilever-Cathode for Noise Investigations of 8-mm C. W. Magnetron—A. E. Barrington. (*J. Electronics*, vol. 1, pp. 421–429; January, 1956.) A tantalum cathode operating at 1,900°C. and heated by hydrogen ion bombardment (see 2798 of 1955) is described. Experiments show that noise is critically dependent on the value of the magnetic field, on mismatch and on cathode position.

621.385.2:621.316.722.1 **1596**
Saturated Diodes—D. L. Hall, D. M. Sutherland, F. A. Benson, and M. S. Seaman. (*Electronic Engng.*, vol. 28, pp. 84–85; February, 1956.) Comments on 3447 of 1955 and authors' reply.

621.385.832.032.2 **1597**
Experimental High-Transconductance Gun for Kinescopes—F. H. Nicoll. (*RCA Rev.*, vol. 16, pp. 612–617; December, 1955.) "Use of electroformed fine mesh on the control grid aperture of an experimental electron gun gives an order of magnitude reduction in required video drive. Focus and current characteristics are acceptable for many applications."

621.385.833 **1598**
Variable-Magnification Magnetic Electron-Optical Systems free from Image Rotation—I. I. Tsukkerman. (*Zh. tekh. Fiz.*, vol. 25, pp. 950–952; May, 1955.) Design theory is presented. One of the simplest systems satisfying the requirements is the so-called solenoid lens giving unity magnification. The results obtained could be applied to television cameras for altering the scale of the image.

621.387:621.37 **1599**
Some New Microwave Control Valves employing the Negative Glow Discharge—D. H. Pringle and E. M. Bradley. (*J. Electronics*, vol. 1, pp. 389–404; January, 1956.) See also 2579 of 1955 (Pringle) and back reference.

MISCELLANEOUS

061.3:621.3 **1600**
Some Thoughts on Technical Meetings—R. M. Fano. (Proc. IRE, vol. 44, p. 260; February, 1956.) A short discussion on the best methods of organizing meetings and literature within the IRE to serve a) researchers in a particular field, b) those engaged on detailed practical developments, and c) those interested in the broad lines of progress in the field.