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Proceedings of the IRE®

contents

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Proceedings of the IRE®

continued

COVER

A 17-foot dish, mounted atop a naval vessel, was used by the Naval Research Laboratory to receive 400-mc test transmissions 700 miles at sea from the M.I.T. Lincoln Laboratory installation at Round Hill, Mass. The results of the tests are reported on page 1401.

PROCEEDINGS OF THE IRE, published monthly by The Institute of Radio Engineers, Inc., at 1 East 79 Street, New York 21, N. Y. Manuscripts should be submitted in triplicate to the Editorial Department. Responsibility for contents of papers published rests upon the authors, and not the IRE or its members. All republication rights, including translations, are reserved by the IRE and granted only on request. Abstracting is permitted with mention of source.

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July, 1958
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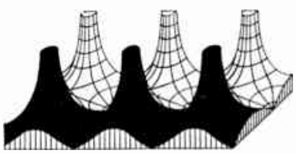
Proceedings of the IRE

Poles and Zeros



So Big! Electronics, as a dynamic growth field, has been well recognized as a leader in the forward progress of the engineering profession. In a world in which a static condition is untenable, electronics has frequently been the forcing function which has created a forward response in areas where the inertial components were somewhat excessive. The magnitude of the job being carried on is never more apparent than upon the submission of the annual report by the Secretary, Haraden Pratt. While mere bigness is not a justification for existence, it may indicate the availability of resources for doing a job, and also may to some extent be an indication that a job is being done. In the case of the IRE, our Constitution specifies this job as that of disseminating technical information and providing leadership in the electronics field which has now become a major portion of electrical engineering, both in engineering manpower employed and in economic size.

Publication is the manner in which our members are most easily reached, and carrying out IRE purposes in this direction last year resulted in publication of 11,168 editorial pages in PROCEEDINGS, two *Convention Records*, the *Student Quarterly*, and 75 TRANSACTIONS issues of 24 Professional Groups. While debate may go on concerning the value of all papers to all members, it certainly seems reasonable that as more papers are published, then more papers will be useful to any given member. And again, one may ask, does an expanding field lead to greater publication, or does greater publication lead to an expanding field? Certainly the Special Issues have been well received. Who can argue in the case of Transistors, Computers, Radio Astronomy and the like, that these volumes have not led to an increased rate of assimilation of new knowledge, and thereby an increased rate of progress?

The Secretary's report always carries a summary of membership data, and any engineer, and the Editor hopes he is still one, could be expected to put the life history of the IRE into a semi-logarithmic plot, as shown in Fig. 1. The indicated dots show recorded membership growth every two years, ending with 66,707 on June first of this year. The line indicates an approximate trend curve which fits the data reasonably well, and this could now be used to tell Founders Goldsmith, Marriott, and Hogan that they should have been able to corral the original 109 members as early as 1901, if they had believed in exponential increase rates in those days! The semi-log plot well shows the radio boom of the 1920's and the negative boom of the 1930's as only small bumps on the face of time, really being inconsequential in the overall progress of the Institute, although of considerable consequence to the budget balancers at the time.

The trend line has a slope indicating a doubling of membership every six years, equivalent to a 12 per cent growth rate, compounded. This is compared to the short-dashed line, which doubles every ten years, with a 6 per cent rate, and is often referred to as the growth rate of the load on the electrical generating capacity of the country. A simple extrapolation beyond 1958 shows that an IRE membership of 100,000 can be expected in 1962, barring cataclysms, catastrophes, or con-

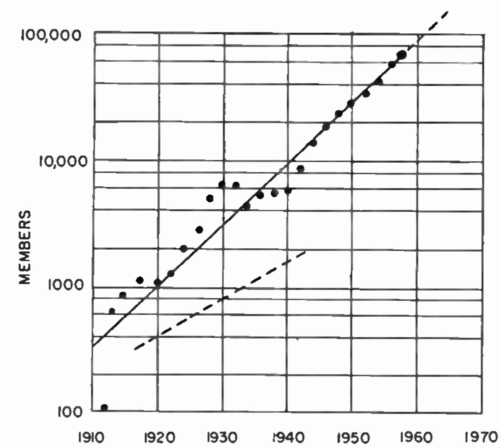


Fig. 1

trovertible calculations. Further data, obtainable from university electrical engineering graduations, and student accessions to membership, supports this amazing figure.

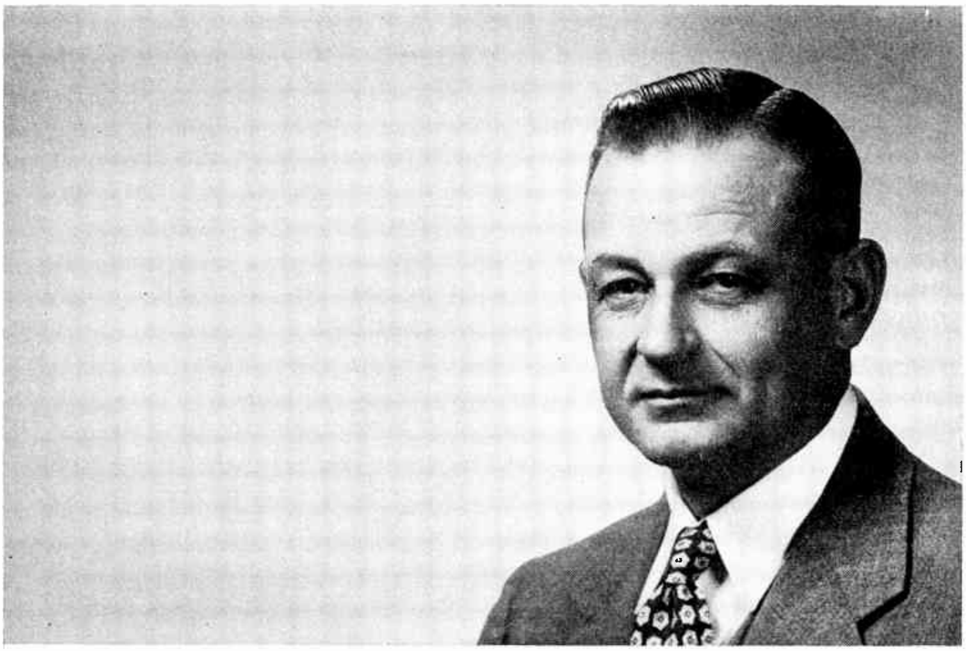
Fortunately, our Board of Directors is not unaware of its duties in preparing to serve such a large professional grouping. Discussions have already occurred and it can be said that with some minor changes, more in the nature of expansions, we feel the framework is correct, the corporate body exists, to serve such a membership. Our 98 Sections, publishing 46 Section magazines and holding 902 meetings per year, our PG Chapters holding 482 meetings, plus 46 other Symposia and Regional conventions, are bodies and activities which are readily expandable to meet growth needs. Our Region layout may also be changed to more equitably share the Regional Director's burdens, and more publication becomes possible and necessary to serve a profession of the size indicated.

In all this forecasting of future burdens on our society, the Board has fully appreciated the extremely important place of the Professional Groups in providing the key mechanism for operation of a very large professional society. The birth of the Professional Group movement coincided with the rapid expansion of the field and the IRE, and seems a highly suitable framework to permit future growth, future broadening of the field, while still retaining a strong central core of unity. This central core now seems to this Editor, at least, to be a common interest in the search for knowledge, for research in the new, anywhere in electrical science.

Because of this realization of the important place which the PG's will have in the IRE future, your Board is scheduling a full-dress discussion of PG problems at a fall meeting. This discussion and evaluation should go far toward laying a solid groundwork for the fantastic figures of 1962.—J.D.R.

Gordon S. Brown

Director, 1958–1960



Gordon Stanley Brown was born August 30, 1907, in Drummoyne, New South Wales, Australia. In 1925 he received the Mechanical Engineering and the Electrical Engineering Diplomas from the Melbourne Technical School. He came to the Massachusetts Institute of Technology in 1929, where he received the Bachelor of Science degree in 1931, the Master of Science degree in 1934, and the Doctor of Science degree in 1938, all in the Department of Electrical Engineering. He was appointed Research Assistant in Electrical Engineering at M.I.T. in 1931, Instructor in 1932, Assistant Professor in 1939, Associate Professor in 1941, and Professor in 1946. In 1952 he was appointed Head of the Department of Electrical Engineering. He was elected Chairman of the Faculty of the Institute for 1951–52. He also served as an Exchange Professor at Purdue University in 1935.

Dr. Brown Established the Servomechanisms Laboratory at M.I.T. in 1941, and served as its Director until 1952. At the start of World War II this was the only university servomechanisms laboratory in the country, and Dr. Brown and his colleagues undertook an extensive program of research and education for the armed services. During the wartime period Dr. Brown also served as Consultant to the Fire Control Department of the Sperry Gyroscope Company, and from 1942 to 1944 he was War Department Consultant to the Fire Control Design section of the Frankford Arsenal.

Dr. Brown received the President's Certificate of Merit in recognition of "Outstanding Services to His Country," the nation's second highest civilian award, in 1948; also the Naval Ordnance Development Award. In 1952, Dr. Brown received the George Westinghouse Award of the American Society for Engineering Education.

Dr. Brown is a Fellow of the American Academy of Arts and Sciences and the American Institute of Electrical Engineers. He is a member of the American Society for Engineering Education, Sigma Xi, Tau Beta Pi, and Eta Kappa Nu. He is a member of the Advisory Council of the Department of Electrical Engineering of Princeton University; of the Board of Overseers of the Thayer School of Dartmouth College; and of the Board of Trustees of the Foundation for Instrumentation Education and Research, Inc. He does, and has done, considerable government consulting, as well as consulting for the publishing companies of John Wiley & Sons, Inc. and McGraw-Hill Book Co. In April, 1956, Dr. Brown was chosen to be Visiting Mackay Professor of Electrical Engineering at the University of California at Berkeley. From April through May, 1958, he was the first J. I. Carroll Memorial Fellow at the University of Sydney in Australia.

Dr. Brown is the author of numerous technical papers and articles on engineering education. He is co-author of the book *Principles of Servomechanisms.*

Dr. Brown joined the IRE as a Senior Member in 1953; subsequently he became a Fellow in 1955.

Scanning the Issue

Reports on the URSI Twelfth General Assembly (starting on p. 1350)—Once every three years leading radio scientists from all over the world gather at a General Assembly of the International Scientific Radio Union (URSI) to exchange technical information and coordinate research efforts on an international basis. Last summer URSI held its twelfth such Assembly at Boulder, Colorado, marking only the second time in 30 years that the U.S.A. has been host to this distinguished gathering. At the instigation of Dr. J. Howard Dellinger, Honorary President of URSI and former President of IRE, the major results of the Assembly have been summarized in a series of brief reports prepared especially for this issue by officials of the seven U.S.A. Commissions of URSI. These reports provide an excellent digest of the latest work going on throughout the world in many fields of scientific investigation. The reports are preceded by special introductory material from the Chairman of the U.S.A. National Committee of URSI and from the President of the National Academy of Sciences. We are especially indebted to Frederick H. Dickson, author of the opening remarks, for overseeing the preparation of this unique world survey of radio progress.

A Parametric Amplifier Using Lower-Frequency Pumping (Chang and Bloom, p. 1383)—This is the eighth article or letter the PROCEEDINGS has carried on parametric amplification so far this year as compared to only one all last year. The preceding reports dealt with amplifiers that drew their energy from an RF pump power supply having a frequency higher than the signal frequency. However, a higher frequency source is not often feasible, especially when the signal frequency is in the microwave range. This drawback has now been remedied by the development of an amplifier that can use a pumping frequency below that of the signal. This paper presents experimental verification of the lower-frequency pumping principle. In one experiment a ferrite core is used as the nonlinear reactance element, and in another, a reverse-biased junction diode. The latter, because of its greater nonlinearity, gave the better results.

A Ferromagnetic Resonance Frequency Converter (Poole and Tien, p. 1387)—The development of new ferromagnetic materials, such as yttrium garnet, and important advances in ferromagnetic resonance theory have led to the recent blossoming of a host of new ferrite and garnet devices—amplifiers, oscillators, detectors, limiters, mixers and frequency doublers—not to mention lower frequency versions of earlier ferrite devices, such as isolators and phase shifters. This paper presents the theory and supporting experimental results of a frequency converter that operates on the same basic principles as the ferromagnetic amplifier developed last year. The converter, like the amplifier, is a parametric type of device which supports three resonant frequencies (input, energizing, and output frequency) that are related so that one frequency is equal to the sum of the other two. The converter differs from the amplifier only in that the energizing frequency occurs at the difference of the other two frequencies rather than the sum. Because of the fundamental similarity of the two devices, the experimental results, in corroborating the converter theory, also provide important verification of the earlier amplifier theory.

A Mathematical Analysis of the Kahn Compatible Single-Sideband System (Costas, p. 1396)—There is at present widespread interest in a number of competing SSB and suppressed-carrier DSB communication systems, which in various ways are superior to standard AM. One of the proposed systems, unlike most others, can be used with conventional AM receivers. Because of this compatability feature, it has evoked a great deal of interest, especially among broadcasters. There has also been some controversy as to its merits because not all he details of the system have been fully disclosed. This paper is the first published attempt to provide a mathematical evaluation of the performance of the system, based on what has been disclosed so far. It is being published, we are frank to admit, despite the reservations of our reviewers as to whether the treatment is broad enough to include the full range of conditions actually embodied in practical applications of the system. The limitations of the analysis stem primarily from the fact that the full details of the system are not known and from certain simplifying assumptions made by the author. On the other hand, an analysis of the system is much needed and the editors feel this paper is not without appreciable merit. To resolve the matter in an equitable fashion it was decided to publish the paper and at the same time give the originator of the system an opportunity to comment on the paper in the same issue. Accordingly, Mr. Kahn's comments have been solicited and appear as a letter to the Editor on page 1429.

Investigation of Long-Distance Overwater Tropospheric Propagation at 400 MC (Dinger, *et al*, p. 1401)—To the growing body of experimental data on long distance tropospheric scatter propagation over land, there is now added for the first time, information concerning transmissions over water. Tests conducted at 400 mc over distances of up to 700 miles at sea show that overwater signal levels are 5 to 10 db higher than overland measurements, providing an important supplement to data reported in the 1955 Scatter Propagation Issue.

The Hall Effect and Its Application to Microwave Power Measurement (Barlow, p. 1411)—In addition to the special reports concerning the URSI General Assembly mentioned above, this issue presents two contributed papers that were given orally at the Assembly. The first presents very concisely an exceptionally interesting development in which the Hall effect in a semiconductor is utilized to measure microwave power. When a thin slab of germanium or silicon is placed in a waveguide, the electric field of the wave produces currents within the slab which interact with the magnetic field of the wave to produce a small voltage across the slab. The voltage is proportional to the product of E and H and, hence, to the microwave power. Although the idea is not yet very practical as a commercial device, it represents a recent development of great theoretical interest in the semiconductor and microwave fields.

Surface Waves (Barlow, p. 1413)—Last year the IRE bestowed one of its highest awards, the Harry Diamond Memorial Award, for the discovery of the surface wave transmission principle seven years previous. Since their discovery, surface waves have excited a good deal of attention, both from wave propagation theorists and communication systems engineers. This work has led to the use of single-wire surface-wave transmission lines of very wide bandwidth for television links, the recent development of surface-wave antennas with unusual physical shapes, and the possibility of using surface waves for short range communications where the earth itself is used as the propagating surface. This second of two URSI papers presents a brief but excellent review defining the principal types of surface waves, describing how they are launched and propagated, and commenting on present and future applications.

Supplement to IRE Standards on the Measurement of Interference Output of Television Receivers (p. 1418)—It has been found that the network specified in earlier IRE Standards to deliver an RF input signal to the receiver under test caused some inconsistency in results. This supplement describes a new testing procedure in which the old network is replaced with a resistive pad having properties that are well defined and easily reproduced.

Scanning the Transactions **appears on page 1434.**

Twelfth General Assembly of International Scientific Radio Union*

FREDERIC H. DICKSON†, MEMBER, IRE

We are privileged to present in the following pages a series of reports covering the major activities of the Twelfth General Assembly of the International Scientific Radio Union held in Boulder, Colo. last summer.

The material was prepared especially for this issue by officials of the seven U. S. Commissions of URSI, under the coordinating guidance of Frederic H. Dickson, international Vice-Chairman of Commission IV and member of the U. S. National Committee of URSI.—*The Editor.*

EVERY three years, the International Scientific Radio Union holds a major international meeting, or General Assembly, which is attended by leading radio scientists from all over the world. Last year URSI held its Twelfth General Assembly at Boulder, Colo. from August 22 to September 5. This was only the second time in 30 years that the United States has had the honor of being host to this important gathering.

More than 500 distinguished radio scientists and their families from twenty-six countries attended at the invitation of the U.S.A. National Committee of URSI and the National Academy of Sciences. The meeting gave the participants an excellent opportunity to exchange technical information, coordinate research programs on an international basis, and make recommendations concerning future courses of scientific action.

The United States preparation for this assembly was the responsibility of Dr. J. Howard Dellinger, former Chief of the National Bureau of Standards Radio Propagation Laboratory, and now an Honorary President of URSI, as Chairman of the General Arrangements Committee. Dr. Dellinger had many able assistants, too numerous to credit individually, who formed the finance, foreign arrangements, technical, and local arrangements subcommittees.

At the suggestion of Dr. Dellinger, several reports summarizing the principal discussions of the seven URSI Commissions during the Twelfth General Assembly have been prepared especially for this issue of PROCEEDINGS, and appear in the following pages. These reports have been prepared either by the U.S.A. Commission Chairmen or by a U. S. reporter of that Commission. The reports are preceded by a brief description of the URSI organization by the chairman of the U. S. National Committee, and the welcoming address presented to the assembly by the President of the National Academy of Sciences.

* Original manuscript received by the IRE, April 17, 1958.
† Coordinator, URSI-IRE Reports; Chief, Signal Corps Radio Propagation Agency, Fort Monmouth, N. J.

The following condensed program will indicate the wide scope of subject matter covered in the technical program of the assembly; its high points are summarized in the reports that follow.

Sessions of the Commissions

Commission I—Radio Measurement Methods and Standards

August 26—Business and miscellaneous.
August 28—Frequency standards (particularly atomic standards).
August 29—Standard frequency and time signal transmissions.
August 30—Power and field intensity measurement.
September 2—Atomic frequency standards and standard frequency transmissions.
September 3—Physical measurements based on radio techniques (velocity of light, etc.).
September 4—Concluding session (resolutions, etc.).

Commission II—Tropospheric Radio Propagation

August 26—Business and miscellaneous.
August 28—Tropospheric propagation within the horizon.
August 29—Tropospheric propagation beyond the horizon.
August 30—Radio meteorology.
September 2—Tropospheric scattering.
September 2—CCIR matters, resolutions.
September 3—Additional discussion of tropospheric scatter propagation, and other unfinished business.
September 4—Concluding session (resolutions, etc.).

Commission III—Ionospheric Radio Propagation

August 26—The opening business meeting.
August 28—The lower ionosphere.
August 28—Geomagnetic influences in the ionosphere.
August 29—Whistlers, etc. (joint session with Commissions IV and V).

August 29—Geomagnetic storms.
August 30—Horizontal movements in the ionosphere.
September 2—Scattering in the ionosphere.
September 2—Business session on urgent matters.
1) Consideration of a proposal to establish a permanent center for ionograms.
2) Collaboration of Commission III in connection with CCIR topics.
September 2—The events of February 23, 1956.
September 3—Rocket exploration of the ionosphere.
September 4—Closing business session.

Commission IV—Radio Noise of Terrestrial Origin

August 26—Business session, report of working groups.
August 28—Whistlers and other vlf phenomena.
August 29—Whistlers, etc. (joint session with Commissions III and V).
August 30—Characteristics of radio noise.
August 30—The measurement and description of the characteristics of atmospheric noise.
September 2—Commission IV activities during the IGY.
September 3—Relation between source and atmospheric.
September 3—Business (resolutions).
September 4—Resolutions and final business.

Commission V—Radio Astronomy

August 26—Business and miscellaneous.
August 28—Techniques of reception.
August 28—Large antennas.
August 29—Solar research.
August 30—Radio sources.
August 30—Radio propagation, joint session with Commission VI.
September 2—The galaxy.
September 3—Planetary system.
Joint sessions as follows:
August 28—Commission VI on large antennas.
August 29—Commissions III and IV on whistlers, etc.
September 3—Commission VII on masers.
September 4—Business session.

Commission VI—Radio Waves and Circuits

August 26—Business; microwave optics and information theory.
August 28—Circuit theory.
August 28—Large antennas (joint session with Commission V).
August 29—Information theory.
August 29—Transition from field theory to circuit theory and optics.
August 30—Information theory.
August 30—Scattering and diffraction.
September 2—Circuit theory.
September 2—Surface waves.
September 4—Business session.

Commission VII—Radio Electronics

August 26—Business session.
August 29—Oscillation phenomena in gas discharges.
August 30—Physics of the cathode.
September 2—Source and nature of noise in electron beams.
September 3—Physics of semiconducting devices.
September 3—Molecular amplifiers (masers).
September 4—Second business session.

What Is URSI?*

H. W. WELLS†, FELLOW, IRE

THE Twelfth General Assembly of URSI was held in Boulder, Colo., August 22–September 5, 1957. Several hundred foreign delegates and a like number of U. S. representatives participated in the meetings. The General Assemblies, now held every three years, had met only once before (1927) in the United States. Excellent facilities were provided for this meeting by the University of Colorado and the National Bureau of Standards, Boulder Laboratories. Besides the technical sessions there were numerous excursions and entertainments. The foreign delegates were given a vivid portrayal of the peace and beauty of western United States. The meeting was pervaded with a remarkable spirit of solidarity and satisfaction. The following international officers were elected for the ensuing three years:

* Original manuscript received by the IRE, April 17, 1958.
† Chairman, U. S. A. National Committee, URSI; Dept. of Terr. Magnetism, Carnegie Institution, Washington 15, D. C.

President: Dr. L. V. Berkner (United States)
Vice-Presidents: Dr. I. Koga (Japan)
Dr. R. L. Smith-Rose (Great Britain)
Dr. G. A. Woonton (Canada)
Treasurer: Prof. C. H. Manneback (Belgium)
Secretary-General: Col. E. Herbays (Belgium)

Commission Chairmen

I. Radio Measurement Methods and Standards: Dr. B. Decaux (France)
II. Tropospheric Radio Propagation: Dr. R. L. Smith-Rose (Great Britain)
III. Ionospheric Radio Propagation: Dr. D. F. Martyn (Australia)
IV. Radio Noise of Terrestrial Origin: Dr. R. A. Helliwell (United States)
V. Radio Astronomy: Prof. A. C. B. Lovell (Great Britain)
VI. Radio Waves and Circuits: Dr. S. Silver (United States)
VII. Radio Electronics: Dr. W. G. Shepherd (United States).

In each nation which adheres to the international organization, the affairs of URSI are administered by a national committee. In this country the U.S.A. National Committee of URSI is organized similar to the international body. It includes representatives of government, industry, and academic institutions. In addition, each of the seven URSI commissions maintains an active membership which is based on a high level of technical competence. Appointments to membership are made by the National Academy of Sciences upon recommendation of the U.S.A. National Committee. Delegates to the General Assemblies are drawn from this roster.

Each spring URSI meetings are held in Washington, D. C. These are usually cosponsored by several professional groups of the IRE. Occasional fall meetings are also held; these are in different sections of the country. At all URSI meetings the emphasis is on a generous exchange of the latest scientific information, stimulated by uninhibited discussion. At a General Assembly the sessions are usually opened with a summary or review paper by an international authority. This is followed by a general discussion which knows no national boundaries. Much of the material is direct from the research scientist and well in advance of publication. Results of experiment or observation are frequently negative or controversial. Often, on the surface, they appear to be completely discordant. But divergent interpretations may be completely resolved in the cross-pollination process which takes place in an international meeting of this nature. The net result is a concentrated scientific effort in many limited areas of electronic science which lays a firm foundation for continued advancement.

In a recent publication,[1] Dr. J. Howard Dellinger, past president of IRE and honorary president of URSI, described the growth, organization, and objectives of the International Scientific Radio Union. Its close liaison with IRE is also demonstrated by the publication in this issue of selected reports from the Boulder meetings.

The success of the Twelfth General Assembly of URSI was due to the generous support of the University of Colorado and the National Bureau of Standards, together with substantial financial aid from government and industry, including the IRE.

[1] J. H. Dellinger, "International cooperation in radio research—URSI and IRE," Proc. IRE, vol. 44, pp. 866–872; July, 1956.

Address of Welcome*

DETLEV W. BRONK†

IT IS my pleasant privilege to extend the welcome of the National Academy of Sciences of the United States to so many of our friends and colleagues from so many other countries. We are grateful to you for having come so far to share with us your friendship and your knowledge. We appreciate the especial honor you have done us by coming during this momentous year of international cooperation for the furtherance of geophysics.

If we can make your visit intellectually profitable and socially pleasant, it will be a small symbol of our great gratitude for your hospitality and friendship of other years in other places, for the inspiration of ideals that we hold in common, for the benefit of shared knowledge.

I wish I had the power to put in adequately expressive words the especial reasons why the friendly associations of international gatherings such as this give Americans so much pleasure. It is in part, I think, because we are so recently come from your native lands. Our nation has been made by those who were brothers of your fathers. To your countries we are indebted for Alexanderson and for Pupin, Steinmetz, Tesla, and Zworykin

* Original manuscript received by the IRE, April 17, 1958. Presented at URSI Twelfth General Assembly, Boulder, Colo., August 22–September 5, 1957.
† President, National Academy of Sciences and Rockefeller Institute.

to mention but a few who are best known to you. Your ancestors were our ancestors too.

Our feeling of friendly kinship is due in part, I further think, to our common cultural heritage. The first visit of an American to your country, or to yours, is a remarkable experience, for one has the bewildering feeling that one has seen it all before. And so one has through the eyes and words of those who wrote the literature of your country, which was the literature of our fathers on which we too were reared.

Another deeply-rooted reason for our feeling of close association with you is the recent growth of science in this country from the seeds brought by our teachers who first studied in your lands. At a time when scientific investigation was just beginning here, Benjamin Franklin was encouraged by election to the Royal Society of London, the Royal Academy of Science at Göttingen, the Academies of Sciences of Paris, of Padua, and of St. Petersburg. From those days of Franklin until now we have a deep debt of gratitude to you for first nurturing those who then developed science here.

And so I say our warm welcome has natural roots in traditions and brotherly associations which we hope you of our mother countries may understand.

Because a scientist is necessarily a partner of many others, our early predecessors organized associations such as yours for the exchange of information, the catalysis of ideas, and for cooperative effort. Even at the beginning of the modern scientific era it was realized that to be an isolationist in science handicaps one's efforts. Thus the oldest ancestor of our Academy, the Accademia dei Lincei of Rome, as early as 1609 laid plans to establish "non-clerical scientific monasteries for scientific cooperation. . . . In each house every observation and every discovery was to be communicated without delay to the head house and to all the sister houses."

From such desire to learn from others and to communicate to others one's thoughts and observations there developed the international spirit of science. Like traders for rare goods, scientists have sought new ideas and newly discovered knowledge wherever they could be found. Such objectives were set forth by Francis Bacon in his description of "The House of Solomon." He proposed that there be twelve scientists of that House who should go from country to country for the exchange of knowledge derived from experimental investigations. Significantly, Bacon said those twelve should be called "Merchants of Light."

In fulfillment of the Baconian ideal, you are modern Merchants of Light. I do not say this lightly. In these dark days of world discord and rising barriers to free communication, every gathering such as this is a significant breach in the walls of silence that separate common people of good will. People would be united by shared knowledge and mutual understanding were they able. Gatherings such as this nurture the awareness of statesmen that, through science, nations can peacefully gain those material benefits which they have sought fruitlessly to acquire through war.

Science has no unique power to create a more peaceful world. But science has in the past liberated men from the uncontrolled domination of natural forces and from ignorance and superstition. It gives promise of freeing men from the control of human force and the imagined necessities for greed and conflict by increasing their intellectual and material welfare. If this be the worldwide goal of scientists, there must be freedom for scientific effort, unrestricted by the boundaries of nations and unlimited by selfish national interests.

This year was chosen as the International Geophysical Year for scientific, solar reasons. But it is timely, too, for international reasons. The example of scientists of many nations working together in cordial cooperation for common aims is a heartening example of what could be a more general pattern of international amity.

Nations have often cooperated in mobilizing their resources for attack against other nations or for defense against aggression. But never before have all the major nations of the world mobilized their resources in a common undertaking for the peaceful benefit of all. The significance of this friendly cooperation will, I think, equal the greatest scientific discovery that may be made during this momentous year.

Scientists are uniquely fitted to persuade their fellow citizens that shared knowledge increases the intellectual resources of every nation and relieves the necessity of conflict for material resources. A discovery of human value usually depends on previous research carried on in many other countries; it is of benefit to the people of all countries. The observations of Galileo and Copernicus and Newton, as you well know, have extended the intellectual horizons of people in every nation. But the present resurgence of selfish nationalism is in direct conflict with that spirit of science.

The broader vision of a great statesman was voiced by Lord Bryce forty years ago when he was Ambassador from Britain to this country. Said he then: "One of the most delightful things of science is that it knows no allegiance to nationality. Science is a republic in which there is no passport to greatness, except service and genius. It is a republic of which everyone is a citizen and where everyone has equal rights in every part of the world. . . . I have veneration for your lofty and disinterested spirit. I have fear for the enormous power you exercise."

The enormous power Lord Bryce feared has indeed been prostituted by those who use the fruits of science for their selfish ends. Science gives man awful power over men as well as nature.

The greater power over man and nature provided by science makes necessary more knowledge and greater wisdom in order that we may control and use our greater power for man's welfare. Science gives us the building stones of a better world, but the world will be as we choose to make it.

In a unique way, you of this union diffuse the knowledge, and thus foster the wisdom necessary for the building of a better world. Radio has profoundly increased the scope of man's mind and the range of his senses. It offers challenging, undeveloped possibilities for communication between peoples and for their better understanding of science which is rapidly reshaping the world in which we live. But you have also made possible domination of the minds of many by a few. You have presented mankind with an opportunity and a challenge. Unless the beneficial power you have provided is wisely used, the peoples of the world will be torn between those who know and those who do not know. No nation and no culture can long survive half free to know, half slave to ignorance and superstition.

Every civilization has been the product of men's minds. The more there were who had the gift to wonder and the desire to know and understand, the more vital was the civilization.

I sometimes fear that scientific knowledge and its applications increase so rapidly that the imagination is dulled and the ability of men to marvel and to wonder is weakened by a surfeit of scientific wonders. As scientists, it is our duty to keep alive the spirit of intellectual adventure. If science is revealed as a great odyssey of the human spirit, man's understanding will be increased and his spirit quickened. Curiosity and the ability to wonder stimulate the mind of man and lead him on toward his divine destiny.

Your modesty and the nature of your daily work may hide from you the marvels of your achievements. But as a biologist I can marvel at the way in which you have increased countless-fold the range of man's normal speech and hearing and vision. By radio you have made possible the control of swift transportation beyond the speed of birds.

These are achievements that should arouse the spirit of wonder in people everywhere who in humility can marvel at the ability of man to increase his power and stature without limit.

The practical uses of those achievements have transformed the pattern of man's lives and habits. But the significance of your achievements is far greater. Yours has been a great adventure of the human mind on the frontiers of knowledge.

Report on URSI Commission I—Radio Measurement Methods and Standards*

ERNST WEBER†, FELLOW, IRE

Objectives

THE FIELD of interest of URSI Commission I is the international exchange of experience and interchange of data on radio measurement methods and standards. Of particular interest are standards of frequency; of power, field strength, and impedance measurements from about 100 mc into the millimeter range; and of all physical measurements based upon radio techniques.

Traditionally, Commission I has been interested in precise measurements of the velocity of light, furnishing recommended values upon which the interpretation of many propagation studies are based. Finally, the transmission of standard frequencies and time signals falls within the purview of Commission I together with the problem of avoiding interference between standard frequency transmitters.

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Technical Program

The meetings at Boulder, Colo., were attended by delegates from all the major nations who participated vigorously in the formulation of final resolutions to guide the activities of the National Commissions during the next three years, until the Thirteenth General Assembly in 1960.

The program of Commission I was arranged in five sessions that dealt with four topics: 1) frequency standards, particularly atomic frequency standards, 2) standard-frequency transmissions and time signals, 3) power and field strength measurements, and 4) physical measurements based upon radio techniques. Each session opened with a résumé of activities during the last three years, since the Eleventh General Assembly held in The Hague in 1954. The reporters had been chosen by the International President of Commission I, B. F. Decaux of France, and in each instance was a renowned expert in the field to be covered. The summaries were well organized and very instructive and were followed by lively discussion. Because of the organization of sessions on specific topics, no individual papers had been invited from the general membership; however, twelve National Committee reports of Commission I were submitted and distibuted to all members, as were abstracts of eight papers of different national origin on topics related to the field of interest of Commission I.

Frequency Standards

In the session on frequency standards, L. Essen of the National Physical Laboratory of England presented a review of the present status and recent progress in the field of frequency standards of all types.

Atomic clocks in the U.S.A. have reached the point where they provide an accuracy of one or two parts in 10^{10}. The official frequency standard is still the quartz clock.

Experiments are under way in the United States and in the United Kingdom to investigate the operation of quartz crystal clocks in a helium bath. It is expected that this will reduce the aging effect and provide increased accuracy in these instruments.

It was pointed out that quartz clocks are now in operation in Germany at a frequency of 60 kc with a drift of 1 part in 10^9 per month. The unique feature of these instruments is that they employ the Pierce oscillator circuit rather than the more conventional bridge circuit.

In the field of atomic clocks, work is under way in Japan on an ammonia absorption instrument.

Work is proceeding in the United States and the Union of Soviet Socialist Republics on ammonia beam maser oscillators. These units have the great advantage of providing exceptional spectral purity in the oscillations. Impurities present are of the order of one part in 10^{12}.

Investigation is under way in all parts of the world to develop solid-state masers. It is presumed probable that these devices are more likely to produce a low-noise amplifier than a usable frequency standard.

Atomic frequency standards presently available include the Atomichron which is commercially available in the U.S.A. and employs the cesium beam oscillator.

A cesium clock has been in operation in the United Kingdom for two years. It has been compared to the period of the earth's rotations. Comparisons of frequency have been made between the U. S. Naval Observatory and the National Physical Laboratory of the United Kingdom. Agreement to one part in 10^9 has been obtained.

This cesium beam oscillator is of the usual type, including the oven for the emission source, two parts of beam deflection magnets, and the pair of rf excited resonant cavities. This oscillator is not subject to any doppler effect or pressure broadening of the line. The effective Q is about 3×10^7.

Coils are provided to eliminate the earth's magnetic field and to provide a small constant magnetic field. This unit was originally installed on a large block of concrete to eliminate vibration effects. It now appears that this precaution was entirely unnecessary.

On investigating the accuracy of this apparatus, it was learned that the resonant cavities must be nearly identical to maintain an accuracy of one part in 10^{10}.

The frequency of operation is very nearly 9200 mc and the rf power input to the cavity was adjusted from 4.5 to 600 μw with no observed effect on the frequency.

An external coil is provided to improve the uniformity of the constant magnetic field. The maximum frequency change observed by varying this field over relatively wide limits was one part in 10^{10}.

This cesium clock has been used to check at two-day intervals the quartz clocks at the NPL, which drift steadily. Comparison of atomic clocks in the U. S. and U. K. indicate that they agree to one or two parts in 10^9 which is much less than the variations in astronomical time.

Standard Frequency and Time Signal Transmissions

W. D. George reported on the present status of standard-frequency and time-signal transmissions, beginning by summarizing report No. 66, CCIR, Warsaw, 1956. This report was concerned with problems in connection with establishment and operations of a world-wide standard-frequency and time-signal service in the allocated frequency bands. The geographical distribution of ten standard-frequency broadcast stations was shown and pertinent data on their operations were listed. It was noted that the services provided by these stations did not represent a satisfactory world-wide coverage because of 1) insufficient signal strength in some areas to overcome radio noise, both man-made and from other sources; 2) decrease in accuracies in the received signals caused by time-variable characteristics of the propagation paths; 3) technical problems in connection with the time pulses and receiving equipment need more attention; 4) continued interference to the standard-frequency service by other types of stations; and 5) serious mutual interference between standard-frequency stations operating on the same carrier frequencies.

In the remarks and discussion following the status report, the following subjects were mentioned. In order to provide better local service, additional standard-frequency broadcast stations have recently been placed in operation. Some of these operate during the daytime only and so cause no additional skywave interference at night. The daytime operation provides a ground wave signal which does not lose much accuracy in transmission and is strong enough in urban areas to overcome man-made radio noise. In this connection, it was noted by George that a new precision navigation system has been developed operating on 100 kc. With use being made only of the ground wave, ranges up to 2000 miles are obtained and provisions of 1 in 10^7 for 1 second and 1 in 10^9 for two minutes measuring time are achieved. It was also noted that improved receivers are now commercially available which have been specifically developed to receive standard-frequency broadcasts. The remainder of the discussion was devoted to the subject of interference. Although some interference has been experienced from stations not broadcasting standard frequencies and time signals, it has not been very serious compared to the mutual interference between standard-frequency transmissions. Some methods of reporting outside interference were discussed, but the questions of what data were needed and to whom the report should be submitted were deferred for consideration at a later meeting.

The subject of mutual interference was discussed at length. It was affirmed by Decaux that interference is indeed a serious problem in Europe and elsewhere. The reception of more than one standard-frequency broadcast at a time, each having comparable power but different modulation and programming, makes identification of stations difficult or impossible, and the use of the standard frequency and time signal is very difficult. Ordinary users do not have complete schedule information and have difficulty separating the transmissions. Particularly troublesome is the reception of accurate time pulses from one station during the time when the tone signal from another station is on.

Methods of reducing trouble from interference were discussed and reference was made to Study Program 101 of the CCIR meeting at Warsaw in 1956. It was recommended that the CCIR study arrangements for programming and modulation to reduce difficulties even in the presence of simultaneous reception of more than one standard-frequency and time-signal broadcast. Also recommended was consideration of special types of transmission such as single-sideband or double-sideband with suppressed carrier.

Power and Field Intensity Measurements

A discussion on power measurements was opened by J. A. Saxton, who gave an account of the very considerable developments that have taken place during the past three years. He also pointed out that improved techniques were still required at frequencies above 30,000 mc and below 3000 mc.

Instruments in which changes of temperature or resistance of an absorbing load were measured had been developed for powers from 1 to 100 watts and had accuracies estimated at from 1–3 per cent, although there might be systematic errors, particularly at the higher frequencies and lower powers. International comparison would be valuable for checking such errors. It was estimated that thermistors and bolometers had errors of as much as 30 per cent at frequencies of about 50,000 mc, but they were still useful if calibrated.

The torque-vane type of wattmeter gave an accuracy of about 3 per cent for powers between 2 and 10 watts, and instruments in which the vane was situated in a cavity were accurate to about 2 per cent in the power range from 5–30 mw, at frequencies of about 10,000 mc. Similar results were obtained at 60,000 mc.

The electron-beam technique could be used for powers of about 50 mw, and its accuracy was being investigated.

H. E. M. Barlow (England) then gave an account of methods depending on the Hall effect and on the pressure of radiation, describing the precautions to be taken and the fields of application of such methods. At present, the Hall-effect instruments give only relative values but there is a possibility that they might be developed to give absolute values.

In opening the discussion on field-strength measurements, R. C. Kirby indicated the fundamental difficulties of relating the quantity actually measured to field strength, and of not disturbing the field by the use of the measuring instrument. He referred also to the need for a uniform nomenclature and mentioned the recommendation of the IRE. In this, electric-field strength is defined as the magnitude of the electric-field vector at a given place, resulting from the passage of a radio wave. The use of the term "electric intensity" was deprecated.

E. W. Chapin (U.S.A.) outlined the problems of noise measurement and stressed the need of greater uniformity in the methods adopted.

Physical Measurements Based on Radio Techniques

P. Grivet, Chairman of the session, presented a progress report on recent measurements of the velocity of light. New methods were developed by using the SHORAN system of navigation in the United States and the OBOE system in England; a modification was developed by Florman in the United States based on phase measurements at 115 mc.

The major error in such long-distance-transmission methods resides in the uncertainty of the refractive index of air and its probable lack of uniformity. An entirely different method by Rank and Plylor (U.S.A.) uses infrared transmission, determining the frequency by means of magnetic resonance, involving quantum theoretical relations.

Improvements in the classical methods of measurement have also been made by L. Essen, using the resonator principle with empirical corrections for the skin effect; by Froome employing spherical waves in a constant-phase waveguide interferometer of very considerable accuracy; and by Bergstrand using the optical method, modulating the light beam by means of a Kerr cell at 9 mc and utilizing the "Halbschatten" comparison method.

It was stated that a value of the velocity of light could now be specified as 299,792.5± 0.4 km.

Grivet then resumed by giving an exposition of measurements of the magnetic field quantity B by means of paramagnetic-resonance phenomena, either utilizing the nuclear resonance effect discovered by Purcell and Bloch in 1948, or the electronic resonance effect discovered by Zavoisky in 1945. He also mentioned the ferromagnetic resonance dicovered by Griffith in 1946 which apparently had not been given adequate attention.

Resolutions

Commission I adopted the following six resolutions to focus the international interchange onto topics of strong current interest.

1) *On Power Measurements*

It is strongly recommended that the national laboratories should intercompare their standards of power measurement at frequencies in the neighborhood of 3000 mc and 10,000 mc. The comparisons are to be coordinated by R. L. Smith-Rose, Director, Radio Research Station, Ditton Park, Slough, Bucks, England.

2) *On Atomic Frequency Standards*

It is resolved that in view of the importance of atomic standards for frequency and time measurements it is recommended that their further development should be intercompared by means of radio transmissions and by the circulation of a single standard around a number of of national laboratories.

Additional Comments: It should be noted that in making the proposed intercomparisons, the frequencies should be expressed either in terms of an atomic frequency such as that of the cesium $F, m(4, 0) \leftrightarrow F, m(3, 0)$ line at zero field or in terms of the unit of time scale UT 2. In the latter case the time signals used should be stated so that the interval between these signals can be expressed in terms of the cesium resonance. If the frequency varies with any parameters external to the atom, the precise values of these parameters should be stated.

3) *On Standard Frequency Transmission*

In order to establish the best means of securing a reliable world-wide service, it is recommended that attention be given to Resolution No. 179, question nos. 140–142, and study program no. 101 of the CCIR Plenary Assembly, 1956. In particular, the following questions should be studied:

a) The merits of frequencies below 100 kc for standard-frequency transmissions and time signals.
b) Methods of recognizing without ambiguity the seconds pulses of different standard-frequency transmitting stations including the case of reception at great distances. The study should include the optimum type of time signal to be used and the advisability of synchronizing time signals from different stations.
c) The number and location of stations required for world coverage. (Any further increase in the number of stations operating in some geographical areas will result in a degradation of the service.)
d) The advisability of reducing the period of tone in favor of pulses.

4) *On Distinction Between Field Strength and Field Intensity*

In order to avoid confusion between the terms radio field strength and radio field intensity, it is recommended that:

Radio Field Strength refer to the magnitude of the electric or magnetic field vector (E or H) at a given location resulting from the passage of radio waves;

Radio Field Intensity refer to the power flux density of electromagnetic waves passing through a surface normal to the direction of propagation.

5) *On Microwave Standardization Program*

In order to stimulate international and national efforts in the standardization programs of high-frequency and microwave quantities such as power, impedance, voltage, current, attentuation, field strength, noise, etc., the Twelfth Assembly of URSI recommends to members of URSI, the IEC, the CCIR, ISO, and other international groups concerned with electrical standards that the following be done:

a) Compile, as soon as possible, a table of rf quantities to be standardized. This table shall specify dynamic ranges, frequency ranges, and corresponding desirable practical accuracies for primary standards. It shall also specify desirable priorities for the various quantities and corresponding ranges.
b) Information and tabular material, as requested in a) above, shall be forwarded to the President of Commission I, URSI, for consolidation and possible adoption at the Thirteenth URSI General Assembly. It is desirable that this table be brought up to date at successive General Assemblies.

6) *On the Velocity of Light*

In view of the progress made since the Eleventh General Assembly in the measurement of the velocity of electromagnetic waves, it is recommended that in radio engineering problems its value in vacuum be taken as

$$299,792.5 \text{ km sec}^{-1}$$

with a probable error of

$$\pm 0.4 \text{ km sec}^{-1}.$$

Report on URSI Commission II—Tropospheric Radio Propagation*

JOHN B. SMYTH†, FELLOW, IRE

Objectives

THE activities of the Commission are directed toward an adequate description of the physical properties of the troposphere and the associated radio wave propagation effects. Current interest includes: dependence of scatter signal on latitude, climate, terrain, distance, frequency, polarization, antenna heights, and gains; classification according to propagation mechanisms and the associated transmission phenomena such as pulse distortion, phase stability, fading rate, diurnal and seasonal variations in field strength; detailed meteorological measurements with emphasis on the study of the fine structure of the atmosphere.

Technical Program

Twelve of the twenty-four members of Commission II were represented at the Twelfth General Assembly. These were Canada, France, Germany, Great Britain, Czechoslovakia, Italy, The Netherlands, Sweden, Switzerland, Japan, U.S.S.R. and U.S.A. Under the chairmanship of R. L. Smith-Rose, International President of Commission II, one administrative session and seven technical sessions were organized and convened. The technical papers and discussions were organized into three broad categories:

1) tropospheric propagation within the horizon,
2) tropospheric propagation beyond the horizon, and
3) radio and meterorology.

An adequate description of radio fields within the horizon must take into account the effects of irregular terrain and the physical properties of the ground, as well as the effects of the medium. J. A. Saxton concluded his introductory remarks on the effects of irregular terrain by pointing out that radio fields between two points within the horizon decrease with distance much faster than would be expected over a smooth spherical earth. The higher the frequency, the larger the difference between the theoretically predicted and experimentally observed median field values.

B. Josephson summarized some experimental studies conducted at frequencies between 30 and 100 mc. In addition to the effects of ice and snow on the reflection coefficient of the ground, the attenuation effects produced by trees were investigated. At a given location field strength variations as much as 10 db were observed in moving around a tree.

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W. S. Ament and L. G. Trolese referred to observations which demonstrated the importance of the terrain in the immediate foreground of the receiving antenna on the received signals. A. W. Straiton summarized reflection coefficient data for overwater and overland taken at 93.2 and 0.86 cm. The overland reflection coefficient for the longer wavelength was somewhat greater than one-half, whereas the reflection coefficient for the 0.86 cm was about one tenth. Peter Beckman set forth a statistical theory of reflection from rough surfaces. Beckman's model of a rough surface ignores all diffraction effects. He expressed the view that a theory based on nonrigorous assumptions at the outset is certainly no poorer than a theory which starts out quite rigorously and makes simplifying approximations later for the sake of computation.

J. B. Smyth introduced the topic dealing with the effects of the troposphere on fields within the horizon. He reminded the audience that there still remains a difficulty in interpreting propagation data in terms of mechanisms since the power absorbed in the receiver is not a single valued function of the antenna aperture distribution of field. K. Naito described some results of a study of transmission over a 55-km path at 4 kmc. It was found that signal fading was well correlated with the formation of low-level ducts below the lowest terminal of the link.

L. J. Anderson introduced some experimental data on tropospheric bending showing that one could calculate the total refraction to within $\pm$ 2 mr for grazing angles greater than 1 degree.

R. S. Kirby, T. Kono, K. Naito, D. J. Grosskopf, W. E. Gerber, and E. W. Allen reported on experimental results of transmissions over mountainous terrain. The so-called "obstacle-gain phenomena" was called upon to explain the demonstrated fact that good quality television pictures are transmitted over circuits with intervening mountains. M. P. Bachynski presented the results of an investigation of diffraction of 24-kmc radio waves by cylindrical obstacle showing that agreement between theory and experiment could be expected.

Beckman briefly reviewed the status of reflection theories in describing the transmission of radio waves through the stratified troposphere. He stated that while both layer reflection and turbulent scattering theories seem to give correct frequency and distance dependence, he believed that day-to-day variations in signals observed on experimental links favored the layer reflection hypothesis. He also noted that there appeared to be good correlation between the signal characteristics and the wind speed at inversion layer heights. W. E. Gordon remarked that large index gradients associated with layers could lead to increased turbulence. C. M. Crain pointed out that the mixing-in-gradient hypothesis was certainly wrong when applied to inversion layers such as those that occur off the West Coast of the United States.

Straiton presented some experimental results of tropospheric attenuation and millimeter waves. T. F. Rogers summarized the rather extensive results of an experimental study of air-to-ground transmissions. Radio fields were measured at elevations up to 40,000 feet and to distances of 1000 km. The highest flights were at least 5000 feet above the tropopause, and, according to Rogers, demonstrated that the long-distance fields could not be attributed to reflections at the tropopause. According to Crain, the Wright Field refractometer data showed small uninteresting index of refraction changes in the tropopause. K. A. Norton asserted that this should not be interpreted to be in contradiction with the Booker-Gordon scattering theory, which, according to him, gave little contribution to the field beyond the horizon from the tropopause.

J. A. Chisholm described experiments over paths extending out to 700 miles. He pointed out that the received fields did not increase when the common volume passed through the tropopause. In the session dealing with the so-called "tropospheric scattering," Chisholm stated that theory should strive to explain not only the existence of the radio fields well beyond the horizon, but also the frequency dependence, the attenuation rate, the variability of signal levels with antenna aperture, the useful bandwidth, and the optimum modulation methods.

Grosskopf described the results of an experiment which was based on the use of the antenna gain-function in determining the angle of arrival of the energy propagated beyond the horizon by the troposphere. Based on transmission studies beyond the horizon at 53 and 1370 mc per second, Saxton concluded that the results might well be interpreted in terms of reflection from elevated layers. He presented some preliminary results of a 10-cm radar scanning vertically with echoes returned from the 3 km height region. F. E. Gherzi described transmission of 200-kc signals over a 300-km path near Hong Kong which were indicative of stable reflecting layers.

Martin Katzin suggested that future experiments be conducted at several frequencies to allow the number of arbitrary parameters available for the different theoretical explanations to be reduced so that the results might be interpreted in favor of some particular propagation mechanism. Kenneth Bullington pointed out that recent television transmissions over a 300-km path between Florida and Cuba demonstrated that there were no long multipath delays.

A. T. Waterman described the results of some beam-swinging experiments which gave the azimuthal scattering pattern of the atmosphere. In reviewing Project Lincoln's tropospheric experiments along the East Coast, Chisholm declared that the delay time appears to be somewhat less than the great circle path to the common volume. The beam-swinging experiments indicate that signals arrive over a wider range of angles in azimuth than in elevation. Gordon suggested that the failure of some of Chisholm's "delay times" to agree with that calculated for the common volume defined by the main lobe may perhaps be caused by sidelobes giving rise to an additional common volume. Tropospheric propagation studies under trade wind inversion conditions were reported by Ament for a link between Cape Canaveral, Fla., and Nassau. Field strength measurements taken at distances well beyond the horizon showed a rather large increase of from 5 to 15 db in the inversion layer as compared to the signal level on either side. During thunderstorm conditions, there were occasional multipath transmissions associated with scattering from lightning flashes.

C. W. Herbstreit opened the session on radio and meteorology with a presentation of some phase measurements made over an optical link. It was observed that the energy density in the phase fluctuation spectrum fell off as the fourth power of the frequency. Norton expressed the opinion that a Bessel autocorrelation function was an outgrowth of the physics of the problem and consequently this particular function should be used in turbulent scattering theory. Crain stated that his experience had shown that the description of the median was quite complex and variable from day to day, and that no one autocorrelation function or spectrum could fit the variety of experimental data obtained. T. J. Carroll pointed out that the proposed Bessel correlation function had an infinite second derivative at the origin which implied, by the Taylor-Richardson theorem, infinite mean square density gradient and energy loss.

R. C. Langille described the transmission studies at 500 mc over an 85-mile path. It was noted that a tenfold increase of the fading rate was associated with the passage of fronts over the path, which indicated that such observations might be used as a meteorological tool to detect passage of weak fronts.

R. M. Fannin presented some results of attenuation measurements of millimeter waves through rain which showed a good agreement with theoretical values when measured drop-size distributions were used. It appears that the Laws and Parsons drop-size distribution as a function of rainfall rate is not correct. Fannin also summarized some index of refraction variations that were measured in the troposphere. Below cumulus clouds, refractive index variations of ten N units are quite common, whereas above the clouds the refractive index variation is quite small. Ten to eighteen N-unit variations have been observed in frontal regions. Refractive index variations are small in divergence regions and large in convergence regions.

B. R. Bean described some studies that he had been conducting on correlation of the signal over nonoptical links with surface refractivity. P. Misme reported that Perlot had noticed a correlation between surface refractive index and radio field strength over a decade ago and had reported this to URSI. He felt that a new concept was now needed, which would bring into being a definition of a "useful gradient." J. Voge commented that a good correlation between radio fields and surface index of refraction observed in Northern France was not found in certain other regions where a better correlation was observed between the index gradient and the radio fields. Ming S. Wong pointed out that the index of refraction gradient at elevations above 30,000 feet is not dependent upon location, and consequently one might question the turbulence scattering hypothesis when the correlation of the radio fields with the surface refractivity is so good. Crain recalled an index of refraction profile measured through a layer at an elevation of some 24,000 feet, which showed great stability above the layer and large index of refraction variations below the layer. He stated that it was impossible to apply the mixing-in gradient idea to explain measured index of refraction fluctuations commonly found in the atmosphere. He further expressed the opinion that the refractive index variations at the higher elevations were far too small to explain the long-distance radio fields.

V. A. Krasilnikov, in describing his theoretical work on the effects of tropospheric irregularities on radio fields, indicated that the structure function is better adaptable to scattering theories than the correlation function. The structure function is the main characteristic in Komolgoroff's theory of local isotropical turbulence, and consequently it is theoretically well grounded. C. G. Aurell commented that there have been many measurements made, but there is still no agreement on the basic physical process involved in the description of the fields well beyond the horizon. Are there current observations that cannot be described by the proposed model? A. D. Wheelon expressed the opinion that the phase and amplitude measurements beyond the horizon should certainly be based on a theory consistent with Maxwell's equations. In addition he felt that the theory should certainly describe the frequency and distance dependence and should be correlated with the meteorological situation. Also, the time and space variation of the field and its dependence upon the aperture of the measuring antenna should be adequately described. Gordon stated that in using the mixing-in gradient hypothesis for computing the scattering of radio waves in the troposphere, the excess of the index gradient over the adiabatic should determine the dielectric irregularities used. Temperature variations of the order of 1° C in the stratosphere are required to explain the radio fields observed. He also pointed out that the maximum realizable gain of an antenna will be about 38 db.

G. Eckart described a method of analyzing the perturbations of dielectric constant in turbulent regions by the use of scattered field observations.

Smyth presented the reflection coefficient for two types of transition layers. He pointed out that although one could not experimentally distinguish the difference between these two layers, the reflection coefficient differed by two orders of magnitude.

Carroll reiterated his belief that normal mode theory adequately describes radio fields within the optical region, the diffraction region, and the so-called twilight or scatter region. Katzin observed that normal mode theory was based on horizontal stratification; consequently, he wondered how it could be modified to describe the time and space variation of the signal.

The discussions of Commission II indicated that all the participants knew well the desired questions, and it was equally clear that no one has yet thought of the proper way of asking the questions.

Resolutions

1) It was recommended by Commission II at the Twelfth General Assembly that:

a) The extent of the dependence of scattered signals on latitude, climate, and terrain should be further studied by means of observations in differing geographical areas.

b) In particular, measurements of field strengths from high-power transmitters should be made at great distances and for various frequencies, polarization, antenna heights and gains, and various types of terrain. Use of aircraft in such measurements is recommended.

c) Propagation studies should be extended to include investigation of pulse distortion, phase stability, fading rates, and diversity properties of the signal.

d) Simultaneous meteorological measurements designed to improve understanding of the propagation mechanism are desirable.

e) Quantitative knowledge of the means of relating the above findings to practical radio results should be extended, especially in the direction of providing satisfactory approximations.

2) In view of the importance of conditions in the lower atmosphere to the propagation of the shorter radio waves, it is recommended that URSI take steps to insure that national meteorological authorities are aware of the need of radio scientists for meteorological observations, and that such observations should be organized so as to provide as much information as possible for application in the radio field. It is recommended that national meteorological authorities should be encouraged:

a) To perform more detailed meteorological measurements, including those with airborne equipment, with emphasis on the study of the fine structure of the atmosphere. Special attention should be given to the detailed variation of the refractive index in the region where this index undergoes significant changes. The use of the refractometer for such measurements is strongly recommended.

b) To complete meteorological data of the nature described under a) for the purpose of using these data as a help in prediction, on a statistical basis, of the propagation characteristics to be expected in various geographical regions.

3) It is recommended that, whenever possible, meteorological measurements of a sufficiently detailed character to throw light on the mechanism of propagation be carried out in conjunction with programs of propagation measurements. It is suggested that several varieties of atmospheric phenomena and methods of study are directly or indirectly germane to tropospheric radio propagation; hence, multipurpose meteorological and radio signal measuring programs are recommended as mutually beneficial and economic.

4) It is recommended that the mathematical problem of the propagation of electromagnetic waves in an inhomogeneous medium with a refractive index which is a function of height above a spherical earth, be further investigated with a view to determining as accurately as possible the field transmitted around the earth. The mathematical investigation shall in particular seek better knowledge of the eigenvalues belonging to the various modes, and a better determination of the height gain functions.

Alternatively, any other method which permits the determination of the fields either exactly, or with an estimate of the error, should be pursued.

5) Commission II, in noting the CCIR Questions 101, and 136–138, and the Study Programs 55, 57, 79, 90, and 91 reports that more than two thirds of its sessions at the Twelfth General Assembly were devoted to active discussion of work relating directly to these subjects from many different organizations. It is clear that useful results are being achieved, and will be communicated to CCIR by various administrations before the next plenary meeting.

6) Commission II concurs unanimously with the following statement of purpose of the Joint Commission on Radiometeorology as formulated at its meeting of August 16, 1957.

That the 1957 meetings of the Joint Commission had provided a successful forum in which specialists in radio science, meteorology, and physics had a unique opportunity to describe their experiences and exchange knowledge about phenomena in the lower atmosphere in which they had a mutual scientific interest, and the following resolutions were adopted unanimously:

a) That the Joint Commission should continue as a forum with a reasonable balance of radioscientists, meteorologists, and as many other physicists as may be necessary, with whom the radiometeorologists can exchange knowledge and experience.

b) That the program for the immediate future should be:

i) Study of vertical and horizontal air movements and refractive index structure including formation of clouds and precipitation and application of the results to radio wave propagation and meteorology.

ii) Study of electrical fields in the atmosphere with special reference to thunderstorms.

c) That the constituent Unions be invited to review their representation on the Commission and make fresh appointments where necessary.

d) That the next meeting of the Commission be held in 1960.

e) That the papers for presentation at the next meeting be submitted to the President of the Commission for approval three months before the meeting.

f) That the Commission wishes to convey its warmest gratitude to the President of New York University and his staff, particularly Prof. Morris Kline, for the facilities, assistance, and hospitality provided in connection with the Commission's meeting.

7) During the IGY the needs of radio scientists studying tropospheric wave propagation should continue to be met by the following program:

a) Radiosonde data up to maximum heights possible should be published in as much detail as the precision of the instrument permits. During World Meteorological Intervals the number of soundings should be at least four per day.

b) It is suggested that, where possible, supplementary observations should be made of meteorological data at lower levels using captive balloons or masts.

c) Where possible, airborne microwave refractometer soundings should be made in various air masses to ascertain the characteristics of the air masses with respect to the vertical distribution of refractive index and the scale and intensity of its fluctuations.

d) The attention of the meteorologists should be drawn to the refractometer as a rapid instrument for the determination of water vapor content when used in conjunction with a temperature measuring element. The refractometer soundings described in c) above have a direct usefulness to the meteorologists in this regard.

Report on URSI Commission III—Ionospheric Radio Propagation*

L. A. MANNING†, SENIOR MEMBER, IRE

Objectives

THE STUDY of ionospheric radio propagation and the physics of the outer atmosphere are inherently international. The ionosphere knows no national or continental boundaries, and the radio signals that it bends back to earth travel from one side of our globe to the other. Cooperation between the research workers and the users of the ionosphere throughout the world is more than desirable—it is quite essential. Thus it is natural that the commission dealing with these topics should be the largest in URSI.

At the Twelfth General Assembly, the foremost workers in the scientific study of the ionosphere gathered from throughout the world to interchange the results of their work, and to formulate resolutions and recommendations for future action. These recommendations covered such topics as fields of study in need of further support, technical symposia that should be organized, the desirability of continuing certain observing stations in operation after the IGY, and the need for financial support of workers at the IGY data centers after the IGY is over. It is expected that these recommendations of URSI will carry considerable weight with those bodies empowered to act in these fields.

Technical Program

The program for the commission meetings was arranged by D. F. Martyn of Australia, International President of the commission, after consultation with the chairmen of the national commissions. It consisted of eight sessions on technical subjects, and three business meetings. Each of the technical sessions was centered upon a single topic, and contributions to the topic were presented by those most active in that field. These topics are listed below, together with the principal speakers.

1) *The lower ionosphere:* A. H. Waynick (U.S.A.), M. Nicolet (Belgium), C. D. Ellyett (New Zealand), W. Dieminger (Germany), J. M. Watts (U.S.A.), C. G. Little (U.S.A.), Mlle. G. Pillet (France).

2) *Geomagnetic influences in the ionosphere:* E. V. Appleton (Great Britain), K. R. Ramanathan (India), K. Maeda (Japan), M. L. White (U.S.A.).

3) *Whistlers* (joint session with Commission IV): M. G. Morgan (U.S.A.), K. Maeda (Japan), R. A. Helliwell (U.S.A.), A. G. Jean (U.S.A.), R. M. Gallet (U.S.A.).

4) *Geomagnetic storms:* K. Maeda (Japan), T. Obayashi (Japan), A. M. Shapley (U.S.A.), R. W. Knecht (U.S.A.), V. Lincoln (U.S.A.).

5) *Horizontal movements in the ionosphere:* L. G. M. Huxley (Australia), A. C. B. Lovell (Great Britain), B. Nichols (U.S.A.), K. Maeda (Japan), M. L. White (U.S.A.), T. N. Gautier (U.S.A.), K. Rawer (Germany), A. M. Peterson (U.S.A.).

6) *Scattering in the ionosphere:* H. G. Booker (U.S.A.), V. R. Eshleman (U.S.A.), C. D. Ellyett (New Zealand), L. A. Manning (U.S.A.), W. G. Abel (U.S.A.).

7) *The event of February 23, 1956:* A. H. Shapley (U.S.A.), R. L. Leadabrand (U.S.A.), S. Matsushita (Japan), C. G. Little (U.S.A.), J. H. Chapman (Canada) J. Aarons (U.S.A.), E. R. Schmerling (U.S.A.), D. K. Bailey (U.S.A.).

8) *Rocket exploration of the ionosphere:* H. Friedman (U.S.A.), M. Nicolet (Belgium), J. C. Seddon (U.S.A.), W. H. Pfister (U.S.A.), K. Rawer (Germany).

A general discussion followed each of the formal presentations, with wide participation. In the sections that follow, some of the high points of the individual sessions will be considered.

The Lower Ionosphere

By the lower ionosphere is meant the region from perhaps 50 to 120 km in height, from which low-frequency and very low-frequency radio waves are reflected. In the opening review, Waynick commented that our knowledge of the region is derived primarily from continuous wave and pulse radio soundings, and from direct rocket measurements. Spectrographic studies of the X-ray and ultraviolet radiation present in the region have now been made at wavelengths of 1 to 100, 1000 to 1500, and over 2000 Angstroms. Thus it is reasonably sure that the ionization near the maximum of the E region is caused by a flux of 0.1 ergs/cm²/sec in the range of 40 to 100 A. Slightly lower ionization is caused by Lyman β flux of about 0.3 ergs/cm²/sec, and by the Lyman continuum. The D region is caused largely by Lyman α flux of 0.4 ergs/cm²/sec. During disturbed conditions, hard X rays of wavelength of 15A and below are appreciable.

The ionized constituents in the D region are thought to be NO ionized by Lyman α and O_2 by hard X rays. The E region is thought to be due to ionization of air by soft X rays, and meteoric ionization. We are now at the stage where studies of the electron density profiles can be made profitably.

In the next talk, Nicolet pointed out that in finding the distribution of molecular oxygen under the influence

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of dissociative radiation, recombination, diffusion, and transport, especial importance attaches to transport. At 100 km the lifetime of atomic oxygen is 3 months. In order to maintain equilibrium over a year, considerable downward transport is needed. To reconcile rocket measurements of pressure made at 70 and 100 km, Nicolet stressed that a very reduced scale height must exist between these levels; in terms of temperature, the indication is that a minimum of 140°K should exist between 80 and 90 km.

The results of some high sensitivity pulse soundings carried out in New Zealand by Gregory were described by Ellyett. Using a 4-kw transmitter sending 10-μsec pulses into a 21-acre antenna at a very quiet location, echoes were found at quite low heights. Echoes at heights of 54, 67, 70, and 75 km were found with a reflection coefficient of 2×10^{-5}, and invariably an echo at 85-km height with a reflection coefficient of 10^{-4}. A connection was suggested between these echoes and the source of the noon-time ionospheric forward scatter signals. The frequency was 1.75 mc.

Some especially interesting sweep-frequency pulse records made in the low-frequency region were shown by Watts. He showed that the "150-km echo" observed by Lindquist and others at 150 kc was the lower branch of an ordinary trace, with penetration frequency of 400 kc.

Geomagnetic Influences in the Ionosphere

The E and F regions of the ionosphere exhibit a number of unusual features that are related to the magnetic field of the earth. These features include the dependence of ionization density on geomagnetic latitude, the "equatorial trough" about the geomagnetic equator, and the changes in layer height and thickness throughout the day to which the other effects owe their origin.

Appleton further stated that distortion of the shape of the ionosphere must be caused by transport of ionization that has already been created. Among the possible causes are electric fields and winds transverse to the earth's magnetic field.

As an indication of transport in the E layer, Appleton pointed out that contours of fixed maximum electron density, when plotted on the globe, are ellipses rather than circles; the center of the ellipses, corresponding to the world-wide maximum of electron density, are always displaced from the subsolar point towards the equator. In the F layer, the layer behavior is related to the ionospheric current system responsible for variations in the geomagnetic field. In particular, exact location of the form of this circulatory current system is important.

In the following paper, Maeda reported that it is possible to compute the vertical drift velocity in the ionosphere if the currents producing the magnetic variations are known. Such calculations explain the observed depression of the maximum electron density in equatorial regions. The layer is "drawn out" or increased in thickness, so that the same total ionization content results in a lower maximum density.

It was demonstrated in discussion by White that vertical oscillations in the ionosphere due to tidal forces are nonlinear. At Huancayo, the second, third, and fourth harmonics of the forcing frequency are quite noticeable.

In general, it may be said that we are finally coming to understand the dynamics of the F layer; theories including the interaction of the earth's field with tidal motion and electric forces are serving to explain why the diurnal, seasonal, and geographical variations of density are not related directly to the ionizing radiation. Further research is certainly called for, however, before these partially quantitative ideas can be applied to practical use.

The Joint Session on Whistlers

This session discussed a topic that is of great interest to Commission III, but which is one of the principal subjects of concern in Commission IV. Briefly, a whistler is the audio frequency electromagnetic signal received from a lightning flash after it has traveled one or more times between the northern and southern hemispheres. The propagation path is approximately that of a line of the earth's magnetic field; while traveling along this path out to a very great height, the original impulse is delayed by about a second, with the high-frequency components arriving at the receiver first. When changed from electromagnetic to acoustic form, the signal sounds like a slowly falling whistle. A fuller discussion of whistlers will be found in the report on the activities of Commission IV. Here let it be said that the high point of the combined session was the résumé by Fuchs of a paper on whistlers (only recently a subject of intensive study) that had been published in 1893. These early observations, made in 1886 on a mountain telephone line, were carried out systematically over an extended period and produced diurnal and seasonal variations in frequency of occurrence in good agreement with those recently reported.

Geomagnetic Storms

One of the primary problems in geomagnetism and study of the outer atmosphere is the geomagnetic storm. Such a storm is a complex phenomenon triggered by the arrival of corpuscular matter from the sun. The auroras are manifestations of the interaction of this material with the earth. Other effects include the changes in ionospheric density and radio wave absorption known as an ionospheric storm, and the changes in the strength of the earth's magnetic field from which comes the name geomagnetic storm. The opening paper on this subject was presented by Maeda, who pointed out that the variations in the intensity of the magnetic components can be studied either in terms of time measured from the beginning of the storm, or in terms of local time. In storm time the duration of the average variation is related to the flow of current in the ring current thought to revolve about the earth at several earth radii. At Tokyo, Sato has considered ionospheric disturbances in the same way. He found that negative disturbances, corresponding to a decrease in maximum F-layer electron density, occur at high latitudes in the summer and equinoxes. Positive disturbances occur only in equatorial regions. For both types of disturbances, the layer height increases. The expected changes in ionospheric height are found by starting with the magnetic variations, and computing the corresponding currents. The vertical drift velocity of ionization is then due to the interaction of the charge with the electric field forcing this current, and to the geomagnetic field.

In a further discussion of the morphology of ionospheric storms, Obayashi presented results on the variations from the quiet day mean of F-layer critical frequencies on storm days. The variations were presented as solar time and storm time averages. Using data from 14 stations, he found that contours of deviation of F2-critical frequency were circular when plotted on a polar projection in storm time. No change of critical frequency was found in the auroral zone; depression occurred nearer the pole. At intermediate latitudes, he found critical frequencies were depressed at times between 09^h and 12^h, and were enhanced from 21^h to 24^h. Individual storms were found to fit this over-all pattern, but with considerable complications. Upon examining the progression of effects in storm time, it was found that the variations mentioned above begin to form during the first six hours of the storm. During the 6th an 18th hours the depression grows, but the enhancement vanishes. From study of the H and Z traces, Obayashi deduces that the height of the current layers causing the magnetic fluctuation is about 120 km.

A new method of presenting ionospheric data now being used by the Central Radio Propagation Laboratory of the National Bureau of Standards was described by Shapley. These "f plots" are useful for giving resolution in time and height, and provide a rapid, integrated picture of a storm's influences. They consist of a graphical presentation of the critical frequencies and other sounding data throughout the day. Thus at a given hour a vertical line is drawn on a frequency scale, so that the highest and lowest frequencies returning echoes are recorded. With the inclusion of further notations, the numerical scalings are reduced to an informative graphical pattern.

A disturbance of the ionosphere somewhat different from the ionospheric storm is the Sudden Ionospheric Disturbance (SID). The SID's are produced by radiation emitted by the sun during solar flares. This radiation enhances the ionization in the D region, thereby causing increased absorption and often a radio blackout, which may last from a few minutes to an hour or more. Miss Lincoln described the results obtained upon reexamining high-frequency field strength records from 1949 to 1953 for even very minor fades. Many very weak SID'S were found in this way, so that the percentage of observed SID's was raised to 85 per cent of the observed solar flares. In the discussion Schmerling pointed out that a suitable notation for cataloging fadeouts has been presented by Bracewell.

Horizontal Movements in the Ionosphere

Winds in the ionosphere are measured in a number of ways. Below about 110 km the drift of ionized meteor trails is measured. In the E region the fading of radio echoes is analyzed for motion of a rough reflector, and the apparent drifts of sporadic-E clouds are tracked. In the F layer the fading analysis method is used. The velocities of traveling disturbances are also noted, but they are probably not wind motions. Huxley from the University of Adelaide opened the discussion by describing the results obtained using the meteor method at his laboratory, and their relation to results at lower altitudes. In the southern hemisphere the wind vector is found to rotate counterclockwise at a semidiurnal rate. In Southern Australia the results indicate very little turbulence at 90 to 100 km altitude. In the discussion, Manning pointed out that data from Stanford, Ottawa, and New Mexico show large shears, with a mean value of 100 m/sec/km for the maximum wind gradient, and a minimum scale of about 1 km. Thus the winds in Australia appear uniquely nonturbulent.

Lovell of the University of Manchester described winds measured at Jodrell Bank again using the meteor echo method. Velocities of 60 to 120 km/hr are general. The height gradient of the average wind was found to be between 0 and 5 m/sec/km, with variations extending to 144 m/sec/km, in agreement with Manning's result. Millman confirmed Manning's comment that wind shears appear to be separated by 5 to 6 km. The ratio of horizontal to vertical motion is about 10 to 1.

A measurement of the motion of reflecting elements in the aurora was described by Nichols. Observing at 41 and 106 mc. echoes were found coming from normal to the earth's magnetic field. A doppler shift of the received echo indicated movements to be taking place. Speeds of 300 to 2000 m/sec were deduced for the movements.

Maeda, reporting for Kato, Hirono, and Kitamura, described the wind system needed to explain the dynamo currents in the ionosphere, and so the variations in the earth's magnetic field. The diurnal speed was from 20 to 50 m/sec, and the semidiurnal component from 8 to 20 m/sec. White of CRPL mentioned that they were also working on the dynamo problem, connecting the theory of tides with the generator motion. He finds the tidal action to be nonlinear.

An attempt to determine the height of the motions of irregularities causing the fading of ionospheric echoes was described by Gautier. Fading signals were simultaneously recorded on several receivers. It was expected that if the wave paths crossed at the heights where fading was produced, the fading should correlate. If the wave paths crossed at some other height, the fading would not correlate. Gautier concluded that the fading is introduced near the level of reflection in the E layer, but well below the level of reflection in the F layer.

The drift of patches of sporadic-E ionization was discussed by Peterson. Using the back-scatter or "scatter-sounding" technique, he found the majority of drifting patches to move at speeds of about 60 m/sec. The direction of drift is mainly to the west. The speed appears to increase with height. He also showed that perturbations at the F2 skip distance as seen on the ppi display reveal traveling disturbances apparently along the magnetic meridian with speeds of 700 to 1500 km/hr.

Scattering in the Ionosphere

The range of the subject for this session was indicated in the opening summary by Booker. He listed the following topics as being related to scattering in some way: fading, spread F, the "Stanford northerly echoes," star scintillation, straight meteor trails, distorted meteor trails, back scatter below E, scatter transmission, auroral echoes, and sporadic E.

Meteoric scatter was the first of these subjects to be discussed. Eshleman described the comparison of the rate of arrival of meteoric signals on an oblique path and the predicted oblique rate based on simultaneous back-scatter observation. The agreement was very good, suggesting that the use of a radar on a routine basis could serve to determine the best directions to aim an antenna on an oblique path. Eshleman also outlined the effect of the distribution of meteor radiants in the sky upon the location of "hot spots" to one side of an oblique path where the antenna beam should be directed. The optimum direction varies with time of day.

Based on southern hemisphere observations, Ellyett described studies of subvisual meteors at 67 mc. He found that many of the meteors that would have been called sporadic using lower sensitivity equipment belong to identifiable radiants at higher sensitivities.

Again concerning meteoric echoes, Manning presented a theory of the fading, attributing it to distortion of the trails into sinuous shape by horizontal gradients in the wind. The features explained include the 0.4-second delay at the start of fading described by Greenhow, the variation of mean fading speed with time throughout the echo, the loss of aspect sensitivity with time described by McKinley and Millman, and some new measurements of the correlation of the fading envelopes of meteors received at separated ground stations. The wind gradient was found to have a mean value for the relative maxima of about 100 m/sec/km as found photographically by Whipple; the deviations in wind velocity become uncorrelated in about a scale height vertically, and there is no evidence for scales of less than a kilometer.

An experimental measurement of vhf field strength in an aircraft was described by Abel. Recordings were made at distances up to 1800 miles. Attenuations of about 140 db were reached at 500 miles, with little increase thereafter. They found no changes in fading properties with distance.

The Events of February 23, 1956

At 0330 UT on February 23 an epochal solar flare-cosmic ray event occurred. Because of its unusual nature, sufficient interest existed in this one isolated geophysical event to warrant a separate discussion. In the opening paper Shapley pointed out that the event started with a solar flare and radio noise burst from the sun. A few minutes later a large enhancement in cosmic ray flux occurred. The ionospheric effects of the flare appeared on *both* the dark and sunlit hemisphere, although they were concentrated at the high latitudes in the dark hemisphere. Increased radio wave absorption occurred in the absence of auroral or geomagnetic activity. The absorption appeared first at high latitudes, and the blackout lasted about 40 hours in the polar cap.

Matsushita noted that a positive and a negative magnetic bay occurred at Resolute Bay and Baker Lake, nothing at other stations. He suggested current occurred only in the polar cap due to the arrival of, say, high-energy protons. If the particles reached 60 km a polar blackout resulted. If they only reached 80–90 km, there would be increased current flow and a magnetic bay. Further observations were reported by Leadabrand, Little, Chapman, Aarons, and Schmerling. It was notable, as Bailey pointed out, that the absorption level was at so low a height that the ionospheric scatter signal was completely lost for the first time in history.

Rocket Exploration of the Ionosphere

The use of rockets has been of great importance in ionospheric research because of the direct measurements of pressure, electron density, and the other physical properties. Of perhaps even greater importance, it has been possible to measure the flux of radiation present in the layers. Friedman of the U. S. Naval Research Laboratory opened with a discussion of the ionizing radiations effective in the lower ionosphere. For radiation of 0.5 to 2.5 Angstroms, the penetration to unit optical depth occurs to 85 km; for 2 to 100 Angstrom radiation, to 100 km; for 150 to 400 Angstroms, to 170 km; and for 500 to 800 Angstroms, penetration occurs to 180 km. Measurements of the intensity of Lyman α emission in the year 1952 gave a flux of 0.10 ergs/cm^2/sec; more recent measurements have yielded 6 to 9 ergs/cm^2/sec. Possibly this difference is real, in which case a very large change in solar radiation has taken place. Atmospheric densities found from the transmission of 50-Angstrom X rays at 100 km are only about one-third of those presented by the Rocket Panel as a best weighted average of many determinations. The discrepancy can only be removed by assuming the presence of 100 to 130 ppm of water vapor.

Friedman noted that the only steady flux of ionizing radiation found in the night sky is the resonance Lyman α, scattered on the dark side of the earth by hydrogen near the earth and in the path of light from the sun. The energy, about 10^{-2} ergs/cm^2/sec/steradian, is about one-hundredth of the energy needed to ionize the E region. Recent balloon measurements in Minnesota show the possibility of 60,000 ev X rays at the 33-km level.

Measurements of electron densities using the aerobee rocket were described by Seddon. Transmitters on the rocket radiated on 7.75 and 46.5 mc. By beating the upper frequency with the sixth harmonic of the lower frequency at the receiver, the index of refraction for the layer is found. An increase in accuracy is obtained by utilizing the Faraday rotation of the plane of polarization of the waves passing through the ionosphere. The altitude of the F2 maximum was found in the range 280 to 340 km both day and night. A Fort Churchill firing on July 4, 1957 revealed electrons starting at 60 km; Canadian stations reported a complete radio blackout.

Detailed rocket studies of the structure of the E layer were reported by Pfister. Considerable irregularity was found, which he attributed to small blobs of electrons at distinct levels of 90, 95, 100, 106, and 111 km. In subsequent discussion, Seddon remarked that the Navy does not observe the strong irregularities that the Air Force sees, but does get discrete levels. Helliwell pointed out that several years ago he had noted stratification at 102, 106, and 111 km based on low-frequency pulse soundings.

Dieminger pointed out that if one uses an expanded range scale on a p'–f record, one finds many shifting cusps at different heights from 1 to 3 mc.

The Business Sessions of Commission III

Three business sessions were held, leading to the appointment of a variety of working groups and subcommissions, and the passage of a number of resolutions and recommendations. At the first meeting, reports were received from the subcommissions on Ionospheric Observation and Reduction of Data, Wave Interaction, the Propagation Time of Radio Signals, and Magneto-Ionic Nomenclature. The commission then considered the need for future symposia on specialized research topics; it was recommended that symposia be held on 1) the Outermost Ionosphere, and 2) The Events of February 23, 1956, but not until after the IGY.

A number of resolutions referred to URSI by the Mixed Commission on the Ionosphere were considered by Commission III, as well as a long list of questions from CCIR. These resolutions and questions were considered individually for possible endorsement or action, and to allow action to be taken more expeditiously on CCIR matters, the President and two Secretaries of Commission III were empowered to deal directly with questions from CCIR in the future.

Among the new resolutions dealt with by Commission III, were proposals that: further work be done on true height calculation; cooperation be encouraged between workers in fluid mechanics, magneto-hydrodynamics, and the ionosphere; collaboration be encouraged in rocket research in view of its importance; that a list of thirty temporary ionospheric observing stations be continued in operation for a year after the IGY.

Conclusion

The meetings of Commission III at the Twelfth General Assembly of URSI were very successful both for the interchange and discussion of technical matter, and as a means of promoting international cooperation in the scientific field.

Acknowledgment

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Report on URSI Commission IV—Radio Noise of Terrestrial Origin*

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Objectives

COMMISSION IV is concerned with the study of the sources, propagation, and effects of various kinds of radio noise of terrestrial origin and their relation to other geophysical phenomena. Although the more common atmospherics have been the subject of most of the Commission's activities in the past, a considerable amount of effort is now being directed to the study of whistlers, dawn chorus, and other VLF emissions of natural origin.

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Technical Program

Commission IV held nine sessions (one joint with Commissions III and V) under the chairmanship of J. A. Ratcliffe (U.K.) and dealt with the following general topics: 1) whistlers and other VLF phenomena, 2) characteristics of radio noise, 3) IGY projects, and 4) atmospheric sources. Thirty reports and papers in the fields of interest were submitted to the assembly. Material from these papers was presented during the sessions, but all papers were not presented in full. Valuable discussions of the various topics were contributed by delegates from many countries.

The Eleventh General Assembly had created two Working Groups: one on the Study of Atmospheric Waveforms and another to study the question: "What are the most readily measured characteristics of terrestrial radio noise from which the interference to different types of communication systems can be determined?" These groups reported on their progress, and recommendations were made for further studies.

Whistlers and other VLF Emissions

M. Morgan (U.S.A.) reviewed past work on study of whistlers and summarized current investigations.

R. Helliwell (U.S.A.) discussed the reception of NSS (15.5 kc) at Cape Horn via the whistler mode of propagation. At a site having no man-made noise and a very low level of natural noise, the signals from NSS were heard with a delay of 0.61 second after the direct wave and with a strength, at times, of 30 μv per meter. Reception by this mode was recorded on 50 per cent of the total days on which attempts were made. The receiving station was located at a point approximately 1000 miles from the magnetic conjugate point of the transmitter.

R. Gallet (U.S.A.) reviewed whistler studies being conducted at NBS, Boulder, Colo. On one occasion 21 echoes were recorded, indicating 42 reflections, with about 20-db loss over the series. He suggested an explanation for some forms of VLF emissions based on interaction between solar corpuscular radiation and the earth's magnetic field.

Helliwell summarized briefly the work of K. Maeda (Japan) on nonsymmetry of whistler paths with respect to the earth's magnetic lines.

A. Kimpara (Japan) presented results of Japanese studies of whistlers at low latitudes: Wakkanai at 35.3° Geomag, and Toyokawa at 24.5° Geomag. He reported the highest frequency of occurrence in the periods two hours before and two hours after sunset. Only short whistlers are heard at Toyokawa and only in winter months.

H. Dinger (U.S.A.) described some unusual VLF phenomena including the periodic types of dawn chorus. Simultaneous records obtained at Washington, D.C. and Ottawa, Canada were shown. The unusual emissions occur most frequently in the spring months and usually in the afternoon, in contrast to normal whistler activity which is lowest in the afternoon.

R. Rivault (France) discussed correlation between whistlers and atmospherics having certain types of waveforms, and mentioned a possible correlation between the D region and whistler occurrence.

G. Jean (U.S.A.) presented some results of simultaneous observations of atmospherics and whistlers made at Boulder and Stanford. Waveforms of the electric field of atmospherics which produced whistlers showed strong 5-kc components.

C. Hines (Canada) commented on a suggestion by Storey that the presence of heavy ions in the propagation medium could change whistler characteristics and might explain some types observed.

Morgan showed some spectrograms of multiple whistlers apparently received by slightly different paths, and discussed the combinations of paths required to explain the dispersions observed. He also showed a three-dimensional representation of the distribution of dawn chorus by geographical location and time.

Helliwell commented that dawn chorus time of occurrence shows a regular variation with latitude. He reported that it peaks at 1400 local time in Alaska and early in the morning at Wellington, N. Z.

There was considerable discussion in the relation between frequency spectra of atmospherics and the possibility of a resultant whistler. The question of possible variation in the lightning energy from strokes occurring over flat ground compared to those occurring over the sea or over mountainous regions was discussed at some length. E. Hill (U.S.A.) stated that he thought lightning energy over mountainous regions peaked at a lower frequency. T. Wormell (U.K.) stated that strong strokes have a higher ratio of low-frequency energy. H. Kasemir (U.S.A.) pointed out that cloud-to-ground strokes have more energy than cloud-to-cloud strokes, and that the length of the stroke probably influences the frequency distribution.

The observations of whistlers associated with local thunderstorms was discussed. Some observers reported a few cases of direct observations of flashes producing whistlers; Dinger stated that he has never received strong whistlers from local storms in several years of concentrated effort.

Joint Session with Commissions III and V on the Subject of Whistlers

Chairman Ratcliffe presented an introduction in whistler phenomena, and summarized Storey's original work.

Morgan discussed the results of simultaneous recordings at a station in the Aleutians and one in New Zealand which are closely conjugate geomagnetically. Good examples of the same whistler train as observed at both locations were presented.

Maeda summarized his theoretical conclusion that the ray paths in the whistler mode deviate outwards from the magnetic lines of force.

Helliwell gave a theoretical explanation of "nose" whistlers with experimental confirmation. He then described the reception of NSS on 15.5 kc at Cape Horn, about 1000 miles from the magnetic conjugate point. Important results related to multipath propagation leading to split echoes and fading, and to poor correlation between reception of whistlers and strong NSS whistler-mode signals.

Jean described simultaneous reception of whistlers at Boulder and Stanford and discussed characteristic relationships between whistlers and the spectra, and geographical location of the originating lightning flashes.

Gallet propounded a theory of VLF hiss and similar phenomena based on the interaction of solar corpuscular streams with the earth's magnetic field. Various possible models of the exosphere were discussed and it was shown that some models led to qualitative explanation of preferred frequencies in hiss and of "hook-type" phenomena. The main conclusions were that the outer ionosphere was of a fibrous nature, that there was likely to be another ionosphere layer outside the F layer, that corpuscular radiation was the cause of some VLF noise, and that corpuscular radiation could sometimes be in a continuous flow and sometimes in clouds.

Morgan reported a correlation between "hook-type" whistlers and flashes in the aurora.

L. Bierman (Germany) advanced reasons why the earth's magnetic field might extend effectively to only 5 or 10 earth radii.

O. Rydbeck, (Sweden) asked what determined the gain parameter of the amplification of the radiation caused by the interaction of corpuscles and magnetic field. This was being studied by Helliwell who reported a preliminary conclusion that the corpuscular kinetic energy was far greater than appeared to be necessary to explain the observed levels of hiss. There was some discussion of whether the hiss originated in the outer ionosphere or in auroral regions; both mechanisms appeared possible.

J. Fuchs (Austria) reported on observations of whistlers in Austria dating back to 1866. Whistlers were heard on a 22-km telephone line without amplification.

Kimpara suggested that diurnal variation of whistler activity depended on geomagnetic latitude and reported on observations obtained at two Japanese stations.

Hines outlined recent work initiated by Storey which showed that the presence of heavy ions could influence whistler spectra at the lower frequencies and could give rise to a mechanism of propagation normal to the magnetic field.

The Use of Waveforms of Atmospherics to Investigate Propagation Phenomena

Wormell presented the report of the working group. Those exchanging data have agreed on four types on waveforms of the return strokes:

1) Regular peaked—nighttime only, out to 8000 km if storm is east and to 2000 km if storm is west of England,
2) Peaky short—daytime, short distances (out to 1000 km),
3) Smooth short—daytime, long distances (beyond 1000 km),
4) Quasi-sinusoidal—nighttime, predominate in Europe when storm is greater than 3000 km to the west.

It appears that even experienced workers have difficulty in independently arriving at the same analytical results. It is suggested that a standard method of analysis should be adopted.

Great care must be taken in interpreting waveforms. First, the record should be of good quality and have a resolution capable of 5-μsec accuracy. Second, the whole waveform must be fitted to the theory.

Kimpara discussed some material which he had published in Volume IV of the *Proceedings of the Institute of Atmospherics*. The chief point was that waveforms were dependent on distance and that 3000 km seems to be significant as a distance beyond which changes in type are noticeable.

J. Wait (U.S.A.) discussed the theoretical aspects of VLF skywave computations using a geometrical-optic concept.

Jean gave some results of calculated VLF reflections from atmospheric recordings made in the Boulder-Stanford simultaneous recording experiments.

H. Norinder (Sweden) discussed some waveform recordings of field currents at different distances from lightning sources. He strongly emphasized the need for simultaneous recordings of the same atmospherics at different distances from the source. It was pointed out that atmospherics are the only signal source for propagation studies below 15 kc.

F. Horner (U.K.) suggested that some of the studies best obtained by waveform analysis are: effective height of the ionosphere, reflection coefficients, and land and sea effects.

The chairman appointed a working group to outline recommendations as to "How the study of atmospherics should proceed so as to improve our knowledge of propagation." The working group consists of the following members: H. Norinder, G. Jean, F. Horner, T. Wormell, A. Kimpara, A. Watt (U.S.A.), and E. Lauter (Germany). It also was suggested that the U.S.S.R. may wish to designate a member.

The Measurement and Description of the Characteristics of Atmospheric Noise.

W. Crichlow (U.S.A.) presented the report of the working group on radio noise characteristics. It recommended that *complete* amplitude distribution measurements be made at only a few selected stations. On a wide-scale basis, measurements of noise to be made are: 1) average power, 2) average voltage, and 3) average logarithm of the voltage. The ratio of rms to average voltage and the effects of bandwidth are also to be studied.

In response to CCIR Recommendation 120, the new radio noise prediction charts have been prepared and published as CCIR Report 65. These curves are in terms of average power only. It is hoped to revise them and include additional parameters as the necessary data become available. Ratcliffe suggested that the working group report might be recommended for publication as an URSI formal report.

Horner reviewed a paper by J. Harwood on the characteristics and variations with time, frequency, and bandwidth, of very low-frequency radio noise described in terms of the average voltage, rms voltage, and amplitude distribution of the envelope at the output of a narrow-band receiver. Horner then discussed his own paper on the detailed structure of noise. Pulses in each lightning stroke seem to be more numerous than it was first thought. He compared noise on 10 kc and 10 mc. The high-frequency noise is stretched out more than the low-frequency components. During the low-frequency noise, the high-frequency components had an apparent null.

Y. Aono (Japan) discussed HF amplitude probability distribution measurements made in Japan. Noontime measurements approximated Rayleigh; nighttime was log-normal.

A. Sullivan (U.S.A.) stated that he did not observe Rayleigh portions of distributions as reported by others. Horner thinks that the Rayleigh portion is due mainly to distant sources.

Watt discussed the effect of noise interference on communication systems. The ratio of the IF to the post-detection bandwidth is important in determining effects. Less frequency shift is desirable for pure thermal noise.

G. Foldes (France) discussed the recording of the mean level of atmospherics on long waves.

Commission IV Activities During the IGY

Helliwell described the IGY whistler program. One chain of 13 stations will be spread out approximately along the 75th meridian from Greenland to Antarctica, and another of nine stations from Alaska to New Zealand. Two stations in Japan and two in Australia will also collaborate in low-latitude studies. In addition, a number of other more or less isolated stations in the U. S., Canada, Great Britain, France, and Sweden will participate. A major problem is data analysis, which is very slow with present equipment. Hines showed examples of filmed data taken on the Raytheon analyzer which appeared to offer some promise. The major drawback is the very high price of the equipment. The AWS sferics films are to be stored in the Asheville data center.

R. Disney (U.S.A.) described the NBS program of radio noise recording using ARN-2 equipments to be employed at 16 sites distributed throughout the world during the IGY (in cooperation with other agencies and governments). It is planned that these measurements will be continued for a number of years after the IGY, possibly as long as 15 years.

N. Izyumov (U.S.S.R.) reported briefly on the U.S.S.R. plans for the IGY which include whistler recordings, DF measurements, and lightning character studies. At least three stations will be recording noise levels.

Rivault stated that most of the French program will be on an individual basis with direct contact with certain collaborators. Whistlers and atmospheric waveforms will be recorded.

Kimpara outlined the Japanese program which will include studies of: 1) whistlers, 2) DF measurements, 3) waveforms, 4) intensities, and 5) sources. Photographs of lightning flashes will be correlated with field variations.

Norinder expects to study whistlers and lightning source simultaneously. He knew of no plans for work in Norway or Denmark (although a station in Godhaven, Greenland, is being operated by the Danish government).

Lauter reported that DF measurements will be made at Potsdam, waveforms at Potsdam and Weissenau, whistlers at Kuhlungsborn and near Frankfurt, and rate and average voltage of atmospherics at Kuhlungsborn, Leipzig, Prague, and Weissenau. Particular attention will be given to variations in the shape of the diurnal curve.

Ratcliffe suggested that since many astronomical observatories made radio noise recordings for flare warning purposes, these data should be used in the radio noise program.

Horner stated that in England measurements will be made of: 1) atmospheric noise, 2) waveforms, and 3) whistlers. The Thomas system measurements will be continued at least until good overlap is obtained with automatic stations. Denmark will operate two Thomas stations in Greenland. CRDF records from England will be sent to the WMO. Tape recordings of noise will be made in England using 300-cycle bandwidth. Three equipments will be set up (Slough, Singapore, and Nigeria) for measuring various statistical properties of noise. Waveform studies in England will be made in conjunction with RDF net operation. There will be a whistler station and an atmospheric mean level recording station at Cambridge.

Ratcliffe mentioned the possibility of a small group working together on certain projects with official URSI recognition. They should then publish a joint paper as the first paper reporting common results.

Kimpara stated that at a Regional Conference in Japan, the U.S.S.R. mentioned that they would have a whistler station in eastern Siberia at about 140° longitude.

Relation Between Source and Atmospheric

Norinder described lightning studies made by his group using the magnetic field components. It has been noted that clouds sometimes remain in the predischarge state for several hours. Horizontal "meander" strokes are sometimes up to 50 km long. Considerable discussion followed on whether the large underwater horizontal loops are truly balanced.

M. Newman (U.S.A.) described lightning research in Minnesota and plans for rocket and balloon launching of antennas from a ship to initiate lightning. An attempt will also be made to generate an artificial whistler source. Considerable discussion followed as to whether the man-initiated stroke will be representative of ordinary lightning.

R. Doherty (U.S.A.) presented some results of the tornado-atmospheric studies in Oklahoma. During tornadic activity the rate of occurrence of atmospherics increases greatly on 150 kc compared with that on 10 kc. Norinder discussed radio noise produced by snow squalls. Field strength is usually about one quarter that of sferics caused by regular lightning.

Kimpara described Japanese studies of lightning sources using high-speed rotating cameras. He obtained similar waveform for cloud-to-cloud and for discharges within clouds. Many discharges may occur within the cloud before stepped leader occurs.

Foldes discussed the log-normal distribution law. If phenomena follow a log-normal law, they are the products of a great many separate events; if they follow a normal law, they are the sum of the events. He proposed that there may be cross modulation between energy from various lightning strokes. This provoked an interesting discussion on the probability of two lightning strokes occurring simultaneously in such a way as to permit the possibility of cross-modulation effects. Ratcliffe stated that waveforms are, in general, distorted in passing through the ionosphere.

Resolutions

Helliwell presented the report of the working group on VLF nomenclature. The report was approved and framed as a resolution containing tentative recommendations. The working group as constituted is to carry on until the next General Assembly. Its members are: R. A. Helliwell, *Chairman*, H. E. Dinger, R. M. Gallet, N. V. Pushkov, A. Kimpara, M. G. Morgan, R. Rivault, L. R. O. Storey, and J. R. Wait.

Wormell reported for the working group on waveforms. Their recommendations formed the basis of draft resolution. Its members are: T. W. Wormell, *Chairman*, R. A. Helliwell, G. Jean, A. Kimpara, and E. A. Lauter.

Crichlow reported for the working group on noise characteristics. The report formed the basis for a resolution. The working group will draft a Special URSI Report on the subject. Its members are: W. Q. Crichlow, *Chairman*, G. Foldes, F. J. Hewitt, F. Horner, H. Shinkawa, and A. W. Sullivan.

The following Resolutions were approved for submission to the General Assembly.

Resolution 1—Measurement of Terrestrial Radio Noise

URSI Commission IV recommends that the following comments on the measurement of atmospheric radio noise be communicated to the CCIR:

"URSI has considered the CCIR question 'What are the most easily measured characteristics of terrestrial radio noise from which the interference to different types of communication systems can be determined?' and has also considered CCIR Study Program No. 96 dealing with the measurement of atmospheric radio noise. The following comments on these topics are offered to the CCIR:

"Considerable progress has been made during the last few years in the measurement and description of the amplitude characteristics of atmospheric noise. Although time characteristics are also required for a complete statistical description of the noise, useful relationships have been found between the amplitude characteristics alone and the interference caused by the noise to many types of radio service.

"There is general agreement on what amplitude characteristics should be measured, and members of URSI are being encouraged to study these characteristics at many more locations, in accordance with the recommendations contained in the Annex." (See next section.)

Resolution 2—URSI Special Report on Atmospheric Noise

Commission IV recommends that a working group be set up under the President of Commission IV to prepare an URSI Special Report on the measurement of the characteristics of atmospheric noise and their relation to radio interference. This report should be based on the material collected to formulate a reply to the CCIR questions.

Resolution 3—Symposium on Naturally-Occurring VLF Phenomena

Considering the wide current interest by members of URSI Commissions III, IV, and V in the study of whistling atmospherics and related types of very low-frequency atmospheric noise, Commission IV recommends that consideration be given to the possibility of arranging a symposium on this subject before the Thirteenth General Assembly.

Resolution 4—Collection of Atmospheric Noise Data from Astronomical Observatories

Commission IV recommends that a communication be addressed to the International Astronomical Union, expressing the belief that measurements of atmospheric radio noise are being made at many astronomical observatories throughout a large part of each day, and requesting that the results of any such measurements be made available to radio workers. The communication should further suggest that there should be consultation between the IAU and URSI to insure that the measurements are made in as useful and uniform a manner as possible for radio as well as for astronomical applications.

Resolution 5—Cooperative Measurement of Waveforms of Atmospherics

Commission IV recommends that where groups of workers have coordinated their work on the recording of waveforms of atmospherics with the object of showing their variations from place to place, and where such workers desire to publish a joint account of their combined work, URSI should facilitate this work by providing means for exchanging data and for joint consultation.

Resolution 6—Working Group Relating to Terminology on VLF Phenomena

Commission IV recommends that a working group be set up under the President of Commission IV to review continually the terminology used in the description of whistlers and related phenomena, and to make further recommendations on this topic to the Thirteenth General Assembly.

Resolution 7—Provisional Terminology Relating to VLF Phenomena

Until the working group appointed under Resolution 6 has reported to the General Assembly, Commission IV recommends that the following terminology be adopted tentatively in work on whistlers and related phenomena.

Atmospherics—natural electrical disturbances originating in the earth's atmosphere. Atmospherics may be subdivided into the following types:

1) Sferics—atmospherics which originate in, and are propagated through, the space between the earth and the ionosphere.
2) Whistlers—atmospherics which originate in lightning discharges and which are propagated through the ionosphere along dispersive paths.
3) VLF emissions—Atmospherics which are *not* produced by lightning. They are usually associated with magnetic disturbance and have often been referred to loosely by the term "dawn chorus." The following subgroups are recognized:
   a) *VLF hiss*—A relatively steady VLF emission generally exhibiting a frequency-dependent amplitude spectrum. Its spectrum and intensity may change slowly (period of several seconds or more) with time.
   b) *Discrete events*—Well-defined VLF emissions having durations of the order of a few tenths to several seconds. A definite and repeatable frequency-time relation is often observed.
   c) *Chorus*—A series of overlapping VLF emissions, with time separations of less than one second.

Annex to Resolution 1

A. Measurements

It is recommended that complete studies of the detailed noise characteristics be confined to a few selected locations with continuous measurements of one or more simple parameters at a larger number of stations.

The amplitude-probability distribution has been measured at a number of locations, and several proposals have been made for the mathematical representation of the distribution. All of these representations of the amplitude time distribution can be described by means of measured moments. Therefore, it is recommended that measurements be made at as many locations as possible of the average power, the average envelope voltage, and the average logarithm of the envelope voltage. If only one parameter is to be measured, priority should be established in the order given.

It is recommended that studies be continued of the relationship between the various parameters such as the ratio of the rms to the average under all conditions; *i.e.*, as a function of time, frequency, and location. Studies of the influence of bandwidth on all of the parameters as well as on the statistical distributions are recommended.

Although DF measurements are desirable at certain selected locations, it is recommended that omnidirectional antennas be used at most stations, in order to insure uniformity of results.

In making any measurement of noise, it is extremely important to state carefully all conditions of measurement so that observations by different experimenters can be interrelated.

B. Techniques

1) Probability Distributions: In making detailed statistical measurements on the instantaneous noise envelope voltage, it is recommended that measurement should be based on counting techniques, for example, using 10-kc pulses gated by the noise. These are the most versatile, since counting equipment can readily be adapted to the measurement of a number of parameters, such as the amplitude probability distributions, the distributions of the pulse lengths, and the intervals between the pulses.

The equipment necessary for making such measurements will generally contain the following components:

1) Antenna,
2) Calibrating signal,
3) Calibrated attenuator,
4) Receiver,
5) Selective circuits of known effective bandwidth,
6) Envelope detector,
7) Amplitude discriminator,
8) Gating circuits,
9) Signal generator (usually about 10 kc),
10) One or more frequency counters.

The design of the receiver must be such that its recovery time is very short upon overload by high amplitude pulses. Except for this limitation, there are no severe dynamic range or linearity requirements. The receiver noise, or course, must be lower than the level of external noise that is to be measured.

The distributions are obtained by gating the 10-kc signal on for the period of time during which the noise level exceeds the threshold of the gating circuits, and by changing the amount of the attenuation at the input of the receiver in known steps. Various lengths of counting time are used at the different threshold levels. In general 100 seconds is used for values of 5 per cent and greater, 200 seconds for values in the range of 0.0005 to 5 per cent, and 300 to 1000 seconds for values less than 0.0005 per cent. In general, a total of about 10 minutes is required to obtain all but the last three low percentage readings which themselves may take 10 to 20 minutes in order to obtain statistically consistent data. The total time required is a function of the time of noise being measured. A longer time is required for noise with a larger dynamic range.

2) *Individual Parameters:*

a) *Average envelope voltage:* The basic equipment for measuring the average envelope voltage is as follows:

1) Antenna,
2) Calibration source (signal generator or noise diode),
3) Frequency selective circuits of known effective bandwidth,
4) Envelope detector (detector capable of following the peaks of the IF cycles at the audio-frequency rate),
5) Integrating circuit (usually an RC circuit with a time constant of 100 seconds or more),
6) AGC or variable attenuator circuit (controlled by the integrated voltage),
7) Recorder circuit (the recorder should indicate the magnitude of the control voltage which is calibrated in terms of the input signal level).

It is essential for the receiver to be linear over the important dynamic range of the noise being observed, for a fixed gain, so that the noise envelope is undistorted at the detector output. This requires an instantaneous dynamic range of 40 db or more. Bandwidths the order of 300 cycles to 1000 cycles are used. The gain stability of the equipment must be adequate to insure repeatability of calibrations. The noise figure of the equipment must be as low as possible to minimize contamination of low noise levels.

b) Average power: The required circuitry for measuring the rms voltage, or noise power, is similar to that required for average envelope measurements, except that just prior to detection a square law circuit is used. This circuit can consist of two tubes with the grids in push-pull and the plates in parallel, thus producing in the plate circuit a voltage at twice the input frequency and with an amplitude proportional to the square of the input voltage. The amplifier and detector that follow must have a much larger dynamic range in order to handle the squared values without distortion. Using a bandwidth of about 300 cps, a dynamic range of 80 db or more is required; however, much smaller bandwidths can be used for the power measurement, since the power is directly proportional to bandwidth regardless of the type of noise. The time constant used will depend to a certain extent on the bandwidth, however, a time constant of 500 seconds seems to give adequate smoothing.

c) Average logarithm: The equipment required for measuring the average logarithm is again very similar to the equipment for average envelope measurements. The principal difference is that a logarithmic amplifier is inserted between the envelope detector and the integrating circuit. A convenient circuit is a triode operating at zero bias and with a high value of grid resistance so that the plate current is an exponential function of the applied grid voltage. With this type of measurement, a time constant of the order of 50 seconds has proven satisfactory. It should be noted that the logarithmic amplifier must be capable of operating at the envelope frequency; *i.e.*, the integration must occur after the logarithmic circuit rather than prior to or within the logarithmic circuit. It should also be noted that the gain control voltage must be obtained after rather than before integration.

Report on URSI Commission V—Radio Astronomy*

F. T. HADDOCK†, MEMBER, IRE

Objectives

THE objectives of URSI Commission V are the international exchange of scientific data, theory, and programs of investigations, and the coordination of observational programs involving international cooperative effort. Of particular interest are the continuous monitoring of solar radio emission at several frequencies, the coordination of Ursigrams, the setting up of a basic solar index from radio observations, the selection of particular radio sources for a standard sequence of radio intensities, and the coordination of effort in various countries toward the protection of certain frequency bands for observational radio astronomy. It also initiates, coordinates, or arranges symposia on subjects of interest to radio astronomers.

Technical Program

The Twelfth General Assembly of URSI in Boulder, Colo. was attended by radio astronomers from over a dozen nations. Commission V's sessions were very heavily attended by both active participants and interested observers. The technical sessions consisted of the following: techniques of reception, large antennas (joint session with Commission VI), solar radio research, radio sources, radio propagation (scintillation, absorption, and refraction through the earth's atmosphere), radio emission from the galaxy, radio studies of the planetary system (radar echo observations of the moon, emission from the moon, the planets and comets). In addition there were joint sessions with Commissions III and IV on whistlers, and with Commission VII on masers.

The chairman of each technical session opened with a résumé of progress in the general field of his session since the Eleventh General Assembly held in 1954.

Techniques of Reception

More than a dozen separate radio telescopes were described. These included the 10-cm solar instrument in Ottawa, the 169-mc interferometer in France, the aperture-synthesis system in Cambridge, the helix interferometer in Washington D.C., the 21-cm Christiansen Cross in Sydney, the precision interferometer in Tokyo, two sensitive traveling-wave tube radiometers in the U.S., the radio polarimeter for solar bursts at Cornell, and the 96-element Yagi array operating on 13 meters at Stanford.

* Original manuscript received by the IRE, April 17, 1958.
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Large Antennas

Large steerable, paraboloidal reflectors 25 meters in diameter and larger were described. These are located in Bonn, Germany; Dwingeloo, Netherlands; Pulkova Observatory, U.S.S.R.; and Manchester, England. Other types described are at Ohio State University, Stanford University, and St. Michel Observatory in France. Plans were reported for large instruments that should be in operation within the next year or two. These included the 140-foot steerable paraboloid for Greenbank, W. Va.; the 230-foot paraboloid for Sydney, Australia; the pair of 90-foot paraboloids on N-S and E-W tracks for use as variable-spacing interferometers for Bishop, Calif.; the 85-foot precision reflectors for Ann Arbor and for Greenbank: the 84-foot reflector now installed at the Navy Research Laboratory in Washington; the plans for a 600 by 400-foot cylindrical paraboloid at Urbana, Ill.; the 25 by 700-meter cylindrical paraboloid reflectors for an interferometer in Russia.

The discussions and reports that followed included the problem of confusion of radio sources within the antenna beam, the tolerances of reflectors, the advantages of flat arrays steered by phase shifting, design problems in paraboloidal reflectors, arguments for high resolution and high antenna gain, the possible use of other reflecting surfaces, the focal ratio of paraboloids, information techniques applied to bandwidth, coherency of signal, etc., aperture blocking by the antenna feed, and importance of slide lobe levels, etc.

Solar Radio Research

Results on the occultation of the radio source, Taurus A (Crab Nebula), by the solar corona during the month of June in the last five years were announced by scientists from Cambridge, Moscow, and Paris. Reports were made on observations of the emission from the quiet sun at a wavelength of 8.6 mm during eclipse, on measurements of the sun at 21 cm with a 0.066-degree antenna pencil beam, and on a number of observations at various wavelengths from 6 mm to many meters. Observations were reported from numerous groups on the nature of solar radiation from both the quiet and the active sun. Polarization of solar bursts, the dynamic spectra of solar bursts, the effects of Faraday dispersion in the solar corona and Faraday rotation in the earth's ionosphere, and the escape of the extraordinary mode of propagation from the sun were described. Correlation of geomagnetic activity, solar flares, and cosmic rays were also reported. Evidence of solar radio emission from relativistic electrons was presented.

Radio Sources

Various characteristics of radio sources, both galactic and extragalactic, were described in nearly two dozen reports. Measurements of the size of radio sources involved interferometer spacings of thousands of wavelengths. This resulted in the measurement of diameters in seconds of arc, and radio effective brightness temperatures of millions of degrees. Detailed "isophotal" maps of the intensity of radio emission over extragalactic nebulas at wavelengths of 21 cm, 120 cm, 370 cm, and 187 cm were reported by various groups. The relative spectra of 30 radio sources using the brightest radio source as a reference were reported by the Cambridge group. Results indicated a slight difference in the spectrum index for galactic sources and extragalactic sources. Reports from Jodrell Bank and from the Department of Terrestrial Magnetism in Washington on the spectra of sources at wavelengths below 30 mc were given. In this region the absorption of radio source emission by interstellar electrons plays an important role. Several reports of "isophotal" maps of the radio continuum emission from the Milky Way were described. Measurements by the French of the radio source Hydra A, which was thought to be intrinsically variable, indicate that no variations greater than the experimental accuracy of about 5 per cent were recorded. The intensity of the four major radio sources at a wavelength of 21 cm was reported by the Dutch to accuracy of about 15 per cent. The Cambridge radio source survey statistics at 160 mc were discussed. This new survey was compared to the old survey at 80 mc and results are the same; they both show an increase in the number density of sources with source faintness. This paper provoked discussion on the confusion of sources within the radio beam. It was stated that in order to avoid confusion one could only consider one source for every ten to twenty beam widths of sky area surveyed as being reliable. This criterion gives 100 sources per steradian with the Cambridge equipment and 400 sources per steradian with the Sydney equipment. The criterion was arrived at in Sydney from detailed analog statistical tests. A discussion of the radio emission from Coma Cluster of extragalactic nebulas then followed. Reports were made on the cosmological implications of the results of the Cambridge survey. The measurement of the linear polarization component in the emission from the Crab Nebula made at a wavelength of 3 cm with the NRL 50-foot reflector was reported. This evidence supports the assumption of radio emission from the Crab Nebula by the synchrotron radiation mechanism. The Russians and the French discussed the occultation of the Crab Nebula by the moon. They differed on the "center" of the radio emission. The Dutch also described similar occultation measurements of the Crab Nebula.

Radio Propagation

Reports on the scintillation of the major radio sources at a number of wavelengths were presented, and the origin of the scintillation associated with spread-F occurrence and with irregularities in the F layer was discussed. Altogether there were six reports over a wide range of frequencies on the scintillation of radio stars. Reports were also given on the atmospheric refraction and absorption at millimeter and centimeter wavelengths. The attentuation of 4-mm waves by the atmosphere and by clouds were reported. Fair weather cumulus clouds produce attenuations as large as 4 db. Various methods of computing the height responsible for radio star scintillations were critically analyzed, and it was concluded that the defects in each method preclude usable height determinations at present. A theory for producing ionospheric irregularities by the infall of interstellar particles was presented and was criticized.

Radio Waves from the Galaxy

This session included four reports on the galactic background radiation from the radio continuum at wavelengths from 15 meters to 22 cm, hydrogen-line studies of the structure of our galaxy and absorption in a region of radio sources, extragalactic 21-cm observations, and a search for the OH-line emission. A report from Sydney on a comparison of Mills crosses operating at 19 mc and 85 mc shows clearly the absorption effects of ionized hydrogen clouds lying in the galactic plane. The Dutch announced an outstanding finding that one spiral arm near the center of our galaxy, as seen in absorption in front of a radio source, is moving at the exceptional velocity of 50 km/sec from the center. The Harvard group reported observations of expanding neutral hydrogen regions with galactic clusters around the Orion and the Lacerta associations. Radio red shift measurements on extragalactic clusters of galaxies were also described by the Harvard group. A report was made on the comparison of the position of 200 sources in Mills' catalog with objects on the 48-inch Palomar Schmidt plates. Various optical objects were associated in position with radio sources: clusters of galaxies, ionized hydrogen regions, ordinary galaxies, double and peculiar galaxies, pairs and triplets of faint galaxies. It was suggested that a number of radio sources could be associated with ghost galaxies which are gaseous galaxies now devoid of stars because of collision between two galaxies, the gas being left behind. An unsuccessful effort to detect the 1667-mc spectral line from the OH radical was reported.

Radio Planetary System

Several reports were made of detailed studies of moon radar echoes. NRL contributed a study of echoes at wavelengths from a few meters to 10 cm. A significant finding was that the echoes from the moon have a sharp clean leading edge which indicates that the echo comes from an unusually small central area of the moon. This makes it possible to measure precisely the distance to the moon. The moon appears to be an extremely smooth reflector of radio waves. The practical use of voice transmission via the moon was reported by the same group as being accomplished in 1954 with a 100-watt transmitter and a 3-kc bandwidth receiver. A tape recording of a speech transmission echoed by the moon was demonstrated to the audience. Reproduction was impressive. Measurements made at NRL at the wavelength of 10 cm display a leading edge measurable to about 2 μsec. The result of two days' observation indicated a systematic error between the observed and the calculated lunar distance of 9 km when based on the Army Map Service value for the earth's equatorial radius. This discrepancy is eliminated when based on the Ephemeris value for earth's equatorial radius. By direct measurement of the distance to the moon it is possible to determine the equatorial radius of the earth within twenty feet. The Jodrell Bank report on the moon also indicated that the lunar echo originated from an area in the central region of the lunar disk. Stanford University reported that at 106 mc, using two cross-polarized receivers, both polarizations frequently faded simultaneously and disappeared completely for twenty minutes at a time, indicating the presence of some unknown effect. This unknown effect was also observed by the Canadians at a frequency of 488 mc. These "double-fade" observations cast doubt on the calculation of the interplanetary electron densities based on the Faraday technique. The NRL group reported the measurement of thermal radio emission from Venus, Mars, and Jupiter. The Ewen-Knight group reported the detection of thermal radiation from Saturn and the detection of radio emission from planetary nebulae. They use a traveling-wave tube receiver at a wavelength of 4 cm which is able to record antenna temperature changes of the order of 0.01°K with an integration time of 5 minutes. The National Bureau of Standards reported the detailed analysis of nonthermal radiation from Jupiter based on a model of the Jovian ionosphere. They conclude that the nonthermal radio source resides on a solid rotating body with a period of rotation slightly faster than that observed optically on the atmosphere of Jupiter. There is an apparent relationship between nonthermal Jupiter radio emission and solar activity. The greater the solar activity, the less often the detection of radio bursts from Jupiter. There were a number of reports of the radio bursts from Jupiter at frequencies in the range from 15 to 30 mc. Ohio State University reported the detection of Jupiter bursts at a frequency as high as 45 mc. Yale University reported the possible detection of Jupiter-like bursts from Saturn. A series of reports followed on detection of radio emission from the bright Comet 1956h. The Belgians reported detection at 600 mc, the Germans at 1420 mc, and Ohio State University possibly at 20 mc.

A large number of observers failed to detect the comet at various frequencies from 19 mc to 10,000 mc.

Report on the Business Session

Numerous points of business were taken up during this session. In particular, the following resolutions were recommended to the Twelfth General Assembly, and were later passed upon. The following Subcommissions of Commission V were continued and their membership was brought up to date: Subcommission on the Basic Solar Index, under the chairmanship of S. Chapman and Subcommission on Standards, under the chairmanship of C. L. Seeger. A new Subcommission on Frequency Allocation was established, under the chairmanship of F. T. Haddock, which is charged with preparing recommendations to be submitted to the International Telecommunications Union meeting in 1959.

Commission V recommended that URSI assent to the request of the International Astronomical Union to sponsor a joint symposium on radio astronomy in Paris, prior to the General Assembly of the IAU in August, 1958.

Commission V also suggested the following persons to serve on the joint URSI-IAU Organizing Committee: J. L. Pawsey (President, Committee 40, IAU) Chairman; A. C. B. Lovell (President of Commission V); R. N. Bracewell, Editor; J. F. Denisse, Local Arrangements; R. L. Minkowski; H. C. van de Hulst; V. V. Vitkevitch; F. T. Haddock, Secretary; Fred Hoyle.

A detailed report of Commission V activities at the Twelfth General Assembly has been compiled. Persons interested can write the author of this report for the few remaining copies.

Report on URSI Commission VI — Radio Waves and Circuits*

E. C. JORDAN†, FELLOW, IRE

Objectives

THE field of interest of Commission VI—radio waves and circuits—divides rather naturally into three general areas, each of which is covered by a subcommission. Subcommission VI.1 is concerned with the general subject of information theory. Subcommission VI.2 deals with circuit theory, and Subcommission VI.3 covers antennas, waveguides, and general electromagnetic theory. Although in many countries these fields are also dealt with by other organizations, URSI provides international liaison and opportunity for interchange of information among scientists in different countries. In the U.S.A. there has been close cooperation between URSI Commission VI and various Professional Groups of the IRE, namely, PGAP, PGCT, PGIT, and PGMTT.

Technical Program

Under the chairmanship of S. Silver, International President of Commission VI, an organizational meeting of Commission VI official observers was held on August 23. Official observers present were: G. Sinclair (Canada), chairman of Subcommission VI.3; P. E. Mattila (Finland); B. D. H. Tellegen (Netherlands), chairman of Subcommission VI.2; B. van der Pol (Netherlands), chairman of subcommission VI.1; E. Hallén (Sweden); E. C. Jordan (U.S.A.); V. B. Il'in (U.S.S.R.). The following program of sessions for Commission VI was arranged.

Microwave Optics and Information Theory—B. van der Pol, Chairman

The first part of the session was concerned with the report of the working group on microwave optics, and in particular with those aspects which had a bearing on information theory. Roy C. Spencer (U.S.A.) reviewed the activity of the working group, explaining that it was a continuation of Commission VI.3 formed at the Tenth General Assembly at Sydney in 1952 to study microwave optics. (The report of this earlier group to the Eleventh General Assembly was published in the IRE TRANSACTIONS ON ANTENNAS AND PROPAGATION in October, 1955.) Spencer mentioned the seven symposia featuring or including microwave optics which have been held since the Eleventh General Assembly at The Hague, August, 1954. A. Blanc-Lapierre (France) then presented a paper titled, "Contribution to the Study of Optical Background Noise—Comparison with Noise in Radio-Electricity," wherein a parallel was drawn between spatially-distributed variations in image formation due to granularity, and the random functions of time designated as "noise" in electric signal formation and transmission. A discussion was given of the work of various authors in the statistical analysis of various models of optical granularity and in experimental measurement of these statistical properties.

J. Loeb (France) presented an outline of an URSI monograph to be written on the application of information theory to the practical design of communication systems. Participating in the writing of this monograph will be J. C. Lochard and Loeb (France); van Duuren and Stumpers (Netherlands); Blachman, Silverman, and Zadeh (U.S.A.); and Siforov (U.S.S.R.). At this session Loeb also discussed the effect of cascading fixed, memoryless binary channels, pointing out that the probability matrix describing the result is the product of the probability matrices describing the component channels.

Circuit Theory—B. D. H. Tellegen, Chairman

Tellegen opened the meeting with a recapitulation of the basic problems in circuit theory which were formulated at the Eleventh General Assembly in The Hague. His report entitled "Survey of Circuit Theory" was read, and was followed by a lively discussion concerning the objectives of circuit theory and its outstanding problems. The discussion centered on Tellegen's definition of circuit theory, *viz.:* "Circuit theory is the theory of networks composed of black boxes characterized by relations between the voltages and currents at the terminals, which relations contain only time as independent variable, and contain neither space nor temperature coordinates."

It was pointed out by van der Pol and others that the relations characterizing a black box may involve variables other than voltages and/or currents, *e.g.*, magnetic flux, electric field, displacement in space, velocity, etc. H. Takahasi (Japan) introduced the question of the finiteness of the number of elements, and S. Silver suggested that the essential point is that the elements should form a denumerable set and should be characterized in terms of external observables. F. Reza, D. Trautman, L. Weinberg, N. Marcuvitz, F. L. H. M. Stumpers, and S. Schelkunoff commented on the exclusion of the space and temperature coordinates, and on the energetic vs information-theoretic aspects of circuit theory

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† Chairman, U. S. A. Subcommission VI.3; Chairman, Dept. of Elec. Eng., University of Illinois, Urbana, Ill.

L. Zadeh brought up the question of including the theory of discrete circuits, *i.e.*, switching devices and sequential machines, in the scope of activities of Subcommission VI.2, and proposed that the definition of circuit theory be broadened sufficiently to make the study of such circuits a branch of circuit theory. The chairman then appointed an ad hoc group to draft a wider definition of circuit theory and present it for further discussion at the September 2 meeting of Subcommission VI.2.

Information Theory—B. van der Pol, Chairman

The second session devoted to information theory treated a number of papers concerning "Properties of Transmission Channels." Stumpers presented an analysis of a number of different binary codes that have been proposed and used in teleprinter service where a feedback path is available for announcing to the transmitter that an error has occurred in transmission, so that the symbol can be repeated. H. C. A. van Duuren pointed out that there are situations in a physical communication link where the simple model of independent errors in successive signal elements breaks down.

H. Takahasi read a paper by S. Muroga, "On the Channel Capacity of a Noisy Channel which is Expressible by Corresponding Two Multistate Diagrams." In this study the channel consists of two linear graphs such as were used by Shannon to describe a Markov information source, plus a matrix of transition probabilities connecting the state changes in both graphs. The channel capacity is computed for a channel with intersymbol constraints defined in this way. The two graphs represent opposite ends of the channel. Zadeh raised the point that the usual definition of channel capacity requires not only that the probabilities of various state transitions in the first linear graph be variable, but also the topological structure of this graph. Takahasi also read a paper by Mine (Japan), "Transformation of Probability Distributions and its Application to Compander Systems."

N. M. Blachman (U.S.A.) presented three studies of communication systems in which the channel disturbance is controllable. Such studies are intended to provide lower bounds for information rates when the exact statistics of the interference are unknown. The interference is chosen to minimize the rate of information flow to the receiver. The first of these papers, "On the Effect of Interference: Prevarication Versus Redundancy," treats the role of the redundancy of the language in overcoming the errors due to interference. In his second paper, "Communication as a Game," the author analyzed the conflict between the communicator and the interference by describing a simple two-person, zero-sum game-theoretic model in which the pay-off is the information rate. Time permitted only a partial presentation of the third paper, " A Remark on the Amount of Interference a Communication System can Tolerate," which asks what is the optimum (worst) form of interference if the signals are like white gaussian noise, as proposed by Shannon, and if the interference depends on the exact forms of the signals.

V. B. Il'in (U.S.S.R.) presented a discussion of a two-velocity scanning system used to allow facsimile transmission of black-and-white printed material with a smaller bandwidth than for uniform scanning, "A Method of Electronic Photo-Telegraphy with High Efficiency of Information Transmission." The slow scan is used only in the vicinity of changes in brightness. An operating system has been built which exhibits a five-to-one reduction in total scanning time over the usual uniform-velocity method for the same bandwidth and for which there is only a slight deterioration in picture quality.

P. E. Green (U.S.A.) presented a paper co-authored by R. Price entitled, "An Anti-Multipath Communication System (Rake)," which discussed the principles, design, and performance of a probability-computing receiver designed to operate with wideband transmitted signal in such a fashion as to minimize the deleterious effects of random multipath and additive noise. A measurement of the multipath characteristic is required, and the discussion involved the question of the averaging time of this measurement.

A paper by D. A. Bell (U.K.) entitled, "The Negative Entropy of Recorded Information" was commented on briefly by R. E. Burgess (Canada). This paper points out that an information loss due to thermodynamic effects is inevitable in the storage elements themselves that form a part of the information handling-systems treated by information theory.

Transition from Field Theory to Circuit Theory and Optics—E. C. Jordan, Chairman

The lead-off paper in this subject was given by L. J. Chu (U.S.A.). He confined his work chiefly to the low-frequency end of the spectrum (*i.e.*, transition to circuit theory). The approach is to write Maxwell's equations for a general problem, separate out the static or quasi-static part, and examine the remainder, in the form

$$E(\omega) = \sum_{0}^{\infty} (j\omega)^n E_n.$$

Inserting this expression into the four Maxwell equations gives an infinite set of equations. The first term is the static solution. Expression for power is of form:

$$\tfrac{1}{2}E \times H^*$$
$$= \tfrac{1}{2}[E_0 \times H_0 + j\omega(H_1^* \times E_0) + j\omega(E_1 \times H_0^*) ++ --]$$

where first term is the DC term, second is the capacitance term, third is the inductance term, and all remaining terms represent radiation and correction to the L and C terms. Reference was made to the early work of Brillouin and to Schelkunoff and Friis. Schelkunoff commented that since the field in free space is entire, the series has no poles (with respect to ω) and hence converges for all ω. Manneback (Belgium) commented that one can also start with a step function transient approach. Marcuvitz mentioned that the series is not always suitable for radiation problems, *e.g.*, in cylindrical problems. Schelkunoff pointed out that solution must be limited to a finite region. Bremmer (Netherlands) smilingly commented that by expanding in $j\omega$ at the low-frequency end and $1/j\omega$ at the high-frequency end, one in theory had a method of attack for all electromagnetic problems.

L. T. Wu (U.S.A.) followed with a brief presentation of the transition to optics dealing chiefly with scattering cross sections at high frequencies where the scattering cross section is often nearly the geometrical optics value, even for sizes near a wavelength. Kline pointed out that the use of series of negative powers of $j\omega$, leading to optics in the first term, is limited to infinite media with no diffraction. Schelkunoff then summarized briefly some of the more important conclusions that result from his work on the relation of Maxwell's equations to the Generalized Telegraphist equations. L. A. Wainstein (U.S.S.R.) outlined the approach and conclusions of his paper, "Group Velocity of Attenuated Waves." For lossy media the usual definition of group velocity, $v_g = \partial\omega/\partial\kappa$, is not suitable. He defined the propagation velocity of a signal of finite duration as the velocity dZ_0/dt of its "center of energy" where $Z_0 = \int z\bar{w}dz/\int \bar{w}dz$. Here w is the volume density of electromagnetic energy, and is a solution of

$$\frac{\partial \bar{w}}{\partial t} + \frac{\partial s_z}{\partial z} + \bar{p} = 0$$

where s_z is the z component of the Poynting vector and p is the dissipation density (the dash indicates time mean).

Because of lack of time discussion on a special paper, "Electrodynamics of Material Bodies" by L. J. Chu, was postponed until the following morning.

Information Theory—B. van der Pol, Chairman

The third session on information theory dealt generally with spectral analysis. It began with a paper by V. E. Siforov (U.S.S.R.), "On the Capacity of Channels with Random Parameter Fluctuations." His formulation provides a lower bound for the channel capacity in cases where there are one or more signal paths from transmitter to receiver, with randomly-varying amplitude and/or delay. In the presence of slow Rayleigh fading of a single path, a maximum deterioration in channel capacity of 17 per cent was found. Feinstein (U.S.A.) stated that with Rayleigh fading a smaller deterioration could be obtained by transmitting pulses instead of white gaussian signals when the signal-to-noise ratio is high. With more rapid variations of one or more parameters, Siforov found that for each channel model there exists a threshold in fluctuation rate below which the channel capacity is infinite, provided that there is no other form of interference present. Above the threshold, the capacity decreases monotonically. In response to a question by Loeb, the author explained that the threshold point depends on the channel model and, for a given channel model, is proportional to the signal bandwidth. Green conjectured that the curve asymptotically approaches a positive value as the fluctuation rate increases and that it is already close to the asymptotic value for a fluctuation rate equal to the signal bandwidth.

Kotel'nikov (U.S.S.R.) pointed out that for high fluctuation rates one must consider that the bandwidth of the received signal is greater than that of the transmitted signal.

Blanc-Lapierre presented a study made by himself and B. Picinbono, "On the Notion of Instantaneous Power Spectra." He gave five conditions that any method of defining instantaneous spectrum should fulfill, and he examined three proposed methods of defining instantaneous power spectrum (one by C H. Page, an analog of this, and a method due to Ville). The conclusion was that none of these three formulations satisfied all five conditions. Stumpers suggested consideration of an approximate measuring scheme whereby a number of adjacently-tuned filters are used, each followed by a square-law detector. Lochard presented a summary of a paper by Deman entitled "Instantaneous Spectra and Signal Analysis—Applications to Problems of Telecommunications." The author uses the theory of analytical signals (as formulated by Gabor) to define a transmitted signal, an additive noise, and a filtering operation at the receiver. He also analyzes the number of distinguishable signals in the presence of noise. Stumpers briefly presented a paper by G. F. Gouriet (U. K.), "A Note on the Definition of Group Delay," pointing out that amplitude slope and delay time are the real and imaginary parts of a complex function of frequency describing a transfer characteristic, and that they are thus each other's Hilbert transforms.

Stumpers then presented a preliminary report by a study group consisting of himself as chairman, J. C. Lochard (France), V. E. Siforov (U.S.S.R.), P. E. Green (U.S.A.), and N. M. Blachman (U.S.A.). This study group was formed to deal with questions touching information theory put to URSI by the CCIR (Comite Consultatif International pour le Radio) during its 1956 meeting in Warsaw. The group met subsequently to improve the wording of the report, which Stumpers presented for adoption at the closing session of Commission VI.

Scattering and Diffraction—N. Marcuvitz, Chairman

The principle speaker, K. M. Siegel, discussed "Far Field Scattering from Bodies of Revolution." In the long wave region, for a plane wave incident along the symmetry axis of a perfectly conducting body of revolution, he obtained the back-scattering cross section

$$\sigma = \sigma_r\left(1 + \frac{e^{-y}}{\pi y}\right)^2, \qquad \sigma_r = \frac{4}{\pi}k^4v^2, \qquad y = \frac{b}{a} \quad (1)$$

where $k=2\pi/\lambda$, V = volume of scatterer, and a and b are the semiaxes. One can use the Rayleigh value ($\sigma=\sigma_r$) except for flat oblate spheroids. Numerical comparison shows the result (1) is correct to 1 per cent for backscattering from all spheroids. In Siegel's paper, (1) is applied to cone (y = altitude/4 radius), circular ogive, elliptic ogive, etc. For very small wavelengths, geometrical optics gives excellent approximations. If the body has a radius of curvature small compared to wavelength, then physical optics predicts the correct k dependence and gives correct leading term of expansion in angle for nose-on backscattering for wedge and cone; however, the theory breaks down if main contribution is from edge. To treat the finite cone, for which effects of base edge are most significant, one can use the exact infinite wedge result, and the approximate base edge of the cone by infinitesimal wedge edge segments.

The subsequent papers and discussion dealt with topics introduced by Siegel. Weston discussed vector wave functions in toroidal coordinates, and applied them to treat scattering by a circular loop. Although the Helmholtz equation is nonseparable in toroidal coordinates, one can approximate the scattered field to an error of the order of $(r/a)^2$ where r = wire radius and a = loop radius. To obtain higher approximations, one uses a combination of the vector wave functions such that the components tangential to the torus are orthogonal to the higher approximation.

Hallén commented that the thin torus antenna could be solved exactly and simply as compared to other antennas, and referred to Rayleigh's (1914) results on the free oscillation problem. In the range $(r/\lambda)\rightarrow 0$, results can be obtained in cartesian coordinates. Free oscillations on torus involve exactly sinusoidal currents. J. B. Keller pointed out that since the toroidal solutions are not orthogonal on the boundary, the procedure is not exact. K. Morita discussed the current distribution on a rectangular plate and its effective radar area. Computations were based on use of the Sommerfeld half-plane results for the currents near the edges, and neglecting interactions as well as corner effects. Currents were also measured directly and compared with theory.

H. J. Neugebauer discussed a Huygen's principle procedure for treating thick screens capped by semi-cylinders, and compared the results with experiments. The intent was to develop a simple procedure for treating obstacle gain phenomena. The procedure was based on "four rays": 1) the direct wave to the semi-infinite "aperture" above the obstacle; 2) the wave specularly reflected from the obstacle to the aperture; 3) a direct wave from the aperture to the field point; and 4) a wave from the aperture specularly reflected from the obstacle to the field point. The reflected waves were multiplied by the appropriate geometrical divergence factors. In addition, as suggested by Fock's work, a "reflection coefficient" of 0.7 was used for vertical polarization, and the geometrical value, −1, for horizontal. Agreement with experiments (40° beam widths, and $kd\approx 250$ with d = distance from horns to obstacle) was better than that obtained from Rice's and Artmann's results. The session closed at 5:15, but owing to the marked interest displayed, the topic was continued later in a special session.

Circuit Theory—B. D. H. Tellegen, Chairman

The following papers were presented:

"The Parametron, An Amplifying and Logical Element Using Varying-Parameter Resonators," H. Takahasi and E. Goto.

"Theory of Negative Impedance Converter," H. Hirayama; presented by K. Morita.

"Methodes Topologiques Appliquees a L'electronique," L. Sideziades; presented by L. Robin.

"A Multiplication Theorem for Positive-Real Functions," F. Reza, presented by L. Zadeh.

"La Theorie des Biquadriondes et ses Applications," P. Marie.

Following the presentation of papers, Tellegen called upon Zadeh to present the views of the ad hoc group on the definition of circuit theory. Zadeh read a statement, which appears below, in which the views of the group were summarized.

In the ensuing discussion, Tellegen and Stumpers expressed views in opposition to the proposed definition of circuit theory, while Lochard and Loeb spoke in favor of it. The discussion was inconclusive and Tellegen suggested that the question of widening the scope of activities of Subcommission VI.2 be deferred for further study.

The last item on the agenda concerned the formulation of problems to be discussed at the next General Assembly. In this connection, the following suggestions were received by the chairman:

1) The identification of network functions by the experimental measurement of phase and gain characteristics,
2) Compilation, in summary form, of the necessary and sufficient conditions for realizability of various types of network functions,
3) An exposition of the techniques of analysis and synthesis of sequential machines.

Rough Draft of a Proposed Definition of Circuit Theory (Wide Sense): The following definition of circuit theory (wide sense) was formulated by an ad hoc group consisting of H. Inose, F. Reza, D. Trautman, L. Weinberg, and L. Zadeh. It is the feeling of this ad hoc group that, in recognition of the rapidly growing use of digital devices in radio communication, it is necessary to broaden the scope of activities of Commission VI in the field of circuit theory in order to encompass the field of switching and sequential circuits as well as other types of non-RLC networks which are of present or potential importance in practice. It is proposed, therefore, that the definition of circuit theory given below be adopted as a rough guide in delineating the scope of activities of Subcommission VI.2.

"Circuit theory is the theory of networks of 'black boxes' which are characterized by relations between the voltages, currents or other variables at their terminals, and which are, in general, abstractions of physical components of electrical systems."

Circuit theory, in the wide sense defined above, has several major branches each dealing with a particular class of black boxes. For example, in the case of classical circuit theory the black boxes are R's, L's, C's, ideal transformers, gyrators, etc. Similarly, switching theory is a branch of circuit theory dealing with switches, relays, and other types of discrete devices (with or without memory). Still another branch is that dealing with probabilistic elements, *i.e.*, black boxes whose input-output relationships are of a probabilistic nature. Such circuits are of importance in reliability studies of communication systems as well as in the analysis of circuits with randomly varying parameters.

The main effect of interpreting circuit theory in the broader sense formulated here would be the addition of switching theory and, to a lesser extent, the theory of probabilistic circuits, to the scope of activities of Subcommission VI.2.

Surface Waves—James Wait, Chairman

This discussion session on surface waves was opened with a survey paper, "Guided Waves," given by H. E. M. Barlow (U. K.). The work on two quite different projects was recalled, *viz.*, the single-wire transmission line supporting a cylindrical surface wave as proposed by Goubau, and a hollow tubular metal waveguide supporting inside it the low-loss circular H_{01} mode at millimeter wavelengths. Although both of these guiding systems have areas of practical usefulness, the single-wire line suffers from radiation loss and cross-coupling with other lines in the vicinity of bends and other discontinuities, whereas the circular waveguide H_{01} mode suffers from mode conversion loss at bends. Even so, transatlantic links using the latter type of guide are a distinct possibility. Some of the physical characteristics of cylindrical surface waves supported on capacitive and inductive surfaces were mentioned, and the launching efficiency of various arrangements was discussed. Although Zenneck-type surface waves are now known to play a part in propagation over the earth, the extent of their significance is still a matter of controversy. Dielectric rod end-fire antennas carrying the dipole type surface wave have been examined, and it has been shown that these antennas may be regarded as a surface wave transmission line acting as a transducer between the feed and the radiating aperture. Helical antennas, slow-wave structures, and strip transmission lines were also considered briefly in terms of guided wave structures.

Van der Pol then reviewed briefly his recent work on "The Sommerfeld Problem." When the session was opened for discussion it quickly became evident that there was a wide difference of opinion as to just what constituted a surface wave. Van der Pol, Barlow, Schelkunoff, Marcuvitz, and Wait, were among the many who participated in a spirited discussion, and were later appointed to a working group charged with the task of attempting to provide a classification of and nomenclature for the various kinds of surface waves.

Closing Technical and Administrative Session—S. Silver, Chairman

Nominations for secretaries for Commission VI were called for. The following were elected: P. Marie (France), French speaking; H. Meinke (Germany), English speaking.

It was moved and passed that Commission VI authorize its Chairman to appoint new Subcommission chairmen between General Assemblies as this is required.

Tellegen then reported for Subcommission VI.2. Two definitions for circuit theory were presented, one of these being that of classical circuit theory, and the other a broader definition which includes switching circuits.

The question of widening the scope of Subcommission VI.2 was deferred for further study. Topics for the Subcommission for the next General Assembly will be decided upon by correspondence between the chairman and official members.

Stumpers reported for van der Pol on Subcommission VI.1, and presented the results of the study group which had been set up to deal with questions touching information theory which had been put to URSI by CCIR during its 1956 meeting in Warsaw.

Sinclair then reported for Subcommission VI.3. The following were appointed members of a working group on the classification and nomenclature of surface waves: James Wait, *Chairman*, H. M. Barlow, N. Marcuvitz, S. A. Schelkunoff, B. van der Pol, and A. L. Cullen.

Topics suggested for further research were listed:

1) Wave propagation in anisotropic media,
2) Theory of surface and leaky wave antennas,
3) Calculation of diffracted fields of bodies in resonance region,
4) Synthesis problems in actual antennas, actual scatterers, etc.,
5) Scattering from periodic and disturbed periodic structures,
6) Study of techniques of field measurements near radiating and receiving systems,
7) Broad-band antennas.

It was recommended that another symposium on electromagnetic theory be held before the next General Assembly as a sequel to the Michigan Symposium of 1955. Toronto is being considered as the location for a symposium in 1959.

Silver then outlined the disposition of problems referred to URSI Commission VI by CCIR.

1) The temporal variations of surface waves are to be studied further during the next period.
2) Commission VI will offer a resolution that the National Committee be asked to urge the addition to Commission VI of members who are interested in the operational aspects of circuit theory.
3) On the question of field strengths in the neighborhood of obstacles, Siegel, Silver, and Neugebauer will act as a subcommittee to draw up a reply to CCIR within six months.

Stumpers was appointed chairman of a working group to give further study to the problem of what measurements to make in the quantitative determination of atmospheric noise.

Silver recommended a close cooperation between Commission VI.3 and Commission V in the design of large antennas for radio astronomy, and Spencer urged further application of communication theory to radio astronomy problems.

The meeting closed with a discussion of procedures at future General Assemblies. It was recommended that sessions consist of invited papers and one or more sessions of contributed papers to be presented only if the author is present.

ACKNOWLEDGMENT

The following members of Commission VI served as U.S.A. reporters for Commission VI sessions: N. Blachman, J. I. Bohnert, P. E. Green, Jr., R. C. Hansen, R. Mattingly, R. C. Spencer, V. Twersky, and L. Zadeh.

Report on URSI Commission VII—Radio Electronics*

W. G. SHEPHERD†, FELLOW, IRE

Objectives

THE field of interest of URSI Commission VII is the international exchange of experience and interchange of data on the noncircuit aspects of radio-electronics.

Technical Program

At the Twelfth General Assembly this Commission sponsored five technical sessions. Delegates from nine nations presented a total of fifty-one papers. At each session, an invited paper was presented by an authority on each topic, followed by the presentation of contributed papers bearing on the general topic and discussion. Each session was intended to summarize the progress in a particular area of electronics over the past three years and to focus attention on unsolved problems. This particular method of procedure was very effective and a great deal of useful discussion was evoked.

Oscillation Phenomena in Gas Discharges

The introductory paper on the subject of plasma oscillations was given by W. P. Allis (U.S.A.). He reviewed the work in this field in recent years and particularly the controversy over the validity of various dispersion relations for the propagation of plasma waves. There were extended comments on this subject by some of the later speakers and by J. R. Pierce. It was shown that in some cases dispersion relations give the incorrect answers for particular problems for which an exact solution is known. A complete list of speakers and their subjects follows.

W. P. Allis (U.S.A.), "Oscillation Phenomena in Gas Discharges"
K. G. Emeleus (U.K.), "Work in U. K. on Oscillations in Plasmas"
I. B. Bernstein (U.S.A.), "Stationary Waves in a Plasma"
W. A. Newcomb (U.S.A.), "Plasma Oscillations in a Magnetic Field"
Kojima, Kato, and Hagiwara; presented by Y. Azumi (Japan), "Plasma Oscillations"
Coupeau; presented by A. Blanc-Lapierre (France), "Interference Phenomena in Gas Discharge"
R. W. Gould (U.S.A.), "Microwave Amplification in a Plasma"
E. Gordon (U.S.A.), "Generation of Plasma Oscillations"
J. Feinstein (U.S.A.), "On Propagation of Plasma Oscillations"
L. G. H. Huxley (Australia), "Motion of Free Electrons in Nitrogen."

In addition to the prepared contributions an extended discussion of Gould's paper was presented by L. D. Smullin (U.S.A.).

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Physics of the Cathode

Nergaard presented the introductory paper in which he advanced four propositions, some of a purposely controversial nature, in order to provoke discussion. These were:

1) Every cathode is a reducing agent.
2) Every cathode lives in equilibrium with its environment.
3) Every cathode is a dispenser cathode.
4) Monolayer film cathodes do not exist.

In the papers and discussion which followed the introductory paper considerable evidence was presented to support the first three propositions. Stout and Beggs reported results of studies in which, by taking advantage of the unusual gettering properties of Ti to minimize adverse environmental influences, exceptional emission performance was attained for oxide coated cathodes. Their results for oxide cathodes were confirmed by Shepherd, Anderson, and Palmer who showed that the equilibrium conditions are strongly controlled by the rate at which reducing agents are dispensed from the base. These authors also presented data exhibiting the major contribution of electrolytic processes to the activation of oxide cathodes.

The most controversial proposition was the fourth and for this case it was clear that no agreement could be reached on the basis of present knowledge. Experiments aimed at a clear-cut resolution for or against this proposal were discussed.

A list of the formal papers follows.

L. S. Nergaard (U.S.A.), "The Physics of the Cathode"

E. S. Rittner; presented by A. van der Ziel (U.S.A.), "Discussion of Propositions Advanced by L. S. Nergaard"

W. E. Danforth (U.S.A.), "Problems of the Thorium Dispenser Cathode"

K. M. Yazawa and H. Yako; presented by M. Hatoyama (Japan), "Study of the Oxide Coating with the Electron Microscope"

W. G. Shepherd, D. E. Anderson, and D. R. Palmer (U.S.A.), "Activation and Deactivation of Oxide Cathodes"

H. Kawamura; presented by M. Hatoyama (Japan), "Factors Affecting the Activity of Oxide Cathodes"

P. A. Redhead and C. R. Crowell; presented by R. E. Burgess (Canada), "Cathode Properties under Space Charge Limited Conditions"

V. L. Stout and J. E. Beggs (U.S.A.), "Titanium and the Oxide Cathode"

A. van der Ziel (U.S.A.), "Flicker Noise and its Contribution to the Understanding of the Oxide Cathode"

K. G. Emeleus (U.K.), "Remarks on Flicker Noise."

Source and Nature of Noise in Electron Beams

The discussion leader, J. R. Pierce (U.S.A.), gave the opening paper on the source and nature of noise in electron beams. He discussed the recent progress in the understanding and the measurement of shot noise in electron beams and its implications for the noise figure of amplifiers. In the past three years, knowledge of this problem has increased greatly and although there are still some gaps in our understanding, these are much smaller than previously. With this increased understanding has also come greatly improved performance of low-noise amplifiers. The other contributed papers discussed in somewhat greater detail the experimental and theoretical aspects of this subject. The detailed program is given below.

J. R. Pierce (U.S.A.), "The Source and Nature of Noise in Electron Beams"

Jiro-Koyama; presented by G. M. Hatoyama (Japan), "Microwave Noise at the Potential Minimum"

Seiyo Okochi; presented by G. M. Hatoyama (Japan), "On the Microwave Noise at the First Anode in Electron Beams"

E. V. Hornelson, R. F. C. Vessock, and G. A. Woonton (Canada), "Current and Velocity Fluctuations at the Anode of an Electron Gun"

P. Grivet (France), "Experimental Results on Noise in Beams"

W. W. Rigrod (U.S.A.), "Noise Growth in Drifting Electron Streams"

L. J. Chu and H. A. Haus (U.S.A.), "The Kinetic Power Theorem for Longitudinal Electron Beams"

H. A. Haus (U.S.A.), "On the Minimum Noise Figure of Microwave Beam Amplifiers"

S. Saito (Japan) and L. D. Smullin (U.S.A.), "The Measurements of Correlation between Currents and Velocity at the Potential Minimum"

J. R. Whinnery (U.S.A.), "Some Three-Dimensional Noise Effects Important for Backward Wave Amplifiers"

W. E. Danielson (U.S.A.), "Emergence of the Travelling Wave Tube as a Practical Low-Noise Device"

J. R. Pierce (U.S.A.), "Summation."

Physics of Semiconducting Devices

This session consisted of a series of papers on semiconductors, the opening paper being given by W. Shockley on the possible high-frequency limits on transistors which can be deduced from an application of scaling laws to the transistor. A detailed program is given below.

W. Shockley (U.S.A.), "Possible High-Frequency Limits of Semiconducting Devices"

A. van der Ziel (U.S.A.), "Theory of Shot Noise in Junction Diodes and Junction Transistors"

K. M. van Vliet (U.S.A.), "Electronic Noise in Bulk Semiconductors"

R. E. Burgess (Canada), "Fluctuation Phenomena in Semiconductors"

N. Nifontoff; presented by A. Blanc-Lapierre (France), "Conductivity and Flicker Effect in Semiconductors"

C. W. Oatley (U.K.), "A New Method for Observing Potential Distributions in *p-n* Junctions"

W. Sasaki; presented by G. M. Hatoyama (Japan), "Acousto-Electric Effect in Germanium"

H. Salow (Germany), "Short Recovery Time Switching Transistors"

A. C. MacPherson (U.S.A.), "*P-N* Junction Model for the Microwave Crystal Rectifier."

Molecular Amplifiers

A joint session with Commission V evoked a considerable interest on the part of other Commissions and was attended by approximately 250 people. The chairman, R. C. Fletcher, opened the session with a brief outline of the history, principle, and application of the maser. C. H. Townes, of Columbia University, acted as the discussion leader and presented the introductory paper, "Properties of Masers-Theory and Present Experience." He pointed up the possible uses of atomic and molecular resonance in providing filters, amplifiers, and oscillators, particularly at wavelengths in the millimeter range. He discussed the factors which control the bandwidth, power levels, and noise characteristics. He discussed a number of practical embodiments of the maser principle. In a following paper, H. E. D. Scovil discussed the problems which arise in a three-level solid-state maser and quoted operating results for an amplifier pumping at 11 kmc and operating at 6 kmc of 20-db gain, a bandwidth of 100 kcs and an effective noise temperature of 150 K. Further remarks on the three-level maser were presented by A. M. Prokhorov, who discussed an equivalent circuit for the system consisting of an RLC circuit, having a complex capacitance. H. Takahashi discussed parametric amplifiers and pointed up the analogy to the three-level maser. H. Suhl gave an extended discussion of the use of ferromagnetic materials for the production of microwave amplification. The importance of low-noise amplification in radio astronomy and radio wave propagation was discussed by J. G. Bolton. The practical limitations of cost and the difficulties in the construction of large antennas put a premium on low-noise amplifiers. Masers appear to be particularly suited to this work.

A paper of Abragam, Solomon, and Combrisson described a liquid state maser which could be used to measure weak magnetic fields by observation of the proton magnetic resonance in water. Characteristics of an ammonia beam type maser investigated by K. Shimoda were presented. A list of the contributors and their topics is given below.

C. H. Townes (U.S.A.), "Properties of Masers—Theory"

H. E. D. Scovil (U.S.A.), "The Three-Level Solid-State Maser"

A. M. Prokhorov (U.S.S.R.), "The Properties of a Maser with Additional Applied High-Frequency Field"

H. Takahashi (Japan), "High-Frequency Amplification with Nonlinear Reactant Elements"

H. Suhl (U.S.A.), "Microwave Amplification using Ferromagnetic Materials"

J. G. Bolton (U.S.A.), "Future Importance of Low-Noise Amplification to Radio Astronomy and Radio Wave Propagation"

Abragam, Combrisson, and Solomon; presented by P. Grivet (France), "Liquid State Maser for Measuring Low Magnetic Fields"

K. Shimoda; presented by G. M. Hatoyama (Japan), "Characteristics of the Beam Type Maser."

At a business meeting of the Commission subsequent to the technical sessions, it was agreed that the general plan of the technical sessions had been highly successful in meeting the objectives of the Commission and it was recommended that at the next General Assembly the same procedure be followed.

A Parametric Amplifier Using Lower-Frequency Pumping*

K. K. N. CHANG† AND S. BLOOM†

Summary—The principle of parametric amplification using lower-frequency pumping has been verified in both a nonlinear inductance and a nonlinear capacitance system. In the former a ferrite core was used and a 30 per cent power gain was observed at a signal frequency of 10 mc and a pump frequency of 7 mc. The low gain is attributed to the small degree of nonlinearity. The nonlinear capacitance system gave much better results because of the larger degree of nonlinearity. Here a reversed-bias junction diode was used as the nonlinear coupling a signal circuit at 380 mc, an idling circuit at 220 mc, and a pumping circuit at 300 mc. A stable net gain of 20 db was obtained at 380 mc with a pump power of only 30 mw. Strong oscillations at 380 mc set in when the gain exceeded 40 db. The full percentage bandwidth is of the order of 0.3 per cent. The noise factor, with a nonisolated load, is in the order of 10 db.

* Original manuscript received by the IRE, February 10, 1958; revised manuscript received, April 28, 1958.

† RCA Labs., Princeton, N. J.

Introduction

PARAMETRIC amplifiers of the nonlinear-reactance type have received periodic attention[1] in the past. More recently, parametric amplification in the microwave region using the nonlinear inductance property of ferromagnetic resonance has been described.[2,3] These amplifiers have, however, conventionally drawn their energy from an RF pump-power supply having a frequency higher than that of the signal to be amplified. *A higher frequency source is usually not practical*, particularly when the signal has a *microwave frequency*.

To remedy this fundamental drawback, a parametric amplifier using *lower*-frequency pumping has been suggested[4] in which two or more pump sources at frequencies lower than the signal frequency are employed. In addition, to be compatible with the multiple pump system, a reactance sample of a higher than quadratic order of nonlinearity is necessary for amplification.

In this paper, a series of experiments which verify the principle of lower-frequency pumping is discussed. The experiments contain a first realization which made use of a nickel-manganese ferrite as the nonlinear reactance. Later experiments were performed with a germanium junction diode having a large degree of nonlinearity between the capacitance and the biasing voltage. Measurements of gain, bandwidth, and noise figure were made and found to be in substantial agreement with theory. Because of the large amount of nonlinearity existing in these junction diodes, the necessary pumping power was found to be exceedingly small.

Since the main purpose of the experiments was that of testing the principle of lower-frequency pumping, the work was carried out, for convenience, in the UHF region. There is, however, no reason why lower-frequency pumping cannot be applied in the centimeter or even millimeter-wave region.

Theoretical Background

Although a general theory on parametric amplifiers has been given in two previous articles,[4,5] it is still worthwhile to review in brief some of the basic equations, particularly because the case discussed here involves the use of a nonlinear capacitance instead of the nonlinear inductance treated before.

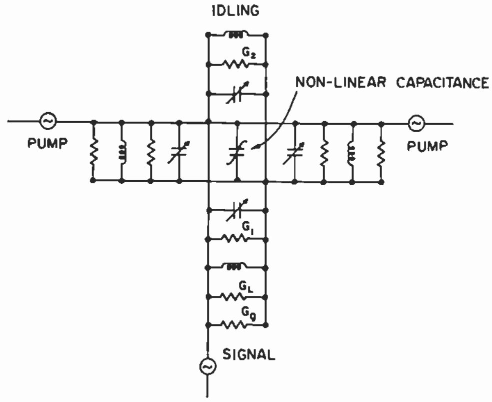

Fig. 1—Equivalent circuit of a nonlinear-capacitance parametric amplifier containing two pump circuits resonant at ω_3 and ω_4, an idling circuit at $\omega_2=\omega_3+\omega_4-\omega_1$, and a signal circuit at $\omega_1<\omega_3$, ω_4.

Consider the four resonant circuits of Fig. 1, coupled through a nonlinear capacitance whose charge, q, is a cubic function of the voltage, v.

$$q = C_0 v - \mathcal{C} v^3. \tag{1}$$

Here C_0 is the linear capacitance, and $\mathcal{C}$ is the coefficient of nonlinearity. The two pump circuits are resonant at frequencies ω_3, ω_4; the signal circuit is at ω_1, and the idler is at $\omega_2=\omega_3+\omega_4-\omega_1$.

It can then be shown[5] that a negative conductance G is formed in the signal circuit:

$$G = \alpha G_T \frac{\omega(\omega_3+\omega_4-\omega)/\omega_1\omega_2}{1+\left(\frac{B_2}{G_2}\right)^2}, \tag{2}$$

where

$$\alpha = \frac{9}{4}\mathcal{C}^2\left|\frac{I_3}{Y_3}\right|^2\left|\frac{I_4}{Y_4}\right|^2\cdot\frac{\omega_1(\omega_3+\omega_4-\omega_1)}{G_TG_2}. \tag{3}$$

The I's are the pumping currents, Y's are the admittances, and the G's are conductances. The total conductance, G_T, of the signal circuit includes the signal generator conductance G_g, the signal tank conductance G_1, and the load conductance G_L.

If the maximum available power output from the signal generator is $I_1^2/4G_g$, then the power gain G_p is

$$G_p = \frac{4G_gG_L}{(G_T-G)^2+\left(B_1-G\frac{B_2}{G_2}\right)^2}. \tag{4}$$

The expressions for the product of voltage gain (G_v) and bandwidth (B) and for the ultimate noise factor (F) are the same as those found[5] for the case of higher-frequency pumping:

$$G_vB = \frac{G_L\omega_2}{G_T\omega_1Q_2}, \tag{5}$$

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[1] R. V. L. Hartley, "Oscillations in systems with nonlinear reactance," *Bell Sys. Tech. J.*, vol. 15, pp. 424–440; July, 1936.
J. M. Manley and E. Peterson, "Negative resistance effects in saturable reactor circuits," *Trans. AIEE*, vol. 65, pp. 870–881; December, 1946.
V. D. Landon, "The use of ferrite-cored coils as converters, amplifiers and oscillators," *RCA Rev.*, vol. 10, pp. 387–396; September, 1948.

[2] H. Suhl, "Proposal for a ferromagnetic amplifier in the microwave range," *Phys. Rev.*, vol. 106, pp. 384–385; April, 1957.

[3] M. T. Weiss, "A solid-state microwave amplifier and oscillator using ferrites," *Phys. Rev.*, vol. 107, p. 317; July, 1957.

[4] S. Bloom and K. K. N. Chang, "Parametric amplifiers using low-frequency pumping," *J. Appl. Phys.*, vol. 29, p. 594; March, 1958.

[5] S. Bloom and K. K. N. Chang, "Theory of parametric amplifiers," *RCA Rev.*, vol. 18, pp. 578–593; December, 1957. See also, H. Heffner and G. Wade, "Gain, Bandwidth, and Noise Characteristics of the Variable-Parameter Amplifier," Electron-Tube Lab., Stanford University, Stanford, Calif., Tech. Rep. No. 28; February 26, 1958.

$$F = 1 + \frac{T}{T_0}\left(\frac{G_1}{G_g} + \frac{\omega_1}{\omega_2}\frac{\alpha G_T}{G_g}\right). \qquad (6)$$

The experiments described in this paper were greatly simplified through the choice of equal pump frequencies, $\omega_3 = \omega_4$. In this case only one pump source and one pump circuit were necessary. The gain and noise factor equations for this single pump case remain the same as above, provided α is placed by

$$\alpha' = \frac{9}{16}\mathcal{C}^2\left|\frac{I_3}{Y_3}\right|^4 \cdot \frac{\omega_1(2\omega_3 - \omega_1)}{G_T G_2}. \qquad (7)$$

Realization

The first realization of the parametric amplifier using lower-frequency pumping used a nickel-manganese ferrite[6] as the nonlinear reactance. The nonlinearity utilized here is obtained through the relationship between the magnetic induction B and the field intensity H; that is,

$$B = \mu_0 H - \mu H^3, \qquad (8)$$

where μ_0 is the linear permeability and μ is again the nonlinearity coefficient.

Since the particular ferrite used had an extremely small coefficient of nonlinearity, μ, a power gain of only 30 per cent was observed at a signal frequency of 10 mc and a pump frequency of 7 mc with a reasonable pumping power level. The gain could be increased by raising the pumping power. However, the particular ferrite used was rather lossy so that higher pumping powers rapidly overheated the sample.

A much larger coefficient of nonlinearity can be obtained through the use of the nonlinear capacitance exhibited by reverse-biased junction diodes,[7] and accordingly, such diodes were used in a second realization of a lower frequency pumped amplifier. These diodes[8] consist of a dot of indium alloyed to a wafer of n-type germanium. When biased in the reverse (nonconducting) direction, the semiconductor junction exhibits a capacitance which varies with the biasing voltage. A typical capacitance vs voltage characteristic is shown by Fig. 2. The capacitance can be shown to be inversely proportional to the square root of the biasing voltage. If the capacitance C is expanded in a Taylor series about the point $V=0$, it can be written, in mks units, as

$$C = (142 - 142V + 213V^2 - 355V^3 + 620V^4) \times 10^{-13} \qquad (9)$$

As revealed by (9), a large amount of nonlinearity of high orders is displayed by the junction diode.

The resonant circuits adapted to the junction diode are made of 50-ohm coaxial lines (Fig. 3). The line circuits, which are individually tuned to the pump frequency, the signal frequency, and the idling frequency by shorting stubs, are coupled through the end connections to the junction diode as in Fig. 3. For simplicity, the two pump frequencies are made equal so that the pumping power can be obtained from a single pump source and only one pump circuit need be used. Numerically, the pump circuit is tuned to a frequency of $\omega_3/2\pi = 300$ mc, the signal circuit is tuned to $\omega_1/2\pi = 380$ mc, and the idling frequency is at $\omega_2/2\pi = (2\omega_3 - \omega_1)/2\pi = 220$ mc.

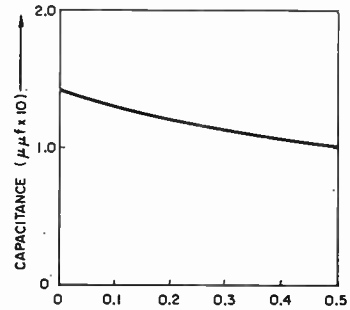


Fig. 2—Nonlinear capacity vs voltage characteristic of the reversed-bias junction diode used in the experiments.

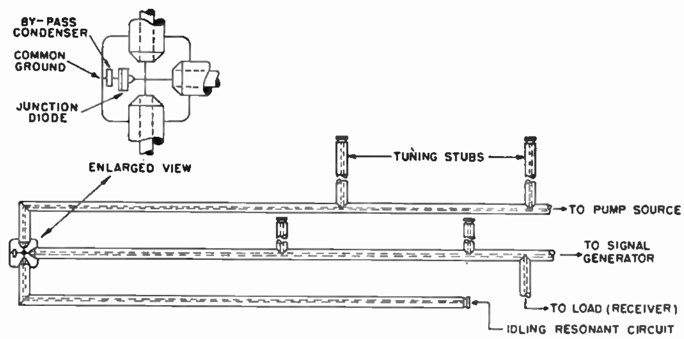


Fig. 3—A nonlinear-capacitance parametric amplifier in which the two pump frequencies, ω_3 and ω_4, are equal. The three resonant coaxial lines are coupled through the junction diode.

Gain and Bandwidth Measurement

With the circuit arrangement shown in Fig. 3, to which the equivalent circuit of Fig. 1 applies, the system gives a stable total available power gain of 35 db at the signal frequency of 380 mc. The insertion loss of the signal circuit is about 5 db, therefore the net gain of the amplifier is 30 db. Strong oscillations rapidly set in as the power gain rises above 40 db. The bandwidth and gain-bandwidth product are shown in Fig. 4 as a function of the power gain. The measured points follow very closely the theoretical curves predicted by (5). In general, full percentage bandwidth of this particular example is in the order of a few tenths at a reasonable gain.

Pumping Power

The pumping power P_p can be roughly computed from (7); it is

$$P_p = I_3^2/G_3 = (4G_3/3\mathcal{C})\sqrt{\alpha' G_T G_2/\omega_1(2\omega_3 - \omega_1)}. \qquad (10)$$

[6] This ferrite was supplied by P. K. Baltzer of RCA Labs.

[7] L. J. Giacoletto and J. O'Connell, "A variable-capacitance germanium junction diode for UHF," *RCA Rev.*, vol. 17, p. 68; March, 1956.

[8] The diodes used in the present experiments were of an improved design provided by C. Stocker of RCA Labs.

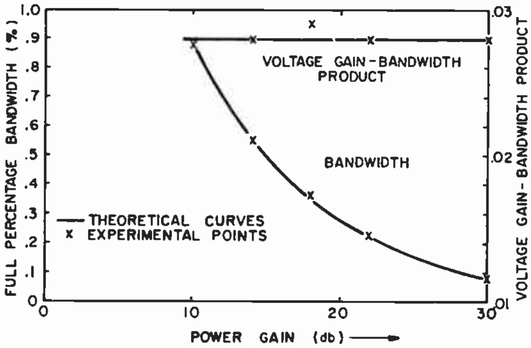


Fig. 4—Full percentage bandwidth and voltage gain-bandwidth product, as functions of the available power gain.

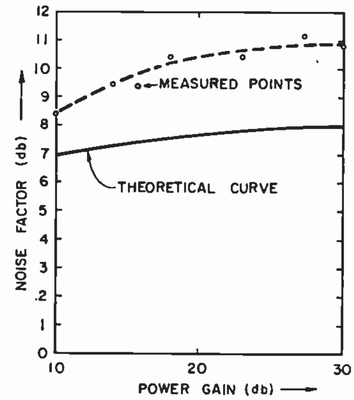


Fig. 5—Noise factor as a function of available power gain.

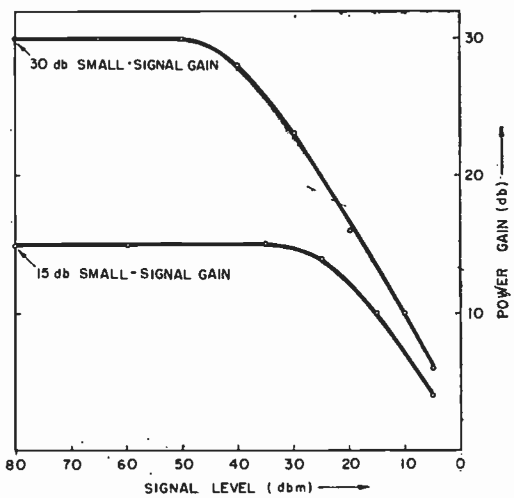


Fig. 6—Power gain as a function of signal power. For the case of small-signal power gain of 15 db, the dynamic range is 50 dbm and for the case of small-signal power gain of 30 db the dynamic range is 30 dbm.

In (10) $\mathcal{C} = 213\times10^{-12}$ farads per volts² from (9) and the generator conductance has the value $G_g = 0.02$ mho. By measurement the total conductance has the value $G_T = 2.7G_g = 0.054$ mho, the pump circuit conductance is $G_3 = 0.02$ mho, and since the load is matched to the transmission line, the load conductance is $G_L = G_g$. The value $G_2 = 0.02$ is obtained from (5) and the measured value of G_vB. With these conductance values, (4) gives $\alpha' = 0.92$ for a gain of 20 db. Thus the pumping power, computed from (9), is $P_p = 20$ mw.

The measured pumping power for this gain is 30 mw. This low value is a very attractive feature of the device, and a direct consequence of the large degree of nonlinearity exhibited by the capacitor.

Noise Factor

The noise factor of the particular amplifier circuit being measured has, according to (6), a theoretical value in the range of 7 to 8 db at room temperature. This value is based on the measured value $G_1/G_g = 0.7$. This large noise factor is due to the large value of the frequency ratio ω_1 to ω_2 and to the large values of the signal-circuit loss conductance, G_1.

Both the theoretical and experimental noise factor are shown in Fig. 5. It is seen that in general the measured values are 2 or 3 db higher than theoretical values. The discrepancy is due to the fact that the measurement was carried out with a nonisolated load.

Gain Saturation

To determine the saturation behavior, the gain was measured as a function of the signal level. The measurements started at the two small-signal power gains of 15 db and 30 db. The gain vs signal level curves are shown in Fig. 6. The two gains remain almost constant until signal levels of 50 dbm and 30 dbm are reached.

Above 40-db gain, the gain rises very steeply with increasing pumping power and oscillation sets in rapidly at 380 mc. Under the oscillating condition, the power output was measured to be 1 mw.

Conclusion

The principle of parametric amplification using lower-frequency pumping has been verified in a series of simple experiments. The first experiment involved the use of a nickel-manganese ferrite as the nonlinear inductance element. A small amount of power gain (about 30 per cent) was observed at a signal frequency of 10 mc and a pump frequency of 7 mc.

A much better verification of the principle of lower-frequency pumping was obtained through the use of a germanium junction diode as the nonlinear-capacitance element. A 35-db gain was observed under very stable operation at a signal frequency of 380 mc. Strong oscillations at 380 mc set in when the gain exceeded 40 db.

Because of the high degree of nonlinearity obtainable from a junction-diode variable capacitance, only 30 mw of pumping power was needed for a net power gain of 20 db.

Although the experiments described above were most easily performed in the UHF region, the principle of lower-frequency pumping is by no means limited to that region. Indeed, it is in the centimeter and millimeter wave region, where higher-frequency local oscillator power is difficult to obtain, that the principle of lower-frequency pumping is most important.

Acknowledgment

The authors wish to express their appreciation to R. D. Hughes for his able assistance in carrying out these experiments.

A Ferromagnetic Resonance Frequency Converter*

K. M. POOLE† AND P. K. TIEN†

Summary—**A frequency converter based on the generation in a ferrite of magnetization at the required difference frequency between input and output signals to provide an alternating environment for the input signal has been operated, and is compared with theory. The principles of the device are those of the amplifier/oscillator proposed by Suhl. Theory and experiment on the converter agree within the expected error of the latter. The support thus provided for the theory is pertinent to the present case and the original amplifier/oscillator.**

I. Introduction

A PROPOSAL has been made by Suhl[1] for an amplifier using a ferro-magnetic material in which microwave power is supplied by a local oscillator to a ferrite sample, causing the magnetization of the ferrite to precess about a uniform magnetic field. If the sample be in a cavity resonant to two frequencies ω_1 and ω_2, such that $\omega_1+\omega_2=\omega$, the frequency of the uniform precession, amplification, or oscillation at either ω_1 or ω_2 may occur. For most effective use of the local oscillator power the cavity should be resonant to ω, as well as to ω_1 and ω_2, and the magnetic field should be adjusted to make ω the frequency of ferromagnetic resonance.

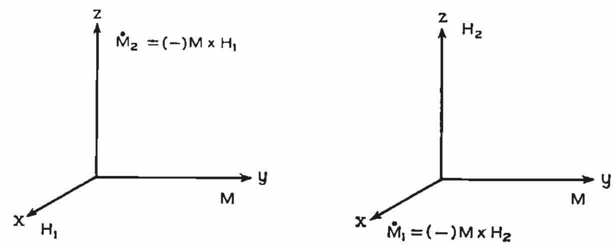
A picture of the operation of such a device may be obtained by considering the equation of motion of the magnetization vector. Neglecting the loss processes, this is simply

$$\frac{d\vec{M}}{dt} = -\gamma(\vec{M} \times \vec{H}). \qquad (1)$$

Both M and H may contain components at all the relevant frequencies, *i.e.*, zero, ω, ω_1, and ω_2. Since the usual precession angles in resonance experiments are very small, we have, first, that H_{dc} and M_{dc} are much larger than any of the periodic components. Further, since the local oscillator power will normally be greater than that at the signal frequency, and since the local oscillator is at the magnetic resonance frequency, we have

$$H_\omega > H_\omega \text{ or } H_\omega; \quad \text{and} \quad M_\omega \gg M_\omega \text{ or } M_\omega.$$

Returning to (1) the major term represents the precession of the magnetization about the uniform magnetic field. This precession is driven by the local oscillator power and results in the appearance of components of magnetization (alternating at frequency ω) in the plane normal to the dc field. The next terms of importance in (1) are those containing the resonant precession frequency and either ω_1 or ω_2. Referring to Fig. 1(a), the



(a) (b)

Fig. 1—Vector diagram showing frequency conversion and amplification or oscillation in ferromagnetic material.

application of a signal field H_{ω_1} in the x direction to a system in which there exists a y component of M_ω results in a magnetization component along the z axis which contains, among other terms, the frequency $\omega_2=\omega-\omega_1$. The magnetization resulting from this stage of the action is the source of an electromagnetic field, where the H component at the sample will be in the direction of the magnetization. Thus in the second stage the signal $H_{\omega_2}(z)$ multiplied with the uniform precession component of $M_\omega(y)$ gives an $\dot{M}$ (and associated H) along the x axis at a frequency $\omega-\omega_2$, *i.e.*, ω_1 [see Fig. 1(b)]. Further, it can be shown that, with the frequencies so related, the additional H_1 is in phase with the original field. Thus, if the magnitude of the uniform precession magnetization is sufficiently great, some small applied field at frequency ω_1 (or ω_2) will be amplified by interaction with the uniform precession.

Suhl's proposal is a new member of a class of oscillatory systems in which the coupling between a pair of resonances is modulated by an energizing source at a frequency equal to the sum of their resonant frequencies. A degenerate case, in which the resonant frequency of an acoustic element is modulated at twice its mean value, was discussed by Lord Rayleigh.[2] Many forms of nonlinearity or time variance have been used in such parametrically excited systems and, without attempting a complete bibliography, some cases will be noted.

Hartley[3] and Hussey and Wrathall[4] have discussed an electromechanical system; Manley and Peterson[5] and Landon[6] have considered systems using saturable in-

* Original manuscript received by the IRE, November 12, 1957; revised manuscript received, February 19, 1958.

† Bell Telephone Labs., Inc., Murray Hill, N. J.

[1] H. Suhl, "Proposal for a ferromagnetic amplifier in the microwave range," *Phys. Rev.*, vol. 106, pp. 384–385; April, 1957.

[2] Lord Rayleigh, "Theory of Sound," MacMillan and Co., Ltd., London, Eng., 2nd ed., vol. 1, p. 81; 1929.

[3] R. V. L. Hartley, "Oscillations in systems with nonlinear reactance," *Bell Sys. Tech. J.*, vol. 15, pp. 424–440; July, 1936.

[4] L. W. Hussey and L. R. Wrathall, "Oscillations in electromechanical systems," *Bell Sys. Tech. J.*, vol. 15, pp. 441–445; July, 1936.

[5] J. M. Manley and E. Peterson, "Negative resistance effects in saturable reactor circuits," *Trans. AIEE*, vol. 65, pp. 870–881; December, 1946.

[6] V. D. Landon, "The use of ferrite-cored coils as converters, amplifiers, and oscillators," *RCA Rev.*, vol. 10, pp. 387–396; September, 1949.

ductors. Goto[7] and K. Takahashi have used a nonlinear inductance circuit as a phase sensitive memory element, coining the name parametron for it, and units have been manufactured in Japan under the name Paramistor. Capacitative parametric devices using ferroelectrics have been described by Mason and Wick[8] and by Higa.[9]

In the microwave region, North[10] has obtained oscillation using the variation with bias of the contact capacity of germanium rectifiers, and Hines[11] has shown the possibility of using silicon units. Finally, Manley and Rowe[12] have given a general treatment of circuits involving nonlinear elements, and their energy relations apply to parametric devices.

Returning to the case of a ferrite with ac magnetization, while the choice of the frequency relation $\omega=\omega_1+\omega_2$ is essential to a system from which oscillation is desired, as may be shown by applying the Manley and Rowe energy relations to a time-varying reactance element,[12] no such restriction exists if we wish only to study the magnitude of the coupling terms relevant to this type of interaction. Thus for study purposes we may choose any of the components of $\dot{M}_2$ [Fig. 1(a)], *i.e.*, any of the frequencies $\omega_2=\pm m\omega\pm n\omega_1$, as the component to be used as the indicator of the magnitude of the interaction.

The process of Fig. 1(b) need not be considered in order to obtain a qualitative picture of the operation, but has to be taken into account in discussing the power and impedance relations in a frequency converting system.

Experimental evidence on the validity of Suhl's theory has been obtained in two cases. Weiss has shown[13] that amplification and oscillation can be obtained by the method indicated by Suhl; comparison between theory and experiment is difficult in this device because of the forms and dimensions of the resonant elements and the ferrite sample. Also, the present paper is to present a quantitative study of a system designed solely to permit reliable comparison between theory and experiment. The system chosen uses simple modes of a rectangular cavity and a small sample of disk form as an approximation to ellipsoidal geometry. With such an arrangement, the output power at frequency ω_2 will be small compared with either input power, and it is desirable to arrange the experiment to observe the generation of signal at frequency ω_2 rather than the impedance changes at the input frequency. Further, filtering of this new, low-level signal from stray signals at the energizing and input frequencies is necessary and seems best accomplished by designing the system so that the output frequency is the highest used and is sufficiently separated to allow effective filtration. This may be done by standard waveguide if $\omega_2=\omega+\omega_1$, and if neither ω nor ω_1 is very small.

Frequency doubling and mixing in ferrites have been discussed earlier by Ayres, Vartanian, and Melchor,[14] and by Pippin.[15] It has been shown that if an applied field consists of two sinusoids with frequencies ω_1 and ω_2, then terms involving sum and difference of the two frequencies appear as second-order small quantities in the equation of motion of the magnetization vector [*i.e.*, (1) in this paper]. In their derivations, tensor relations between the magnetization and the field were used and damping was ignored; the two frequencies considered must, therefore, be far from ferromagnetic resonance. In the present converter, however, one of the two frequencies is at the ferromagnetic resonance; damping or line width of the sample must be included in the calculation. Furthermore, the field which has its frequency at resonance is much larger than that of the other frequency so that the terms involving the square of the precession angle, which have been omitted in the earlier theories, are important in the present converter. These are the terms which determine the conversion efficiency of the converter; they are also the terms which make amplification possible in Suhl's proposal.

II. Experiment

A. Experimental Arrangement

In designing the ferromagnetic resonance frequency converter a triply resonant rectangular cavity was considered most suitable. The design was governed by several conditions; the cavity modes had to be chosen so that in some region of the cavity strong microwave magnetic fields of all three modes coexisted in the appropriate directional arrangement; simultaneously it had to be possible to choose the dimensions of the cavity to satisfy the condition that $\omega_2=\omega_1+\omega$; the energizing frequency had to be such that, with some sample form, we could be assured that parasitic oscillation of static modes[16] could not exist; and the form of sample and its location in the cavity had to be such that mechanical and thermal support were available.

The experimental arrangement is shown in Figs. 2 through 5. Fig. 2 shows the cavity modes in question and the arrangement of the coupling irises and waveguides. The sample is a disk 0.0023 inch thick and

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[11] M. E. Hines, unpublished work.

[12] J. M. Manley and H. E. Rowe, "Some general properties of nonlinear elements—Part I. General energy relations," Proc. IRE, vol. 44, pp. 904–913; July, 1956.

[13] M. T. Weiss, "Solid-state microwave amplifier and oscillator using ferrites," *Phys. Rev.*, vol. 107, p. 317; July, 1957.

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[16] L. R. Walker, "Magnetostatic modes in ferromagnetic resonance," *Phys. Rev.*, vol. 105, pp. 390–399; January, 1957.

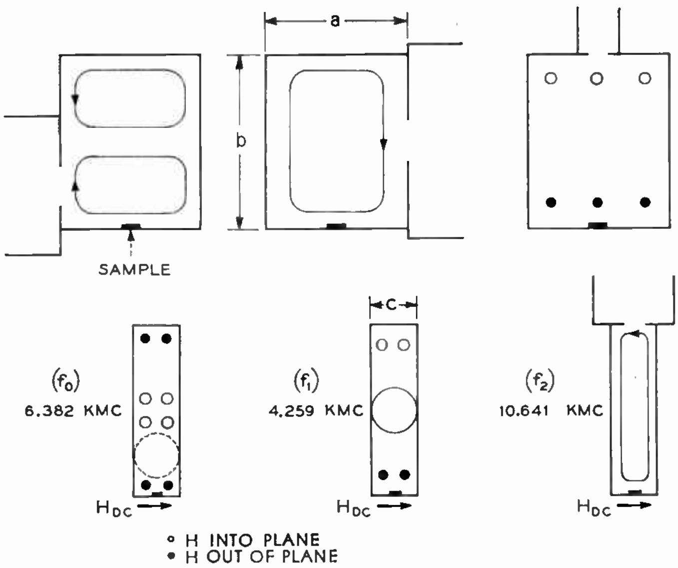

Fig. 2—Magnetic field patterns of resonant modes of cavity. (Coupling waveguides and irises shown only on sketch of corresponding mode.)

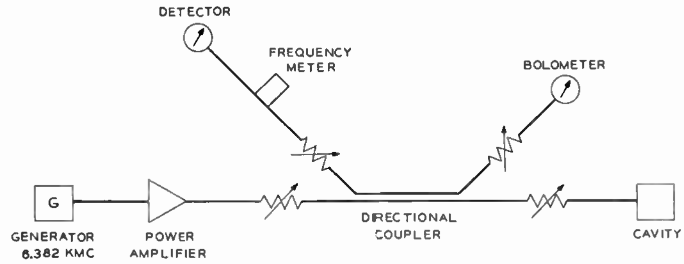

Fig. 4—Waveguide circuit supplying signal input to cavity.

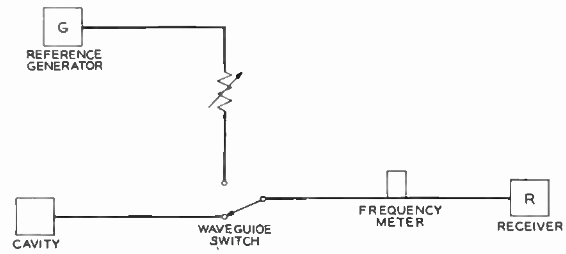

Fig. 5—Waveguide circuit for detection and measurement of output signal.

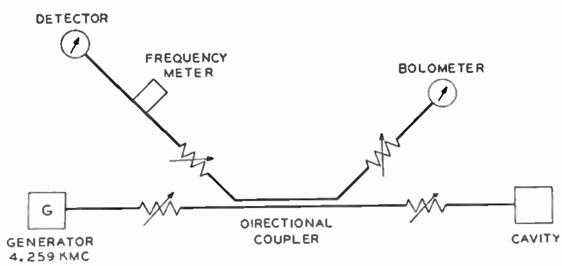

Fig. 3—Waveguide circuit supplying energizing power to cavity.

0.046 inch in diameter cut in the 110 plane from a single crystal of yttrium iron garnet.

The cavity used had the following dimensions and resonances (Fig. 2).

$a = 4.486$ cm.
$b = 1.466$ cm.
$c = 5.446$ cm.
$f_1 = 4.259$ kmc.
$f_0 = 6.382$ kmc.
$f_2 = 10.641$ kmc.

The resonant frequencies are significantly affected by the coupling holes which are: for f_1, 0.5-inch diameter, $\frac{1}{8}$-inch wall thickness; for f_0, 0.531-inch diameter, $\frac{1}{8}$-inch wall thickness; for f_2, 0.312-inch diameter, $\frac{1}{16}$-inch thickness.

The frequency of the other modes of the cavity were calculated before constructing the unit and found to lie more than 100 mc away from the desired modes. No difficulty with alternative modes was experienced in practice. It will be seen that the applied rf magnetic field at the energizing frequency is in the same direction as the signal frequency field. The component of the energizing frequency precession which is appropriate to the discussion for Fig. 1 is, however, the magnetization component at right angles to both the energizing magnetic field and the uniform field. The steady magnetic field indicated in Fig. 2 is supplied by an electromagnet having $3\frac{1}{2}$-inch diameter poles and a $2\frac{1}{16}$-inch gap.

Figs. 3 through 5 show the microwave circuit arrangements used at the energizing, signal, and output frequencies, respectively.

B. Resonance Line Widths

Following preliminary observations of frequency conversion action in which an initial conversion gain of about the expected magnitude was followed by a decrease to an equilibrium value some 20 db lower, recorder plots of the magnetic resonance at 6.382 kmc were made using the same microwave input arrangement as intended for the converter. Fig. 6 is a plot of the output power at constant input power as a function of magnetic field. The peak power transmitted towards the cavity was 3.8×10^{-3} watts and the duty cycle 0.5. After allowing for the known reflection at the iris, the mean absorbed power was approximately 1.3×10^{-3} watts.

Similar plots were made over a wide range of incident peak powers and duty cycles. These serve to separate effects due to heating of the sample from those due to broadening of the line by high power effects. The results are illustrated by comparison of Fig. 6 with Figs. 7 and 8. Fig. 7 was obtained with a peak incident power of 6.12×10^{-1} watts and a mean absorbed power of approximately 2×10^{-1} watts, while for Fig. 8 the corresponding figures were 6.0×10^{-1} watts and 2×10^{-3} watts. From these and other measurements of the same type we conclude that with our particular sample and thermal contact conditions, heating effects become significant at about 4×10^{-2} watts mean absorbed power, while the broadening due to high power effects is appreciable only near the limits of the available energizing

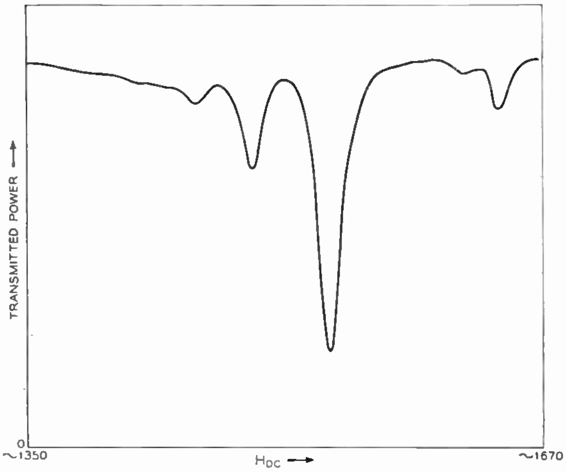

Fig. 6—Low-power resonant absorption in sample at energizing frequency. Peak incident power 3.8+10⁻³ watts, mean absorbed power 1.3+10⁻³ watts.

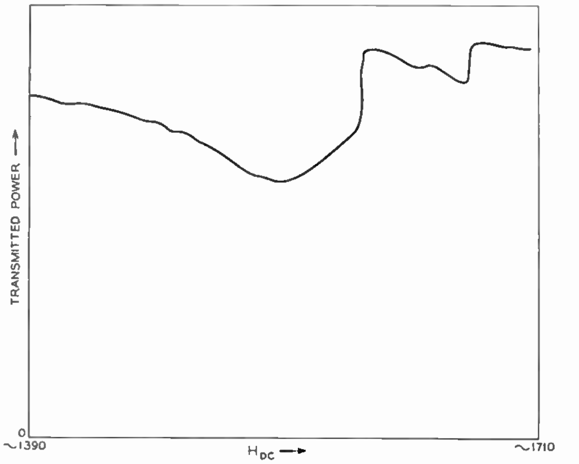

Fig. 7—High-power absorption line. Peak incident power $6.12+10^{-1}$ watts, mean absorbed power $2.0+10^{-1}$ watts.

power. At the highest available peak powers (~3 watts) line broadening and a very small low-field subresonance have been observed. Separate measurements of the line width indicate a value of approximately 8 to 9 oersteds with an increase to 11 oersteds at the highest powers.

C. Conversion Gain Measurements

In the light of these conclusions on the conditions for temperature broadening and for power broadening, valid conversion measurements at high energizing power levels could be made either by pulsing the energizing signal with a duty cycle of less than 0.01, or by taking advantage of the finite thermal delay under conditions where the absorbed power might be too high for a significant equilibrium measurement. For reasons associated with the characteristics of available equipment, measurements of the output power as a function of signal and energizing powers were made by using a 0.1 per cent duty cycle on the energizing power, without establishing accurate absolute levels; an absolute measurement at one particular combination of conditions was made by taking advantage of the thermal delay.

The former measurements are plotted in Fig. 9. The lines drawn are derived from the theoretical relationship

$$P_{\text{output}} = C \times P_{\text{signal}} \times P_{\text{energize}},$$

which is based on the assumption that the line width (and hence the related parameters of the microwave resonance) are independent of signal level. Fig. 9 shows a deviation of the order of 2 db from the idealized model.

An effect outside the scope of currently available theory was observed during the operation of the converter. By reducing the magnetic field, ferromagnetic resonance absorption of the lower frequency (lower power) input may be obtained, thus interchanging the identification of the signal and energizing inputs. Because of the relative power levels, enhanced by the fact that the higher power signal in this condition sees the

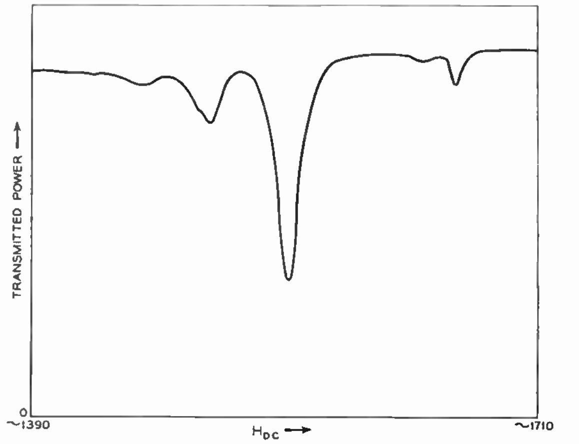

Fig. 8—Pulsed signal absorption line. Peak incident power $6.12+10^{-1}$ watts, mean absorbed power $2.0+10^{-3}$ watts.

higher cavity, Q, a relatively small precession at the new energizing frequency now forms the environment for a relatively high signal field. Fig. 10 shows the output power as a function of magnetic field for constant input powers of 1 watt at 6.382 kmc, 20 mw at 4.259 kmc. Examination of the lower field peak of Fig. 10 showed that in this power range the output varied as the product of the low-frequency (energizing) power and the cube of the high-frequency (signal) power. Onset of saturation with respect to the signal power was just observable at the 4-watt input level, the highest available. No further study has been made under these conditions.

In order to make an absolute comparison with theory in the "normal" condition, *i.e.*, where the energizing power is substantially higher than the signal power, the following parameters were measured and the indicated values obtained.

Signal frequency = 4.259 kmc.
Loaded Q = 1690.
Incident power = 5×10^{-2} watts.
Power transmission factor of coupling iris = 0.395.

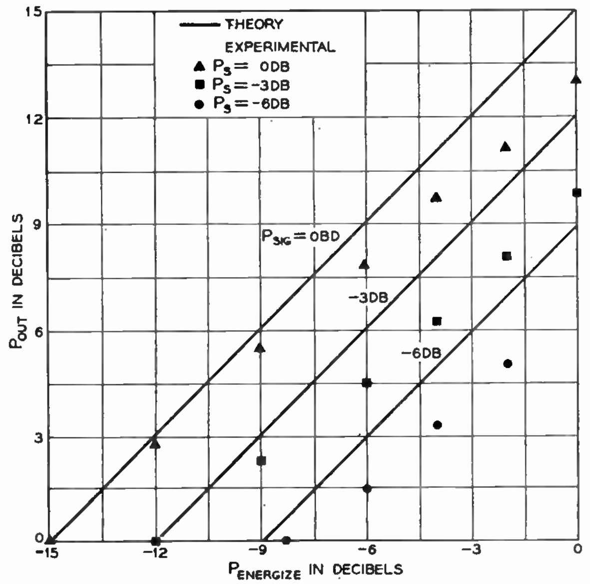

Fig. 9—Output power at 10.641 kmc as function of signal power (at 4.259 kmc) and energizing power (at 6.382 kmc).

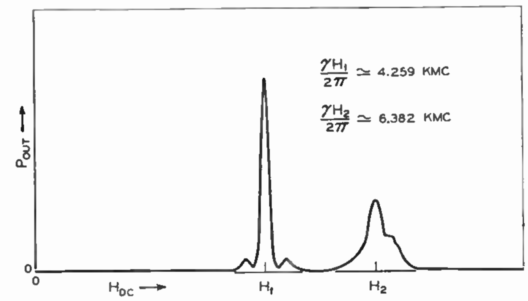

Fig. 10—"Anomalous" operation ($H_{dc}=H_1$) and "normal" operation ($H_{dc}=H_2$) of frequency converter.

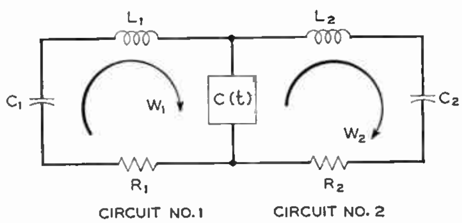

Fig. 11—Low-frequency model of parametric conversion and amplification or oscillation.

Energizing frequency = 6.382 kmc.
Loaded Q (at ferromagnetic resonance) = 1170.
Incident power = 3 watts.
Resonance line width = 11 oersteds.
Power transmission factor = 0.8.

Output frequency = 10.641 kmc.
Loaded Q = 6000.
Output power = 3.7×10^{-10} watts.
Power transmission factor = 0.35.
(Measured by use of external generator)

These will be compared with theory in a subsequent portion of this paper.

III. Theory

A. A Low-Frequency Model

The principles of the frequency converter, or modulator, can easily be demonstrated by the low-frequency circuit shown in Fig. 11, which is the same as that used by Suhl to explain his amplifier. In Fig. 11, two circuits resonant to the angular frequencies ω_1 and ω_2, respectively, are coupled together through a common time-varying capacitor $C(t)$. In the presence of the energizing power supplied by a local oscillator, $C(t)$ is assumed to vary in time as

$$1/C(t) = g_1 \cos \omega t \tag{2}$$

where g_1 is a constant. The physically inevitable constant portion of $C(t)$ has been assumed to be incorporated in C_1 and C_2. In the present converter, ω_1 is the input signal frequency, ω_2 is the output frequency, and the frequency, ω, of the energizing power is equal to the difference between ω_2 and ω_1. We wish to show that the converter absorbs power at the frequency ω_1 at its input and delivers power at the frequency ω_2 to the output through the parametric effects of the time-varying coupling capacitance.

For simplification in calculation, we shall assume: 1) that g_1 in (2) is a small quantity. Its presence only disturbs the (otherwise uncoupled) resonant circuits slightly. 2) that the selectivity or Q, of each of the two resonant circuits is so high that only currents of the frequencies ω_1 and ω_2 can flow in circuits no. 1 and no. 2, respectively.

Consider a signal voltage, V_1, of frequency ω_1, which introduces a current i_1 in circuit no. 1,

$$\left.\begin{aligned} V_1 &= A_1R_1 \cos(\omega_1 t + \theta) \\ i_1 &= A_1 \cos(\omega_1 t + \theta) \end{aligned}\right\}. \tag{3}$$

The current is blocked from circuit no. 2 because of the selectivity of the resonant circuit. It however develops a voltage across the time-varying common capacitance $C(t)$,

$$\begin{aligned} \frac{1}{C(t)}\int i_1 dt &= \frac{A_1 g_1}{\omega_1}\sin(\omega_1 t + \theta)\cos\omega t \\ &= \frac{1}{2}\frac{A_1 g_1}{\omega_1}[\sin[(\omega + \omega_1)t + \theta] - \sin[(\omega - \omega_1)t - \theta]]. \end{aligned} \tag{4}$$

The first term on the right-hand side of (4) has the frequency

$$\omega + \omega_1 = \omega_2.$$

This component of the voltage must be balanced by a voltage at the same frequency in circuit no. 2 and thus introduces a current

$$i_2 = \frac{1}{2}\frac{A_1 g_1}{\omega_1 R_2}\sin(\omega_2 t + \theta). \tag{5}$$

Similarly the current i_2 develops a voltage across $C(t)$, which has a component at the frequency ω_1 and thus introduces an additional current in circuit no. 1,

$$\Delta i_1 = -\frac{1}{4}\frac{A_1 g_1^2}{\omega_1\omega_2 R_1 R_2}\cos(\omega_1 t + \theta). \qquad (6)$$

Since g_1 is a small quantity, Δi_1 must be much smaller than i_1. The further effects of Δi_1 may be neglected in the first-order approximation.

It may be seen that, because of the voltage across $C(t)$ due to i_1, the current i_2 flows, and similarly, because of the voltage developed across $C(t)$ by i_2, an additional current Δi_1 is added in circuit no. 1. We notice that the currents i_1 and Δi_1 are in opposite phase (irrespective of the initial phase, θ, between the energizing power and the input signal). That is, the larger the output current i_2, the smaller the resultant current, $i_1+\Delta i_1$, in circuit no. 1. Since there is no positive feedback to the input circuit in the process, the converter never oscillates.

The output power at the frequency ω_2 is

$$W_2 = \frac{1}{2} i_2^2 R_2 = \frac{1}{8}\frac{A_1^2}{\omega_1}\frac{g_1^2}{R_2}. \qquad (7)$$

A part of this power is contributed by the input power at the frequency ω_1. It is

$$W_1 = \frac{1}{2} V_1(\Delta i_1) = \frac{1}{8}\frac{A_1^2 g_1^2}{\omega_1\omega_2 R_2}. \qquad (8)$$

The rest of the output power, $W_2 - W_1$, is supplied by the energizing power at the frequency ω. From (7) and (8) we have

$$\frac{W_2}{\omega_1} = \frac{W_2}{\omega_2} = \frac{W_2 - W_1}{\omega}. \qquad (9)$$

This equation has been derived by Landon for nonlinear inductive circuits,[6] and for general reactive systems by Manley and Rowe.[12] If $\omega_2 > \omega_1$ as it is in the present arrangement. W_2 must be larger than W_1. The additional output power, $W_2 - W_1$, originates in the energizing source, but is controlled by the signal at ω_1. The difference between the ferromagnetic amplifier discussed by Suhl and the present experimental arrangement originates in the choice of the frequency relationship $\omega = \omega_2 + \omega_1$ for the former and $\omega = \omega_2 - \omega_1$ for the latter. In terms of the low-frequency model, the Suhl case leads to a value of Δi_1 of opposite sign to that of (6); *i.e.*, Δi_1 is in phase with i_1 and results in regenerative amplification or oscillation.

B. The Ferromagnetic Converter

In the ferromagnetic converter, a small ferrite sample is placed inside a cavity which supports three resonant modes. The modes are resonant to the input frequency ω_1, the output frequency ω_2, and the energizing frequency ω, respectively. At the location of the sample, the magnetic fields of the ω and ω_1 modes are in the x direction and that for the ω_2 mode is in the z direction. These fields will be expressed as H_x, H_{x1}, and H_{z2}. Here the subscripts x, y, and z denote the directions of the fields, and the subscripts 1, 2, and 0 denote the frequencies of the fields (ω_1, ω_2, and ω). For convenience, the subscript 0 will often be omitted. For example, H_x is the x component of the magnetic field at the energizing frequency. The energizing field, H_x, is excited by a local oscillator and is much larger in magnitude than the fields, H_{x1} and H_{z2}. The fields are assumed uniform over the sample.

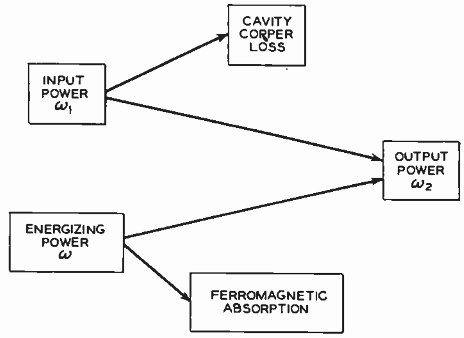

Fig. 12—Power flow in frequency conversions

A uniform dc magnetic field is applied in the z direction so that the sample is resonant to the energizing frequency. In the actual experiment, a disk sample is used, which may be considered as an ellipsoid with the Kittel demagnetizing factors $N_x = N_z = 0$ and $N_y = 4\pi$. Let the applied dc field be H_{dc}. The resonant frequency of the sample is then

$$\omega = [(\omega_H + \omega_x^d - \omega_z^d)(\omega_H + \omega_y^d - \omega_z^d)]^{1/2}. \qquad (10)$$

Here

$$\begin{aligned} \omega_H &= |\gamma| H_{dc} \\ \omega_x^d &= |\gamma| N_x M \\ \omega_y^d &= |\gamma| N_y M \\ \omega_z^d &= |\gamma| N_z M. \end{aligned} \qquad (11)$$

M is the total magnetization of the sample and γ is the gyromagnetic ratio (equal to 2.8 mc per oersted).

Since H_x is much stronger than the fields at the other frequencies and the sample is resonant to the energizing frequency, the magnetization of the sample precesses mainly at the energizing frequency with small nutations driven by H_{x1} and H_{z2}. It will be clear in the later sections that it is this complicated motion of the magnetization which causes power to be transferred from the field at one frequency to that at the other. The operation of the ferromagnetic converter in the case of a small sample may better be understood from the block diagram shown in Fig. 12. The input power fed to the cavity is partly dissipated in the cavity wall as the copper loss and partly transformed to the other frequency as the output. Similarly, most of the energizing power is absorbed by the sample at the ferromagnetic resonance and only a small part of it is transferred to the output. In the actual experiment, a few watts of the energizing power coupled with a few milliwatts of the input power gives an output in the order of 10^{-10} watts.

C. Motion of the Magnetization

We shall calculate the motion of the magnetization induced by the fields H_x, H_{z1}, and H_{z2} of the cavity. Since the converter cannot oscillate, we shall consider the steady solutions only. The sample is resonant to the energizing frequency. The motion of the magnetization at this frequency may be considered as being excited exclusively by the energizing field H_x. Let H_x at the sample be of the form

$$H_x = - h_x \sin \omega t \tag{12}$$

where h_x is a constant, since the field is assumed uniform over the sample. Using the equation of motion in the form proposed by Landau and Lifshitz[17]

$$\frac{d\vec{M}}{dt} = - \gamma[\vec{M} \times \vec{H}] + \frac{\alpha}{M}\left[\vec{M} \times \frac{d\vec{M}}{dt}\right], \tag{13}$$

it can be shown that the ω component of the magnetization motion is

$$M_x = \frac{1}{2} M \frac{h_x}{\Delta H} \rho \cos \omega t$$
$$M_y = \frac{1}{2} M \frac{h_x}{\Delta H} \sin \omega t. \tag{14}$$

Here

$$\Delta H = \frac{1}{2} \frac{\omega}{|\gamma|} \frac{1 + \rho^2}{\rho} \alpha$$
$$\rho = \left[\frac{\omega_H + \omega_y{}^d - \omega_z{}^d}{\omega_H + \omega_x{}^d - \omega_z{}^d}\right]^{1/2}. \tag{15}$$

ΔH as used in these equations is the line width as measured in a resonance experiment. The quantity $h_x/\Delta H$ will be denoted by θ, and the calculation will be limited to the case of small θ. The magnetization vector of the sample thus deviates from its equilibrium position only slightly and contains a large dc component in the z direction.

To calculate the magnetization at the frequencies ω_1 and ω_2, we may ignore the dissipation term in (13), since these frequencies are far from the ferromagnetic resonance. We notice that H_x in (12), and M_x and M_y in (13), are small compared with the dc applied field $H_{z\,dc}$ and the dc component of the magnetization, $M_{z\,dc}$. We also recall that H_{z1} and H_{z2} are even smaller than H_x, M_x, and M_y. If we ignore the quantities of order $H_{z1}{}^2$ as we shall always do later, the only nonlinear terms left in the term $\gamma[\vec{M}\times\vec{H}]$ of (13) are the products $\gamma M_y H_{z1}$, $\gamma M_y H_{z2}$. These are the nonlinear terms corresponding to the voltages across $C(t)$ described in Section III-A; they couple the field of one frequency to that of the other and make power transfer possible among the fields of different frequencies. Put

$$H_{z1} = h_{z1} e^{j\omega_1 t}$$
$$H_{z2} = h_{z2} e^{j\omega_2 t}$$
$$M_{x1} = m_{x1} e^{j\omega_1 t}, \quad M_{y1} = m_{y1} e^{j\omega_1 t}, \quad M_{z1} = m_{z1} e^{j\omega_1 t}$$
$$M_{x2} = m_{x2} e^{j\omega_2 t}, \quad M_{y2} = m_{y2} e^{j\omega_2 t}, \quad M_{z2} = m_{z2} e^{j\omega_2 t}. \tag{16}$$

Again using (13) and ignoring both the dissipation term and quantities of order $H_{z1}{}^2$, we have finally the ω_1 and ω_2 components of the magnetization:

$$m_{x1} = \frac{1}{\Delta_1}\left[\omega\rho \frac{\omega_m}{4\pi} h_{z1} - \theta \frac{\omega_m}{16\pi} h_{z2}(\omega\rho^2 - \omega_1)\right]$$
$$m_{y1} = \frac{1}{\Delta_1}\left[-j\omega_1 \frac{\omega_m}{4\pi} h_{z1} - j\theta\rho \frac{\omega_m}{16\pi} h_{z2}\left(\frac{1}{\rho}\omega - \rho\omega_1\right)\right] \tag{17}$$
$$m_{z1} = 0$$
$$m_{x2} = m_{y2} = 0$$
$$m_{z2} = -\frac{1}{4} \theta\rho \left[m_{x1} - j\frac{1}{\rho} m_{y1}\right].$$

Here

$$\Delta_1 = \omega^2 - \omega_1{}^2$$
$$\omega_m = 4\pi |\gamma| M. \tag{18}$$

Similar expressions can be obtained for $M_{1,2}$'s which vary as $e^{-j\omega_{1,2}t}$. They may then be combined with those in (17) to form sinusoidal functions. It is, however, equally convenient to manipulate quantities in the form $e^{j\omega_{1,2}t}$(or $e^{-j\omega_{1,2}t}$) bearing in mind that they are actually sinusoidal functions in time.

D. Maxwell's Equations

We shall now proceed with Maxwell's equations, in the same way as was done by Suhl for his amplifier, except that a driving term will be added in the equations, since the power in the modulator is extracted from the input to the output. We expand the fields inside the cavity, including the sample, into normal modes

$$\vec{H} = \sum_n A_n e^{j\Omega_n t} \vec{h}_n(\vec{r})$$
$$\vec{E} = \sum_n B_n e^{j\Omega_n t} \vec{e}_n(\vec{r}) \tag{19}$$

where A_n and B_n are constants and $\vec{h}_n(\vec{r})$ and $\vec{e}_n(\vec{r})$ are the electric and magnetic fields of the normal mode no. n. They are real and time-independent functions, and satisfy

$$\nabla \times \vec{h}_n = \frac{\Omega_n}{c} \vec{e}_n; \quad \nabla \times \vec{e}_n = \frac{\Omega_n}{c} \vec{h}_n$$
$$\nabla \cdot \vec{h}_n = 0; \quad \nabla \cdot \vec{e} = 0 \tag{20}$$

[17] L. Lindau and E. Lifshitz, "On the theory of the dispersion of magnetic permeability in ferromagnetic bodies," *Physik. Z. Sowjetunion*, vol. 8, pp. 153–169; June, 1935.

as well as the boundary conditions of the empty cavity. The fields in the cavity must satisfy Maxwell's equations

$$\nabla \times \vec{H} = \frac{1}{c}\frac{\partial \vec{E}}{\partial t} + \frac{4\pi}{c}\frac{\partial \vec{P}}{\partial t}$$

$$\nabla \times (\vec{E}_{1(\text{app})} - \vec{E}) = \frac{1}{c}\frac{\partial \vec{H}}{\partial t} + \frac{4\pi}{c}\frac{\partial \vec{M}}{\partial t}. \quad (21)$$

Here $\vec{E}_{1(\text{app})}$ is the applied electric field at the input frequency ω_1. It is separated from the rest of the fields $\vec{E}$ and will be considered as a driving term in the equations. Eventually we will compute the power associated with $\vec{E}_{1(\text{app})}$. The form of the driving term is therefore immaterial as long as we can compute power from the form in which we express it. Substituting (19) and (20) into (21), and using the orthogonal relations of the normal modes, we have for the fields at the frequency ω_1,

$$\Omega_1 A_1 - j\omega_1 B_1 = 4\pi\epsilon_{\text{eff}}(j\omega_1) B_1 \left[\frac{\int_{\text{sample}} e_1^2 dv}{\int_{\text{cavity}} e_1^2 dv}\right] \quad (22)$$

$$\Omega_1(B_{1(\text{app})} - B_1) - j\omega_1 A = 4\pi j\omega_1 \left[\frac{\int_{\text{sample}} \vec{m}_1 \cdot \vec{h}_1 dv}{\int_{\text{cavity}} h_1^2 dv}\right]. \quad (23)$$

Here $\vec{P} = \epsilon_{\text{eff}} \vec{E}$. Put

$$4\pi\epsilon_{\text{eff}} \frac{\int_s e_1^2 dv}{\int_c e_1^2 dv} = \delta$$

and eliminating B_1 from (22) and (23), we have

$$\omega_1 B_{1(\text{app})} - \left[j\omega_1 + \frac{\Omega_1^2}{j\omega_1(1+\delta)}\right] A_1 = 4\pi j\omega_1 \left[\frac{\int_s \vec{m}_1 \cdot \vec{h}_1 dv}{\int_c h_1^2 dv}\right]. \quad (24)$$

To include copper loss in the cavity, put

$$\Omega_1 = \omega_1\left(1 + \frac{j}{2Q_1}\right)$$

where Q_1 is the unloaded Q of the cavity at the frequency ω_1. After evaluating $\int_s \vec{m}_1 \cdot \vec{h}_1 dv$ from (17) and ignoring small quantities, we have finally

$$\omega_1 B_{1(\text{app})} - \frac{\omega_1}{Q_1} A_1 = -\frac{1}{4} j\omega_1 \frac{1}{\omega^2 - \omega_1^2} \theta\omega_m F_1 A_2(\rho^2\omega - \omega_1) \quad (25$$

where

$$F_1 = \frac{\int_s h_{z1} h_{z2} dv}{\int_c h_1^2 dv}.$$

Following exactly the same procedure as outlined above, we have the equations for the frequency ω_2,

$$\frac{\omega_2}{Q_{L2}} A_2 = -\frac{1}{4} j\omega_2 \frac{1}{\omega^2 - \omega_1^2} \theta\omega_m F_2 A_1(\rho^2\omega - \omega_1). \quad (26)$$

Here Q_{L2} is the loaded Q of the cavity at the frequency ω_2, and

$$F_2 = \frac{\int_s h_{z1} h_{z2} dv}{\int_c h_2^2 dv}.$$

E. The Power Relations

Multiplying (24) by $(1/8\pi)A_1\int_c h_1^2 dv$ and (25) by $(1/8\pi)A_2\int_c h_2^2 dv$ and rearranging the terms, we have

$$\frac{1}{8\pi}\omega_1 A_1 B_{1(\text{app})}\int_c h_1^2 dv = \frac{1}{8\pi}\frac{1}{Q_1}\omega_1 A_1^2 \int_c h_1^2 dv + \frac{1}{32\pi}\frac{1}{\omega^2 - \omega_1^2}\omega_1 A_1(-jA_2)\theta\omega_m(\rho^2\omega - \omega_1)\int_s h_{z1}h_{z2} dv \quad (27)$$

and

$$\frac{1}{8\pi}\frac{1}{Q_{L2}}\omega_2 A_2^2 \int_c h_2^2 dv = \frac{1}{32\pi}\frac{1}{\omega^2 - \omega_1^2}\omega_2 A_1(-jA_2)\theta\omega_m(\rho^2\omega - \omega_1)\int_s h_{z1}h_{z2} dv. \quad (28)$$

The first term at the left of (27) is the total input power at the frequency ω_1, fed to the cavity. The first term at the right of (27) is the part of the input power which is dissipated as the cavity copper loss, and the second term is the part of the input power which is transformed to the output. In (28), the term at the right is the total power generated in the modulator at the frequency ω_2. It must be equal to the term at the left, which is the sum of the power at the same frequency, dissipated as the cavity copper loss and that absorbed by the output load. Denoting the second term at the right of (27) by $\overline{W}_1$ and the term at the right of (28) by $\overline{W}_2$, we have

$$\frac{\overline{W}_1}{\omega_1} = \frac{\overline{W}_2}{\omega_2}$$

which is Manley's relation again.

In the actual experiment, the second term at the right of (27) is small compared with the first term at the right. That is, most of the input power is dissipated as copper loss, and only a negligible part of it contributes the output. In that case, we may consider the input power, P_1 as

$$P_1 = \frac{1}{8\pi}\frac{1}{Q_1}\omega_1 A_1^2 \int_c h_1^2 dv. \quad (29)$$

Denote the total power generated in the modulation at the frequency ω_2 by P_2'; we have then from (28) and (29) and the definitions of F_1 and F_2,

$$\frac{P_2'}{P_1} = \frac{1}{16}\frac{\omega_2}{\omega_1}\frac{1}{(\omega^2-\omega_1^2)^2}\omega_m^2\theta^2(\rho^2\omega-\omega_1)^2 F_2F_1Q_1Q_{L2}. \quad (30)$$

If $Q_{(ext)2}$ is the external Q of the output circuit, we have finally the power absorbed by the output load

$$P_2 = \frac{Q_{(ext)2}}{Q_{L2}} P_2' \quad (31)$$

which is actually measured in the experiment.

IV. Comparison Between Theory and Experiment

Using the set of experimental data given in Section II-C and the cavity dimensions we may calculate the expected output power. First by transmission line methods we calculate the unloaded cavity Q values and the matching impedance ratios. These values are:

1) $\omega_1 = 4.259$ kmc. For this resonant mode,

$$1-\Gamma^2 = 0.395 \qquad \therefore \Gamma = 0.788$$

$$\therefore \frac{R}{n^2Z_0} = 8$$

where Γ is the voltage reflection coefficient at the coupling iris, R is the impedance of the cavity mode at resonance, Z_0 is the characteristic impedance of the guide, and n is the "voltage ratio" of the waveguide to cavity coupling.

Hence, since $Q_L = 1690$, $Q_0 = 1900$.

2) $\omega_2 = 6.382$ kmc.

$$1-\Gamma^2 = 0.8 \qquad \therefore \Gamma = 0.447$$

$$\frac{R}{n^2Z_0} = 2.61.$$

Hence, since $Q_L = 1170$, $Q_0 = 1620$.

$$1-\Gamma^2 = 0.35 \qquad \therefore \Gamma = 0.706$$

$$\frac{R}{n^2Z_0} = 9.29.$$

3) $\omega = 10.641$ kmc.

Before applying (30), we require the value of θ.

Now,

$$W_s = \frac{\mu_0 h^2 V_c \lambda_g^2}{8\lambda^2}$$

which, since

$$V_c = 35.8\ 10^{-6}\ \text{m}^3$$
$$\lambda_g = 5.45\ \text{cm}$$
$$\lambda = 4.07\ \text{cm}$$
$$\lambda = 4\pi\ 10^{-7}$$

gives

$$W_s = 7.54\ 10^{-12}\ h^2\ (\text{mks}).$$

If P is power transmitted toward the cavity, Q_0 is the unloaded Q and ΔH the line width

$$P(1-\Gamma^2) = \frac{\omega W_s}{Q_0} = \frac{\omega \times 7.54\ 10^{-12}\ h^2}{Q_0} = \frac{7.54\ 10^{-12}\omega(\Delta H)^2\theta^2}{Q_0}$$

or, for the prescribed conditions

$$\theta^2 = 0.0168.$$

In (30) P_1 is the power fed through the coupling port into the cavity, P_2 is total power generated in the ferrite sample, Q_1 is the unloaded Q at the input frequency, and Q_2 is the loaded Q at the output frequency.

From the observed quantities we find that

$$F_1F_2 = (1.19\ 10^{-6})^2,$$
$$Q_1 = 1900\ (\text{unloaded}),$$
$$Q_{L2} = 6000\ (\text{loaded}),$$
$$\omega_m = 2.8 \times 2000 = 5.6\ \text{kmc},$$
$$\rho^2 = 2.34,$$
$$P_1 = 50 \times 10^{-3} \times 0.395 = 19.75\ 10^{-3}\ \text{watt},$$

which lead to

$$P_2' = 5.95\ 10^{-0}\ \text{watts}.$$

In (31)

$$\frac{Q_{(ext)2}}{Q_{L2}} = \frac{n^2Z_0}{n^2Z_0 + R} = 0.0973.$$

Finally,

$$P_2 = 0.0973\ P_2'$$
$$= 5.79\ 10^{-10}\ \text{watts}$$

compared with an experimental value of

$$P_2 = 3.7\ 10^{-10}\ \text{watts}.$$

V. Conclusion

We have shown agreement between theory and experiment, a discrepancy of 2 db remaining. The essential data for the computation of theoretical output power are two power input values, three cavity Q's, three reflection coefficients, and one value of line width. A very rough estimate of the sources of error in the above-mentioned quantities and in the measurement of the actual output power suggests an over-all uncertainty of about ±4 db. On the basis of this agreement between theory and experiment, we can claim support for the validity of the theory outlined in Section III. As stated in connection with both the low-frequency analog and the detailed theory of the effect, the theoretical treatment of the present experiment is very similar to the treatment of the Suhl amplifier/oscillator. The resemblance is so close that the theory of both conditions may well be regarded as being supported by the present experimental results.

VI. Acknowledgment

The yttrium iron garnet crystals used in this work were grown by J. W. Nielsen and the samples cut by P. M. Ness. H. Suhl provided the basis for the present study, and much encouraging interest in its course.

A Mathematical Analysis of the Kahn Compatible Single-Sideband System*

JOHN P. COSTAS†, SENIOR MEMBER, IRE

Leonard Kahn's comments on the following paper appear in a letter to the Editor on page 1429 of this issue.—*The Editor.*

Summary—A system has been proposed by Kahn for the generation of an SSB signal which may be received on an AM receiver without distortion in the receiver output signal. For this reason, the system is said to be a "compatible" SSB system. The mathematical analysis of this system is fairly simple except for that part of the circuit which performs a limiting of the input full-carrier SSB signal. It is shown that Granlund has analyzed circuits of this type in great detail and that the results of Granlund's work can be used in a very direct manner to obtain a fairly complete analysis of the Kahn system. From the resulting analysis, computations are made of the CSSB signal spectra for various input signal conditions. The theoretical results are also used to predict certain system operating characteristics. The results obtained are presented without comment as no attempt is made to evaluate the Kahn system relative to other compatible SSB systems which have been proposed.

Introduction

In the past few years, there has been considerable discussion concerning the use of SSB in radio communications for services which at present employ other forms of modulation. For many of these services it has become apparent that the introduction of suppressed-carrier SSB transmissions would prove disruptive to normal service operation and that a transition SSB system would have to be employed, at least initially. Specifically in those services where AM is now employed, it has been argued that any SSB transmission system introduced must be capable of being received on conventional AM receivers and hence must be a compatible SSB system in the above sense of the word. At the present time, there seem to be two main schools of thought as to how this compatibility requirement may be met. One group proposes the transmission of a conventional SSB signal together with a full-carrier signal. Kahn has pointed out that such a system is only conditionally compatible since a considerable amount of distortion may result when a full-carrier SSB signal of the conventional type is received with an AM receiver. As a possible solution to this problem, he proposes a system which is said to be single-sideband and which is claimed to permit AM detection without distortion. This information is presented as background material only because the author, for rather obvious reasons, has no particular desire to enter into this controversy even in a small way.

The purpose of this paper is to present a theoretical analysis of the Kahn system which to the author's knowledge has not yet been made available to the industry. At first hand, an examination of the Kahn system appears to present a serious challenge to the mathematical analyst. However, further examination shows that the really difficult work involved in analyzing this system has already been done by Granlund[1] and that a rather simple manipulation of Granlund's results will yield a fairly complete mathematical treatment of the system.

* Original manuscript received by the IRE, September 11, 1957.
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[1] J. Granlund, "Interference in Frequency-Modulation Reception," M.I.T., Cambridge, Mass., Res. Lab. of Electronics, Tech. Rep. No. 42, pp. 39–48; January 20, 1949.

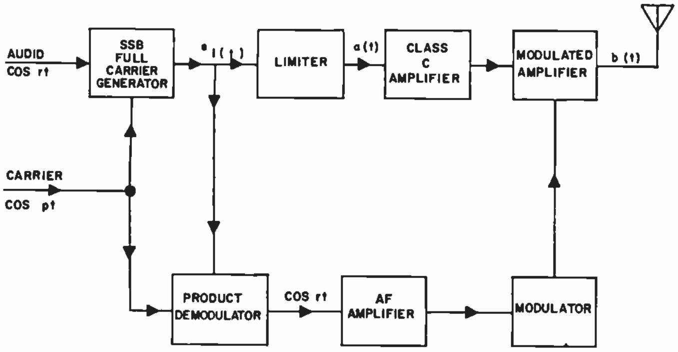
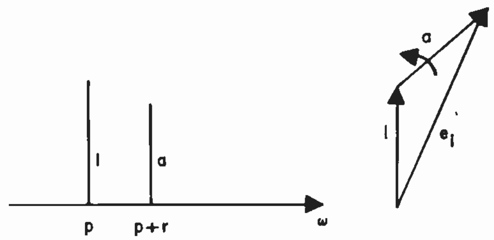


Fig. 1—Block diagram of basic Kahn compatible single-sideband system.



(a) (b)

Fig. 2—Full-carrier SSB signal frequency spectrum and phasor diagram. (a) Frequency spectrum. (b) Phasor diagram.

System Operation

The block diagram of the basic compatible SSB system as published by Kahn[2] is shown in Fig. 1. The input to this system is composed essentially of a conventional full-carrier SSB signal and a separately available carrier signal. The full-carrier SSB signal is passed through a limiter which removes all amplitude variations, but retains the phase information of the original signal. This limited signal is then used as the input for a class-C amplifier which drives the modulated amplifier in the normal manner associated with AM transmitters. The full-carrier SSB signal and the carrier signal are also combined in a product demodulator to obtain the audio signal which is subsequently amplified for the purpose of driving the AM modulator. The modulated amplifier is driven at the rf input by the limited SSB signal, and at the audio input by the original audio signal. The output wave of this system will have an amplitude variation proportional to the original modulating voltage and it will have an rf phase variation as dictated by the limiter action on the original full-carrier SSB signal. By this process, it is claimed that the output signal is compatible with an AM receiver and at the same time is single-sidebanded. It will be our purpose in the next section to analyze the idealized system of Fig. 1 in order to determine the exact nature of the signal which is generated.

System Analysis

Before considering the mathematical details, a few rather obvious questions and deductions are forthcoming from some very simple physical reasoning. Fig. 2 shows the frequency spectrum and phasor diagram of a full-carrier SSB signal having a carrier amplitude of unity and a sideband amplitude of a volts. The diagram, of course, assumes that the modulating signal is sinusoidal. An examination of the phasor diagram reveals that the envelope of the resultant SSB signal (which is equal to the magnitude of the resultant vector e_i) will not vary sinusoidally in time if the sideband amplitude a approaches the carrier amplitude. Precisely for this reason a conventional full-carrier SSB signal produces distortion in the output of an AM receiver since an AM detector responds only to the magnitude of e_i. On the other hand, it is rather obvious from an examination of Fig. 1 that the Kahn system will produce a compatible signal since the amplitude variations of the output signal of Fig. 1 must follow precisely the input audio variations. Thus, we are faced with a temporary dilemma. We have shown that a true SSB signal as presented in Fig. 2 cannot possibly be compatible, yet we observe that the output signal of Fig. 1 is necessarily compatible by virtue of the amplitude modulation process employed. Hence, we arrive at a very simple conclusion: *The output spectrum of the CSSB system of Fig. 1 must contain frequencies in addition to those shown in Fig. 2(a), and it is these additional components which render the CSSB system compatible.* This much is very clear since without these additional components the spectrum of the CSSB signal would be that of Fig. 2(a) which represents a signal shown to be incompatible, especially for values of a approaching unity. Since we have now determined that the CSSB signal cannot possibly be a single-sideband signal in the strict sense of the term, we must analyze the CSSB system in detail to determine the magnitudes of the additional components and their frequency locations.

Referring now to Fig. 1, we shall assume a sine wave of audio input and, consequently, there will result at the input to the limiter a signal given by

$$e_i(t) = \cos pt + a \cos (p + r)t. \qquad (1)$$

The output of the limiter will be designated for the present simply as $a(t)$ and much more work will be done on this function at a later time. When $e_i(t)$ and the carrier term $\cos pt$ are combined in the product demodulator, the output of this demodulator will be $\cos rt$ as shown in Fig. 1. The output signal of the CSSB system $b(t)$ will be given by

$$b(t) = (1 + k \cos rt)a(t) \qquad (2)$$

which is merely the mathematical formulation of the amplitude modulation process. The term k in (2) represents the percentage of amplitude modulation and, as

[2] L. R. Kahn, "A compatible single-sideband system," presented at Second Annual Symposium on Aeronautical Communications, Utica, N. Y.; October, 1956. Published as a part of ARINC-AEEC Letter No. 57-1-3; November 5, 1956.

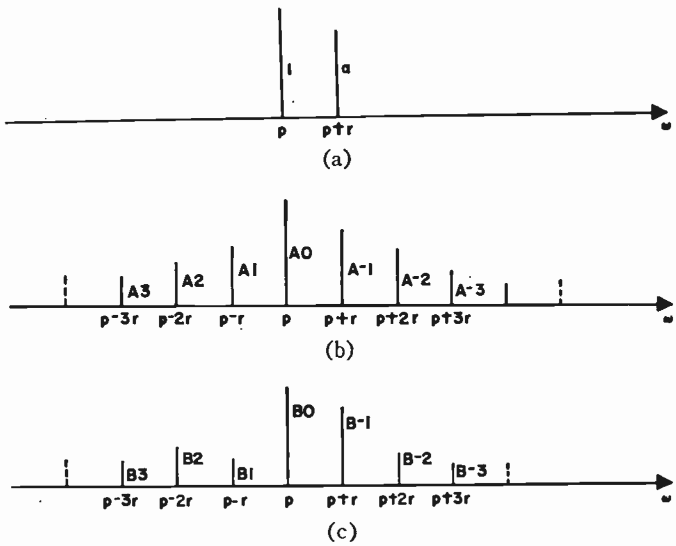


Fig. 3—Spectra associated with limiter and modulator action. (a) Limiter input spectrum. (b) Limiter output spectrum. (c) Modulated amplifier output spectrum.

will be shown, this term must be adjusted for lower sideband cancellation. The real difficulty which will be encountered in this analysis will be the determination of $a(t)$ which results from the limiter action on $e_i(t)$. Fortunately, Granlund has solved this problem for us and he shows that $a(t)$ will be given by

$$a(t) = \sum_{n=-\infty}^{\infty} A_n \cos (p - nr)t. \tag{3}$$

The diagrams shown in Fig. 3 illustrate very clearly the action of the limiter and Granlund's expression. Note that only two frequencies are present at the input to the limiter, p and $p+r$. The output of the limiter, on the other hand, contains many additional frequency components which are grouped about the carrier frequency p and separated from each other by the modulating frequency r. The amplitudes of these terms are given by the A_n's which Granlund has tabulated to ten-place accuracy. The A_n's are functions of both n and a, the input sideband-to-carrier ratio.

We may now write the expression for the CSSB output signal by combining (2) and (3) to obtain

$$b(t) = (1 + k \cos rt) \sum_{n=-\infty}^{\infty} A_n \cos (p - nr)t. \tag{4}$$

By combining terms in (4), and using some simple trigonometric identities, we obtain finally an expression for the output signal

$$b(t) = \sum_{n=-\infty}^{\infty} B_n \cos (p - nr)t \tag{5}$$

where

$$B_n = A_n + \frac{k}{2} (A_{n-1} + A_{n+1}). \tag{6}$$

The spectrum associated with (5) is sketched in Fig. 3(c). We notice that the amplitude modulation process has not resulted in the generation of new frequencies, but rather has served to modify the magnitudes of the frequency components of the limiter output spectrum which serve as the rf input to the modulated amplifier. Eq. (6) shows how the limiter output spectrum is modified by the amplitude modulation process and represents the key to the operation of the Kahn system. Note that the amplitude of any particular component, B_n, of the system output spectrum is influenced by the corresponding frequency component at the limiter output plus the two immediately adjacent components in the limiter output. Note further that the contribution of these adjacent components is directly proportional to the depth of amplitude modulation factor k. A brief consideration of the mathematical significance of amplitude modulation will reveal very quickly that (6), relating the B_n's and the A_n's, is precisely in the form that would be expected.

An examination of (6) and Fig. 3 indicates that if the lower sideband is to be suppressed, the factor B_1 must be equal to zero. This condition yields at once

$$k = \frac{-2A_1}{A_0 + A_2} \tag{7}$$

which is the percentage of amplitude modulation necessary for lower sideband cancellation. Since the A terms of (7) are functions of the input sideband-to-carrier ratio a, we note that the depth of modulation will be a function of this same factor a. Clearly, if k is a linear function of a, this system will not be level sensitive. However, if k is not a linear function of a, this system will be level sensitive, at least to some degree. We shall have more to say about this situation later, but it should be kept in mind that if the lower sideband is to be completely cancelled, k must be adjusted to the value given in (7).

If we now assume that under all conditions the system is adjusted for complete cancellation of the lower sideband, we may derive the following equations:

$$B_0 = A_0 + \frac{k}{2} (A_{-1} + A_1) \text{ carrier} \tag{8}$$

$$B_{-1} = A_{-1} + \frac{k}{2} (A_{-2} + A_0) \text{ upper sideband} \tag{9}$$

$$B_{-2} = A_{-2} + \frac{k}{2} (A_{-1} + A_{-3}) \text{ first upper spurious, etc.} \tag{10}$$

$$B_2 = A_2 + \frac{k}{2} (A_1 + A_3) \text{ first lower spurious} \tag{11}$$

$$B_3 = A_3 + \frac{k}{2} (A_2 + A_4) \text{ second lower spurious, etc.} \tag{12}$$

Eq. (8) gives the output carrier amplitude while (9) gives the amplitude of the desired upper sideband term. If k is adjusted as indicated by (7), then the lower sideband term would be zero and hence is not tabulated in the list. The remaining above equations give the magnitudes of the various upper and lower spurious components. These components are spurious in the sense that they do not belong to a true single-sideband signal but they are very necessary in the CSSB system in order that the output wave have an envelope which may be detected with an AM receiver without distortion. Thus, these additional terms are spurious in the true single-sideband sense only.

Results

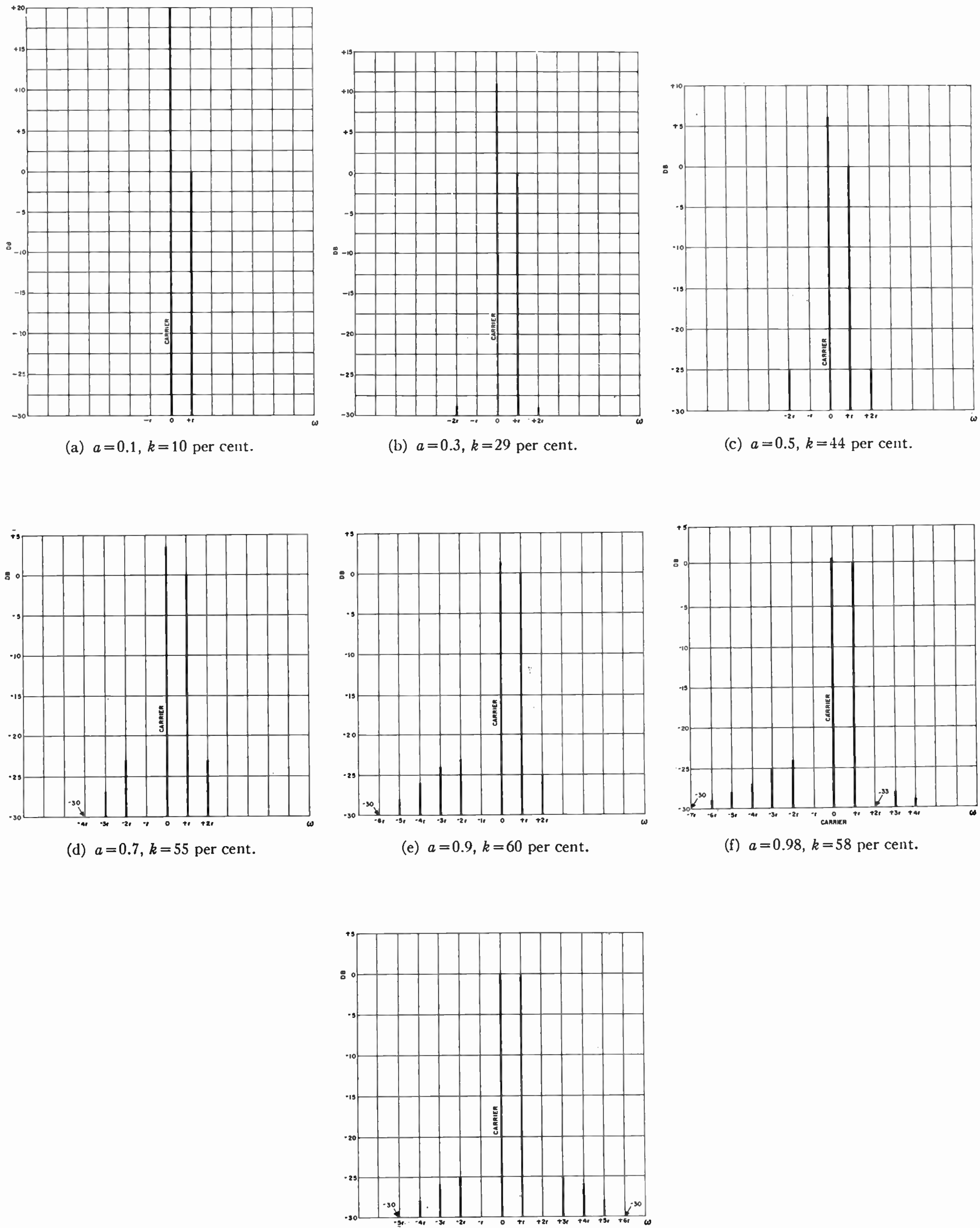
The above equations were used in conjunction with the ten-place tables provided by Granlund to compute the spectral magnitudes of the CSSB signal for various values of a, the input sideband-to-carrier ratio. For each value of a, the modulation factor k was calculated and then used to compute the various B_n's. Spectral diagrams were then drawn for each case calculated using the upper sideband as reference level. Spectral components which were greater than 30 db below the desired sideband were not considered. These spectral plots may be found in Fig. 4(a) through 4(g), next page. Starting in Fig. 4(a) with a equal to 0.1, there are no spurious components above the -30-db level. A little thought will show that when the sideband is small compared to the carrier, these two terms alone form essentially a compatible signal and there is almost no need for additional terms. Turning now to Fig. 4(b) which is drawn for an a of 0.3, we note the appearance of two spurious terms, one above and one below the carrier frequency, each being 29 db below upper sideband level. Here again, the carrier is large compared to the sideband (plus 11 db) so that relatively small additional signals are apparently all that are needed to produce a compatible signal. In Fig. 4(c), drawn for an a of 0.5, there are still only two spurious components, but these have increased in value to -25 db. In Fig. 4(d) and 4(e), drawn for an a of 0.7 and 0.9, respectively, we note the appearance of higher amplitude spurious terms along with a larger number of them which become necessary to the signal as the upper sideband amplitude approaches the carrier amplitude. In Fig. 4(f), drawn for an a of 0.98, we note the appearance of five lower spurious terms and two upper spurious terms. This trend is what would normally be expected; however, it is to be noted that the percentage of amplitude modulation required for lower sideband cancellation has now dropped from 60 per cent at an a of 0.9 to 58 per cent at an a of 0.98. This strange behavior of the modulation factor k was carefully checked in two ways. First, k values for intermediate a values in the vicinity of a of 0.9 were computed, and the results seemed to indicate that the k factor definitely reached a peak and then began decreasing for increasing a. As a second check, the case for equal input sideband-to-carrier ratio ($a=1$) was computed by a completely new method. The details of this computation need not be given here except to mention that under this condition, the input to the limiter is a DSB (suppressed-carrier AM) signal of center frequency $p+r/2$ which makes the calculation of the limiter output spectrum fairly simple. The CSSB spectrum and modulation factor k for $a=1$ were thus calculated independently and the results are shown in Fig. 4(g). The percentage modulation was 55.5 for this case which again confirmed the strange behavior of k vs a. In comparing Fig. 4(f) and 4(g), note that some of the lower spurious in Fig. 4(f) have diminished in magnitude and have been replaced by stronger upper spurious terms. The spectrum of Fig. 4(g) is symmetric as expected for this particular case.

One of the more interesting results of this analysis seems to be the behavior of the modulation factor k as a function of a, the input sideband-to-carrier ratio. A plot of this relationship is shown in Fig. 5, from which it appears that the maximum AM modulation permissible if the lower sideband is to be completely eliminated is about 60 per cent. To further verify this situation, calculations for k were made for values of a exceeding unity and the downward trend of k was again substantiated. The calculations necessary for values of a greater than unity require special manipulations of Granlund's data which need not be discussed here. The spectra resulting for a values greater than unity were not calculated because it was felt that no purpose would be served in operating the system at values of a exceeding 0.9. In order to understand why the percentage of modulation behaves in this peculiar way, the process of sideband cancellation employed in the CSSB system as expressed by (6) should be kept in mind. Since cancellation of the lower sideband depends upon the modulation percentage and the spectral situation at the output of the limiter, it is not too surprising that k behaves as it does since the limiter output spectrum varies in a very complicated manner with increasing a. Thus, it should be expected that k should also vary in a somewhat complicated manner with increasing a.

On the basis of the above analysis and calculated results, we can predict a few operating characteristics of the CSSB system. The system will be level sensitive at least to some degree for values of a below 0.9. This means that if the input sideband voltage is raised relative to the carrier, a readjustment of system audio gain will be necessary in order to restore lower sideband suppression. If the input sideband-to-carrier ratio exceeds 0.9, the system will definitely show a need for audio gain readjustment as is obvious from the curve in Fig. 5. Thus, it would appear that the input sideband-to-carrier ratio should be kept below 0.9, and for good sideband suppression should be preferably below 0.6 in order to stay in the linear portion of the curve of Fig. 5. This would indicate that the modulation percentage should be limited to 50 or 60 per cent at maximum. Again we may predict, from a theoretical point of view at least, that for modulation percentages above 60 per cent, the lower sideband cannot be completely eliminated.[3]

A second prediction which might be made from these results is, of course, that there are spurious components generated even in an ideal CSSB system. For values of a in the neighborhood of 0.9, it appears that the majority of dominant spurious components fall below the carrier frequency. This might possibly give the appearance in actual operation using low audio frequency modulation that the CSSB signal has a "vestigial" side-

[3] A calculation was made for a equal to 0.9 and 1.0 at 100 per cent modulation. The lower sideband was found to be suppressed only 13 to 14 db relative to the upper sideband under this condition.



(a) $a=0.1$, $k=10$ per cent.

(b) $a=0.3$, $k=29$ per cent.

(c) $a=0.5$, $k=44$ per cent.

(d) $a=0.7$, $k=55$ per cent.

(e) $a=0.9$, $k=60$ per cent.

(f) $a=0.98$, $k=58$ per cent.

(g) $a=1.0$, $k=55.5$ per cent.

Fig. 4—CSSB signal spectra for various sideband-to-carrier ratios.

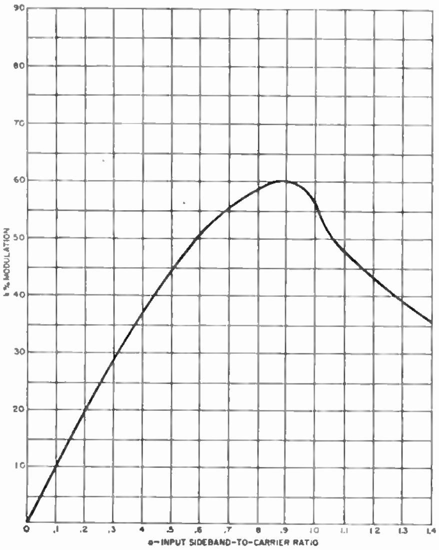


Fig. 5—Per cent AM modulation required for lower sideband cancellation vs input sideband-to-carrier ratio.

band. It can be seen however, that this vestigial effect is quite different from that encountered in normal vestigial-sideband systems. For example, for an a of unity the vestigial effects are equally distributed above and below the carrier frequency.

Conclusions

As was pointed out earlier, the author is aware of the current controversy concerning the various types of compatible single-sideband systems. This paper was written because it was felt that a theoretical analysis of the Kahn system might prove of some interest and use to those in the industry concerned with these matters. Consequently, nothing which has been written in this paper should be construed as either an endorsement or criticism of the Kahn system. The author is in no position to decide whether or not the system is applicable in any specific situation. This is a matter for the user of communications and the decision must naturally be based upon many factors other than a purely mathematical analysis. Thus, as far as this paper is concerned, there are no conclusions.

Perhaps a word of warning should be given at this point concerning the interpretation of the results presented. It should be remembered that a very simple (sinusoidal) modulating voltage was assumed. In a nonlinear system such as this, it can sometimes be very dangerous to extrapolate the results of a sinusoidal analysis in an attempt to cover more complicated modulating signals, such as multiple tones or voice. Secondly, it was assumed above that system adjustments were made for complete elimination of the lower sideband. The spurious signal situation could possibly be improved by an adjustment which does not completely eliminate the lower sideband. Calculations for this situation were not performed but there is sufficient material presented in this paper to permit an investigation of this situation in a very straightforward manner if so desired. Finally, the system assumed was an ideal one. The results in practice could very easily be considerably different from the results presented here.

Investigation of Long-Distance Overwater Tropospheric Propagation at 400 MC*

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Summary—**The results of an investigation of overwater tropospheric propagation under both summer (July, 1955) and winter (February, 1956) conditions are presented. Transmissions were from a point on the south shore of Massachusetts, near New Bedford, to a ship traveling along great circle courses to a maximum distance of 630 nautical miles (724 statute miles) from the transmitter.**

A 10-kw, 385.5-mc transmitter feeding a 28-foot paraboloid antenna was used for the summer phase. For the winter investigation, this same facility was used, supplemented by a 40-kw transmitter feeding a 60-foot paraboloid for use at the greater distances. The frequency used for the winter was 412.85 mc. The receiving antenna aboard the ship was a 17-foot paraboloid for both series of tests. All antennas were horizontally polarized and approximately 100 feet above sea level.

The data obtained are presented to show the median path loss vs distance. The strip chart recordings of the received signal levels were analyzed with respect to fading characteristics in an effort to separate out those transmissions which were enhanced by superrefractive conditions. The fast fading signals, which were well represented by the Rayleigh distribution, were assumed to be unaffected by superrefractive conditions. The data for the fast-fading Rayleigh type signals appear to show a cyclic variation of the attenuation rate with distance although there is no substantial deviation from a linear rate of between 0.16 and 0.18 db per nautical mile.

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Introduction

SINCE about 1947, when high-powered transmitters and more sensitive receivers became available, many experimental studies of beyond-horizon tropospheric propagation have been made.[1-3] None of the work, however, embraced studies of surface-to-surface overwater paths at distances out to five or six hundred miles.[4]

In 1952 the Naval Research Laboratory initiated an experimental program designed to determine in what manner overwater results might differ from those obtained over land. In 1953 and 1954 some preliminary investigations were made by receiving aboard a small naval vessel on path lengths out to about 130 miles. This work indicated the desirability of more extensive studies. The M.I.T. Lincoln Laboratory had been making overland studies at frequencies of about 400 mc and had the necessary suitable transmitting facilities located on the south shore of Massachusetts, ideally situated for transmissions seaward. In 1955 a cooperative project was established between NRL and Lincoln for some investigations covering both summer and winter conditions and using a naval vessel as the receiving terminus.

This paper will be confined to the results obtained during this cooperative project which covered a two-week period in July, 1955 and three weeks in February, 1956. Unmodulated transmissions emanating from the installation at Round Hill, Mass. were continuously recorded aboard the receiving ship, using both graphic and level distribution recorders. The data have been analyzed to show the hourly median path loss vs distance. An analysis of the fading characteristics is also given in an attempt to separate the data that were believed to have been enhanced by superrefractive conditions. Probability distributions of the signal level for representative samples taken at various distances and for signals with different fading characteristics are also given.

Transmitting Facilities

The transmitting facilities were located at the M.I.T. Round Hill field station near New Bedford, Mass. During July, 1955 a continuous-wave 10-kw, 385.5-mc transmitter was used with a 28-foot paraboloid antenna 95 feet above sea level. During February, 1956 the same transmitting facilities, tuned to 412.85 mc, were used, supplemented by a 40-kw, 412.85-mc transmitter with a 60-foot paraboloid 113 feet above sea level for use at the greater distances. The calculated gains of the various antennas and other data are given in Table I. Both antennas were horizontally polarized and had unobstructed views of the horizon when directed over the paths used. A map showing the area involved and the paths used is given in Fig. 1. The choice of paths was determined by local obstructions at the transmitting site and convenience in scheduling the movements of the ship.

TABLE I
System Parameters

Transmission Frequency	385.5 mc.	412.85 mc
17-ft Shipboard receiving antenna		
Gain over isotropic (calculated)	24.2 db	24.8 db
Gain over isotropic (measured)	21.5 db	23.0 db
Height above sea level	95 ft	92 ft
Transmission line loss (approx)	1 db	1 db
Effect of superstructure	2 db	5 db
28-ft Transmitting antenna		
Gain over isotropic (calculated)	28 db	29 db
Height above sea level	95 ft	95 ft
Transmitter power	10 kw	10 kw
Transmission line loss	negligible	negligible
Effective radiated power	6.3 mw	8 mw
60-ft Transmitting antenna		
Gain over isotropic (calculated)		35 db
Height above sea level		113 ft
Transmitter power		40 kw
Transmission line loss		1 db
Effective radiated power		100 mw

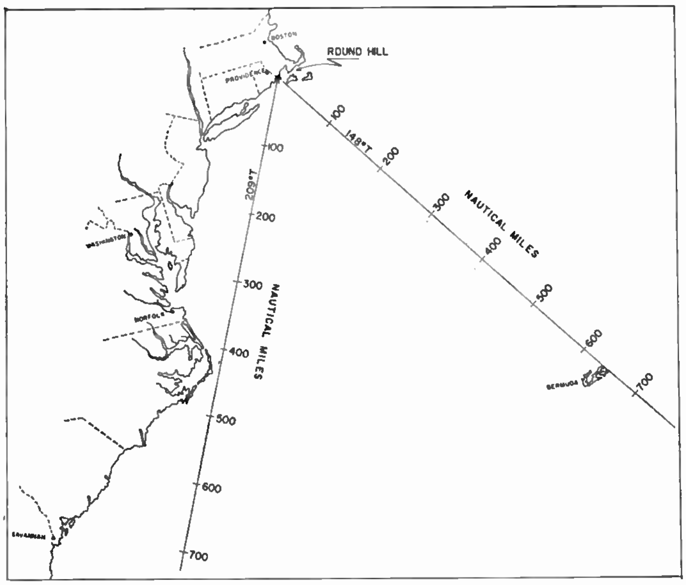

Fig. 1—Map showing transmission paths.

Receiving Installation

The receiving installation was very similar for both the summer and winter phases of the investigation, although two different ships of the same type were actually used. The antenna was a 17-foot paraboloid, directionally controlled from the ship's gyro, and mounted on the after quadrapost (Fig. 2). The beam was unobstructed by the ship's superstructure except when di-

[1] M. Katzin, R. W. Bauchman, and W. Binnian, "3- and 9-centimeter propagation in low ocean ducts," Proc. IRE, vol. 35, pp. 891–905; September, 1947.

[2] E. C. S. Megaw, "Scattering of electromagnetic waves by atmospheric turbulence," *Nature*, vol. 166, pp. 1100–1104; December, 1950.

[3] I. H. Gerks, "Propagation at 412 megacycles from a high-power transmitter," Proc. IRE, vol. 39, pp. 1374–1382; November, 1951.

[4] During the course of the work covered in this paper, the "Scatter Propagation Issue" (Proc. IRE, vol. 43; October, 1955), was published. The papers presented in that issue along with their bibliographies form a comprehensive reference in this field.

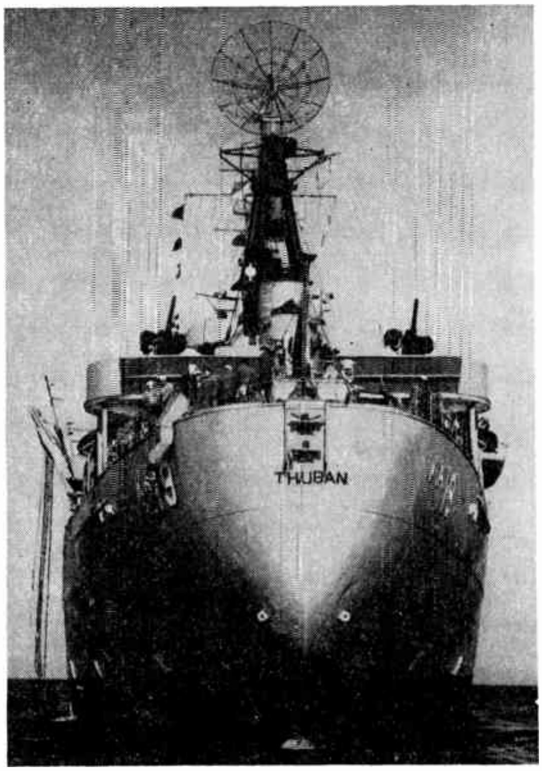

Fig. 2—Stern view of ship used as the receiving terminus showing the 17-foot paraboloid antenna used for the propagation tests.

rected within a small sector (about 10°) over the bow. For practically the entire time that signals were being recorded, the ship was so oriented with respect to the transmitter that the antenna was directed over the bow or the stern. When directed over the bow, the signal level was affected by the superstructure. The magnitude of this effect was measured both within and beyond the horizon and was taken into account in evaluating the true signal levels. The signal loss due to the superstructure and the antenna gains for both frequencies are given in Table I. The measured gain of the receiving antenna was used in computing the path loss.

A block diagram of the receiving and recording equipment is shown in Fig. 3. A photograph of the shipboard installation except for the level distribution recorder is presented in Fig. 4. The signal level was continuously recorded on two Esterline-Angus strip chart recorders; one operated with a chart speed of $\frac{3}{4}$ of an inch per minute, and the other at 3 inches per hour. The slower speed recorder, the circuit of which had a time constant of approximately 10 seconds, was used primarily for continuously recording a level from which the median could be readily estimated. The circuitry of the faster recorder had a short time constant so that the fading rates and magnitudes of the received signal were reasonably well reproduced, and these charts were used to categorize the received signals as to their fading characteristics. At selected intervals the signal level was also recorded on a high-speed Edin recorder which, along with its circuitry, was capable of following fading rates in excess of 60 per second. The probability distributions

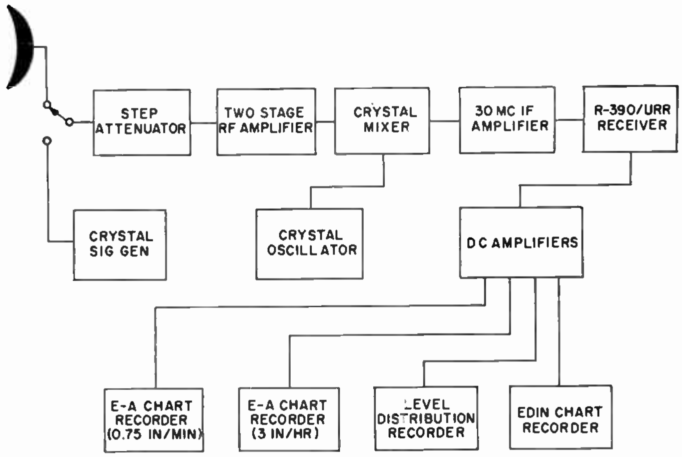

Fig. 3—Block diagram of the signal level measuring and recording system.

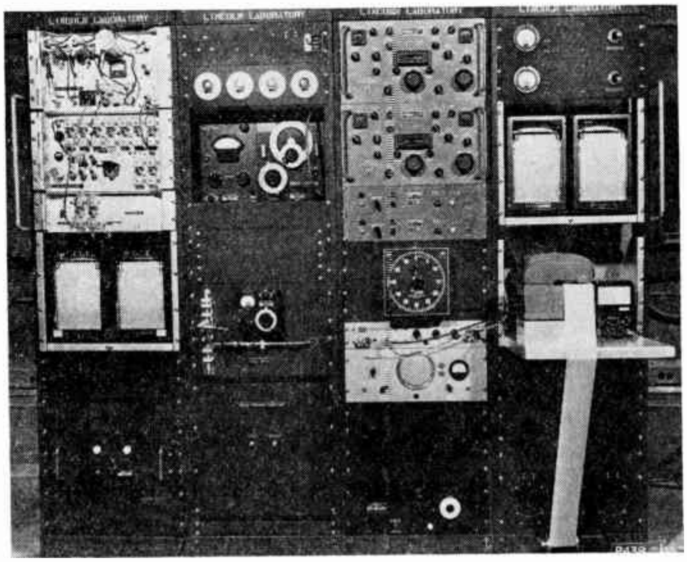

Fig. 4—Signal level recording equipment installed on ship.

of the signal levels were determined by the use of a ten-channel level distribution recorder (LDR) which was normally operated for 50-minute sampling periods.

The receiving system was so sensitive that an input of −138 dbm (db above 1 mw) was detectable on the strip charts. This input was equivalent to 0.028 μv across the 50-ohm input of the receiver.

Data Analysis

In analyzing the results, the LDR data were used to determine the median signal levels and were checked against the slow speed E-A chart recordings. The medians were generally determined over periods of 50 minutes to one hour except when significant changes in the signal were observed. The speed of the ship was such that the change in distance produced relatively small changes in the signal level over a period of one hour when well beyond the horizon.

The prime objective of these investigations was to determine the attenuation of the tropospheric scatter propagated signal with distance. (In using the term "scatter" it is not intended to infer a particular mechanism for this mode of propagation.) It is well established that signals on frequencies in the range of those used in this study are often enhanced by superrefractive conditions. If signal level measurements of signals so affected were averaged in with those for scatter propagated signals, the results would be very optimistic, particularly for comparatively short-time studies. It is difficult under most conditions to separate accurately the true scatter signals from those enhanced by superrefractive conditions. The fading characteristic, however, appears to be indicative of the type of propagation conditions existing over the path. The scatter-type signals are associated with rapid fading, usually with total excursions of 10 to 20 db or more. Signals enhanced by superrefractive conditions are relatively steady with possibly an occasional slow, deep fade. The signal-level data were categorized, therefore, according to type of fading of the signal received during each particular period; the high-speed ($\frac{3}{4}$ inch/min) E–A charts were used for this.

The fading characteristics of the received signals were divided into three groups: fast fading, slow fading, and relatively steady signals. This grouping is rather arbitrary and the recordings often showed characteristics intermediate to the three types, but for simplicity in reporting all data have been categorized into one of the three general groups. The fast fading type is indicative of the scatter signal, while the relatively steady type appears to be the result of superrefraction, and in general is associated with a higher signal level. The slow—often called roller—type of fading appears to be an intermediate condition to the other two. Photographs of portions of E–A charts showing each type are presented in Fig. 5.

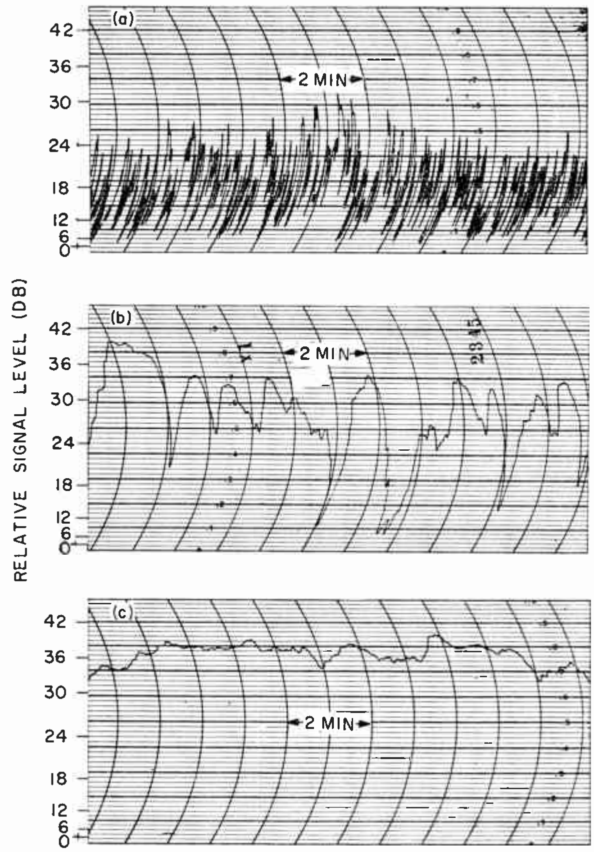

Fig. 5—Esterline-Angus recordings showing the three general types of fading of the received signal well beyond the horizon; (a) fast fading, (b) slow fading, (c) relatively steady.

Signal Levels

Particular emphasis will be placed on the results of the winter investigation, with comparisons made with the summer results. More hours of data were obtained during the winter tests, with much less of the data affected by superrefractive conditions than during the summer. The data are given in terms of "path loss" which can be calculated from

$$L_p = 10 \log_{10} \left(\frac{P_t}{P_r}\right) + G_t + G_r, \qquad (1)$$

where L_p is the path loss in db, P_t is the power available for radiation from the transmitting antenna, P_r is the received signal power, and G_t and G_r are the gains of the transmitting and receiving antennas, respectively, over an isotropic radiator. The path loss used herein is, therefore, that which was measured between the two antennas approximately 100 feet above sea level and is not the loss between the two horizons. The path loss in free space, L_{pf}, can be determined from

$$L_{pf} = 37.81 + 20 \log_{10} D + 20 \log_{10} f_{mc} \qquad (2)$$

where D is the distance in nautical miles between the isotropic antennas, and f is the frequency expressed in megacycles.

The February, 1956 data are plotted in Fig. 6 which shows the results obtained on each trip of the ship. GMT date-time groups for the data at the beginning and end of each trip are given; the first two numbers are the date in February except for the first point which was on January 31. Each point plotted is, in general, the median path loss over a period of 50 minutes. The data recorded while the receiving antenna beam was partially obstructed by the ship's superstructure are shown as solid symbols. The effect of this obstruction, which was measured in both the near and scatter fields to be 2 and 5 db for the summer and winter tests respectively, was taken into account in determining the true path loss. (The difference was due to different physical arrangement rather than season.) Each point plotted in Fig. 6 is also coded as to the fading characteristic of the received signal (Fig. 5) during the sampling period. The receiving antenna was a 17-foot paraboloid in all instances, but the transmitting antenna was either a 28-foot or a 60-foot paraboloid as indicated on the graphs.

All the winter data (median path loss vs distance) from Fig. 6 are combined in Fig. 7 with no designation of the fading characteristics of the signals. Of the 218 hours

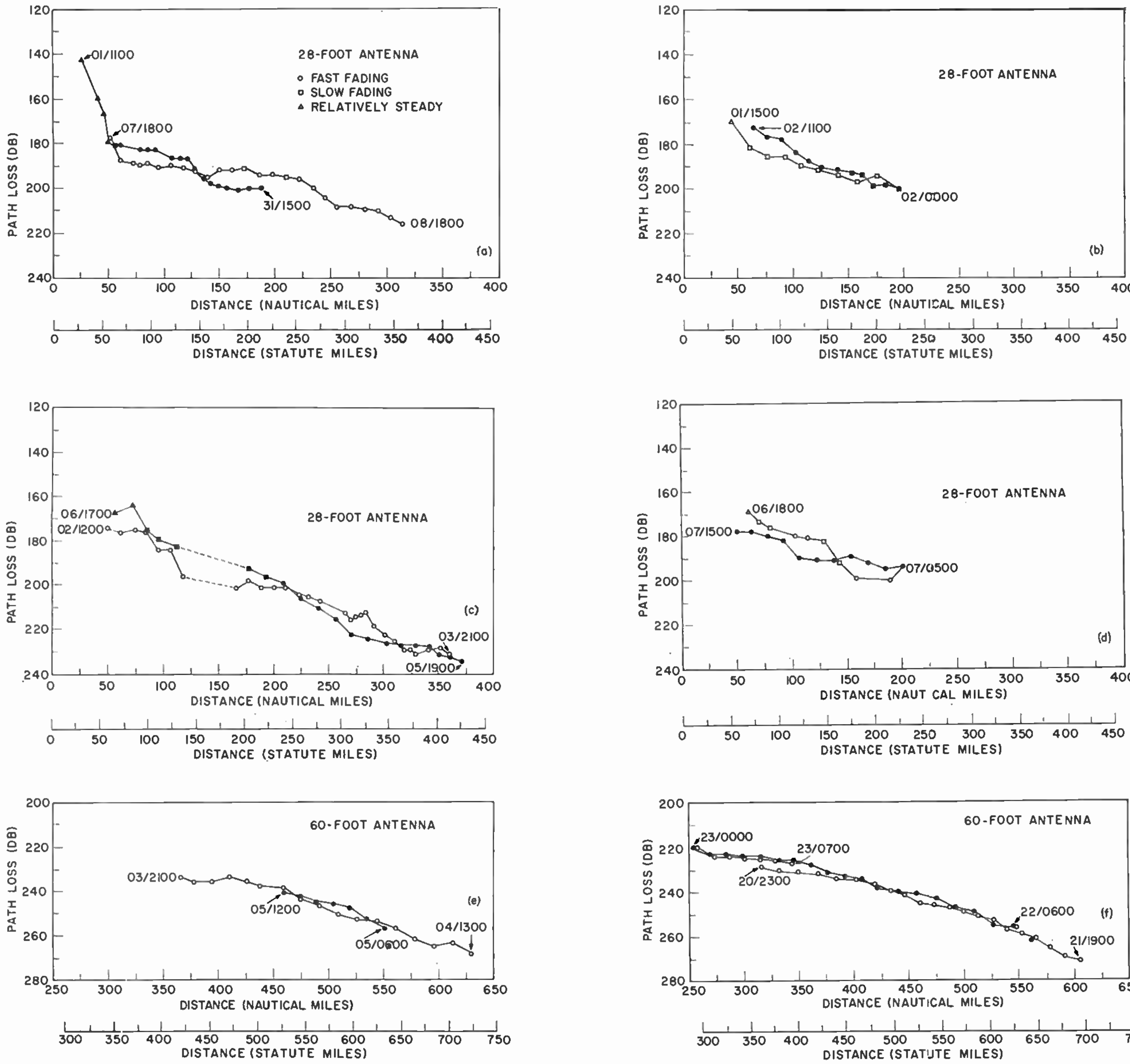

Fig. 6—Median path loss as a function of distance for the individual runs of the ship during the winter measurements.

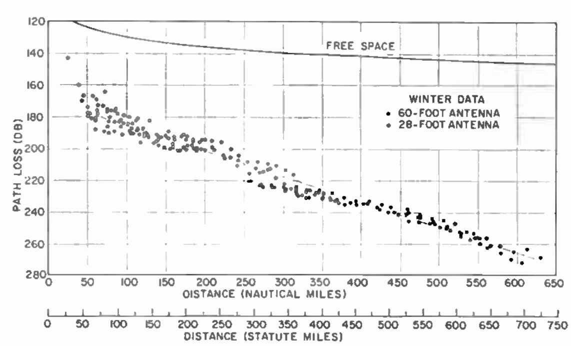

Fig. 7—Median path loss as a function of distance showing all winter data. The dashed line has a slope of 0.16 db per nautical mile.

of data presented in Fig. 7, 198 hours were at distances greater than 75 miles. Unless otherwise stated, all distances will be expressed in nautical miles. At no time during these 198 hours did the received signal show signs of being enhanced by superrefractive conditions by having a relatively steady fading characteristic [Fig. 5(c)], and 87 per cent of that time the signal was of the fast fading type [Fig. 5(a)]. The use of open and solid symbols in Fig. 7 denotes which transmitting antenna was being used, the 28- or 60-foot paraboloid. The grouping of the data from both antennas in the overlapping region between 250 and 375 miles suggests that there was little, if any, loss in gain of the 60-foot antenna over the 28-foot antenna. Only once during the tests were the two transmitting facilities switched instantaneously and at that time the calculated gain difference of the two antennas was realized; this was at a distance of 365 miles. Also, other work by Lincoln Laboratory[5]

[5] J. H. Chisholm, W. E. Morrow, J. F. Roche, and A. E. Teachman, "Tropospheric path loss measurements at 400 mc over distances 25–830 miles," paper presented at WESCON, San Francisco, Calif.; August, 1957.

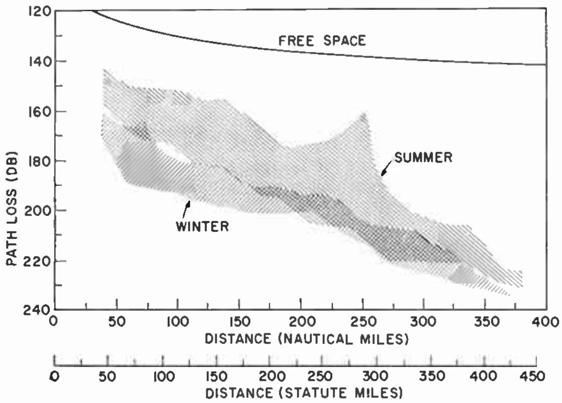

Fig. 8—Median path loss as a function of distance showing the relative magnitude and spread of summer and winter data.

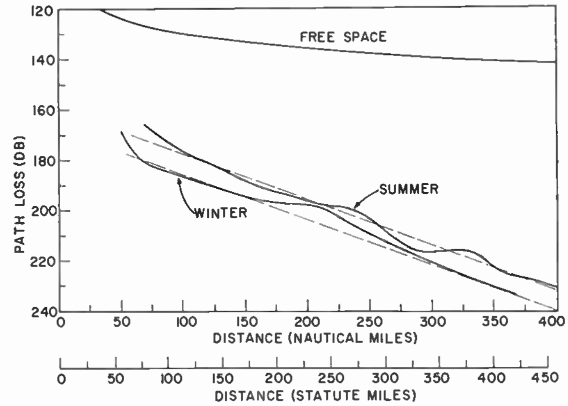

Fig. 9—Average median path loss as a function of distance for the summer and winter data after eliminating all data believed to have been enhanced by superrefractive conditions.

has shown that, on the average, the calculated gains of paraboloid antennas up to 60 feet in diameter are realized in beyond-horizon tropospheric propagation.

A straight, dashed line has been drawn approximately through the average of the points in Fig. 7. This line represents a linear attenuation of signal level with distance equal to 0.16 db per nautical mile or about 0.14 db per statute mile. It can be seen that the path loss is roughly linear with distance. However, there is a definite cyclic trend in the data with maxima at approximately 225 and 475 miles and minima at 275 and beyond 600 miles. The rate of attenuation near 600 miles appears to be increasing; whether it continues to increase beyond 630 miles or not cannot be stated, since at approximately that range the transmitted signal became undetectable on two different trips about two weeks apart. The repeatability of the data beyond 350 miles should be noted since, as can be seen in Fig. 6(e) and 6(f), the data were obtained on different trips approximately two weeks apart. The good repeatability also indicates that the different transmission paths (Fig. 1) had little effect on the results since the data given in Fig. 6(e) were taken on the 148° path while those in Fig. 6(f) were taken on the 209° path.

Fig. 8 was prepared to show the comparison of the spread in signal level in terms of path loss recorded during the winter with that obtained during the summer. Data were recorded for only 93 hours in July, 1955 while at distances greater than 75 miles. Of this time, the received signal had a fading characteristic of the fast type 38 per cent of the time, the slow type 41 per cent, and the relatively steady type 21 per cent. Average curves drawn through the summer and winter data which were believed to be unaffected by superrefractive conditions are shown in Fig. 9. The winter data include only those obtained while using the 28-foot transmitting antenna, since that was the only antenna used during the summer tests and the distance was limited to 400 miles. The linear, dashed curves also included have a slope of 0.18 db per nautical mile which fits the data better out to 400 miles than the 0.16-db slope. It can be seen that after eliminating the enhanced signals the summer data average about 8 db higher than the winter. The cyclic trend shown in the summer average curve, which shows more variation in a given distance than the winter curve, was also apparent in the data of many of the individual trips. However, the quantity of data is insufficient to allow any conclusions to be drawn.

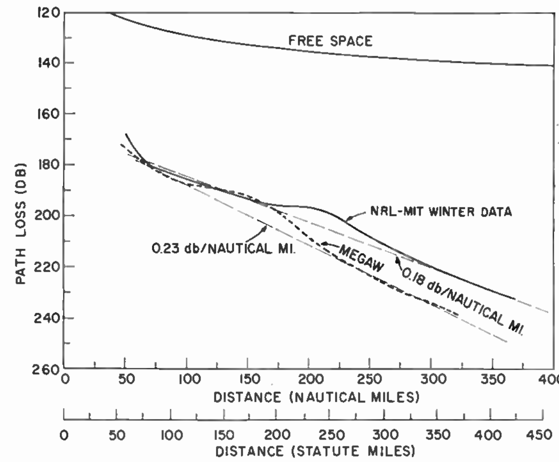

Fig. 10—Comparison of average median path loss as a function of distance with that published by Megaw.

Megaw[2] made some overwater signal level measurements at 3000 mc in the North Sea in the summer of 1949. His measurements extended over a period of two and half weeks and, in reporting the results, all data that appeared to have been influenced by superrefraction were omitted. The average curve of his data is shown in Fig. 10 along with the winter average curve given in Fig. 9. The similarity in the shapes of the two curves is very apparent although the humps occur at different distances. The average attenuation rates of the two sets of data, however, differ considerably. This may be due in part to the nearly 7-to-1 frequency difference, although Gerks,[6] in consolidating the results published by four different sources, found the loss rate to be largely independent of frequency and on the order of 0.14 db per nautical mile.

Fade Rates

The three classifications of fading previously discussed (Fig. 5) apply, in general, to most of the signal level recordings made during both phases of this investigation. However, during the winter tests, there were periods of very fast fading—much faster than the sample shown in Fig. 5(a). The received signal had this very fast fading rate for a total of 22 hours of the 198 hours of data at distances greater than 75 miles. Portions of E-A and high-speed Edin recordings made during such a period, and representing the fastest fading observed, are shown in Fig. 11. The very fast fading was observed only while at the midranges of the path, between 100 and 340 miles. The fast type of fading shown in Fig. 5(a) was observed at distances from 50 miles out to the point where the signal was undetectable (630 miles) during February, and between 75 and 400 miles in July. The February recordings did not show any of the relatively steady type of signals [Fig. 5(c)] beyond 70 miles while the July records show that type of signal existing out to 275 miles. The roller fading signals, individual fades of which were often as great as 30 db, were recorded between 50 and 200 miles in February and between 50 and 275 miles in July.

There appeared to be no correlation between fade rates and distance, and, although the fading of the transmissions from the 28-foot antenna appeared to be a little faster than those from the 60-foot antenna, the difference was slight and mostly in the small scintillations. Facilities were not available for determining the meteorological conditions of the higher atmosphere, but such information as wind, temperature, and wave height at the receiving ship were recorded. During the first two weeks of the February tests, winds greater than 20 knots were recorded 65 per cent of the time. The wind velocity often exceeded 30 knots and these conditions were prevalent throughout the path area. The fade rates of the received signal correlated well with these surface wind measurements during the February tests. It is possible that the motion of the ship and the wave motion of the sea may have had an effect on the fade rates but this could not be determined. The periods of very fast fading, however, did not correlate with the wave height, whereas it did correlate with the surface wind at the ship. The lowest wind velocity during any very fast fading period was 20 knots and generally was greater than 28 knots.

[6] I. H. Gerks, "Factors affecting spacing of radio terminals in a uhf link," Proc. IRE, vol. 43, pp. 1290–1297; October, 1955.

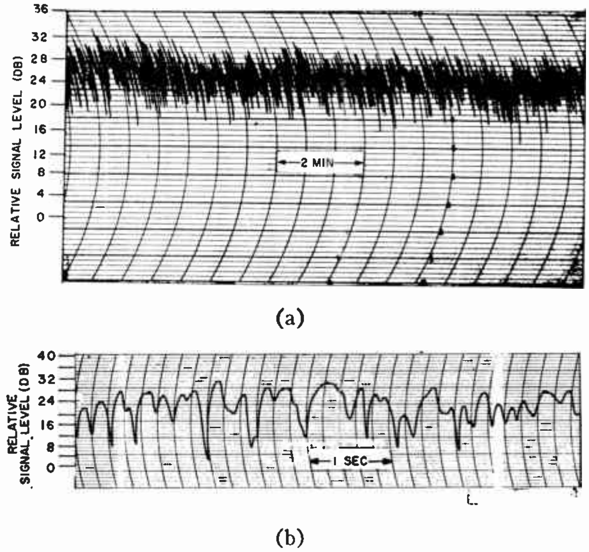

Fig. 11—Recordings of signal having the fastest fading rates observed during the winter tests; (a) Esterline-Angus recording, (b) Edin recording of a portion of the same period as in (a).

Probability Distribution

The data obtained from the LDR were plotted as cumulative probability distribution curves. It was found, as also reported by others,[7,8] that the short-time fading of the scatter propagated signals is best represented by the Rayleigh distribution. Plots of the distribution of three 50-minute sampling periods when the receiving antenna beam was unobstructed by the ship's superstructure are shown in Fig. 12. These three samples were randomly chosen from the winter data to be representative of the various types of fading and transmitting facilities. The data presented in Fig. 12(a) were for a period during which the fade rate was very fast (Fig. 11) and the 28-foot transmitting antenna was used. The data of Fig. 12(b) were for a period of fast fading illustrated in Fig. 5(a) and the 60-foot transmitting antenna was being used. The received signal was of the slow fading type [Fig. 5(b)] during the sampling period presented in Fig. 12(c). The summer data showed similar results.

The partial obstruction of the receiving antenna beam by the ship's superstructure not only reduced the received median signal level, as previously discussed, but also altered the probability distribution of the received signal level in varying degrees when at distances less than 200 miles. The LDR data taken under these conditions were plotted as a straight line on Rayleigh coordinate paper, but with slopes differing from that of a Rayleigh distribution. Slope as used here refers to the

[7] J. H. Chisholm, P. A. Portmann, J. T. DeBettencourt, and J. F. Roche, "Investigations of angular scattering and multipath properties of tropospheric propagation of short radio waves beyond the horizon," Proc. IRE, vol. 43, pp. 1317–1335; October, 1955.

[8] K. Bullington, W. J. Inkster, and A. L. Durkee, "Results of propagation tests at 505 mc and 4090 mc on beyond-horizon paths," Proc. IRE, vol. 43, pp. 1306–1316; October, 1955.

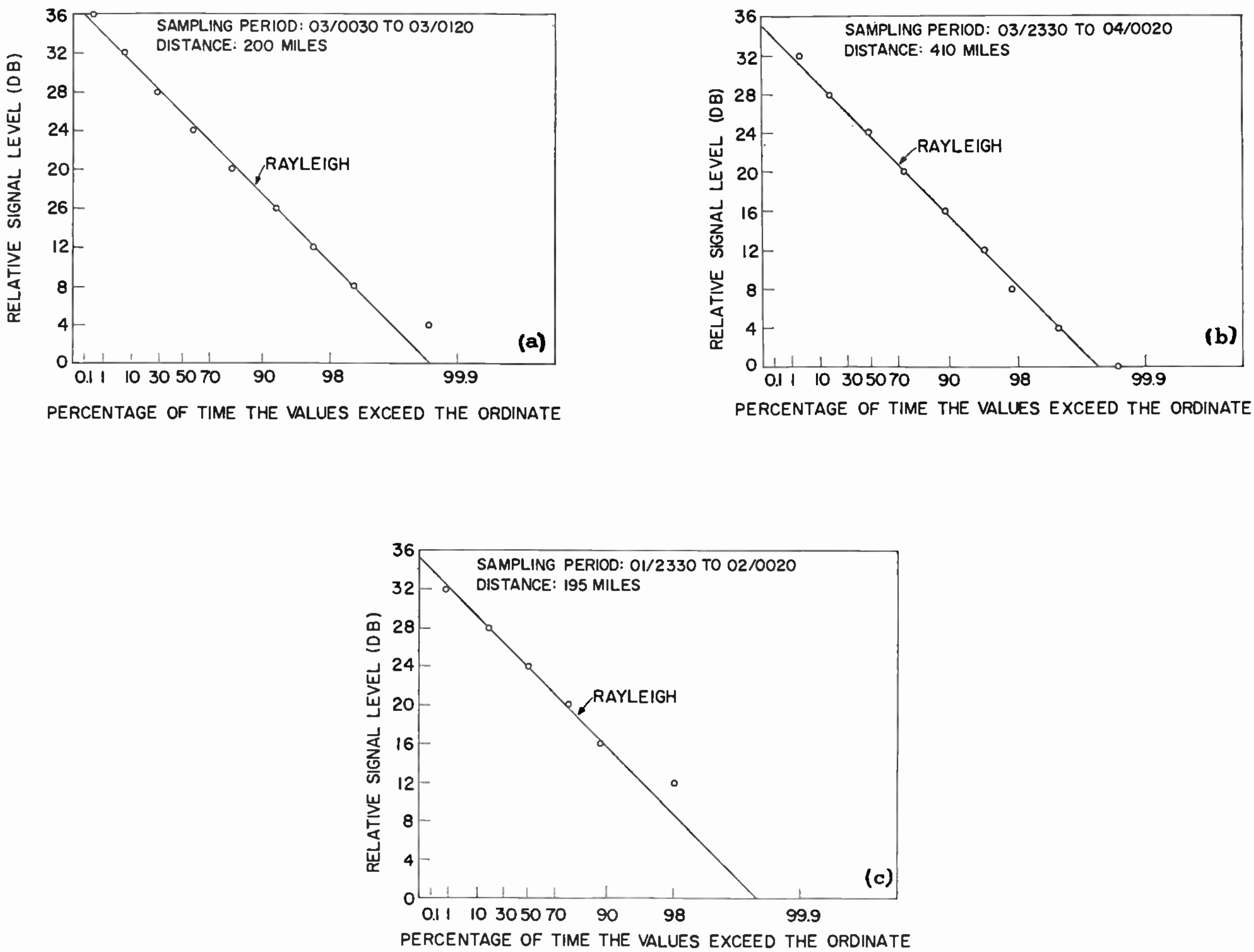

Fig. 12—Probability distribution of received signal level; receiving antenna beam unobstructed. (a) Period during which the fading rate was very fast (illustrated in Fig. 11) and the transmitting antenna was the 28-foot paraboloid. (b) Period of fast fading illustrated in Fig. 5(a) while using the 60-foot antenna. (c) Period of slow fading illustrated in Fig. 5(b).

difference in signal levels, expressed in db, exceeded 10 and 90 per cent of the time. This value is an expression for the fading range of the signal, which for a Rayleigh distribution is 13.4 db. Most of the 50-minute periods under partially obstructed conditions showed fading ranges of approximately 9.5 db when the distance was less than 200 miles (Fig. 13). For distances greater than 200 miles the fading range remained constant at the Rayleigh value of 13.4 db. Additional data are required in order to complete the picture of this interesting effect.

Sampling periods of 50-minute duration were found to be technically feasible and operationally convenient. Results reported here show that 50-minute periods gave good Rayleigh plots when receiving antenna was unobstructed, and the period had to be extended to about 2 hours before substantially deviating from Rayleigh. This differs from results reported by Chisholm *et al.*,[7] operating on higher frequencies where it was found that the sampling periods could be no longer than a couple of minutes to show a Rayleigh distribution. To demonstrate the effect of lengthening the sampling time on the distribution, Fig. 14 and Fig. 15 are presented (pp. 1409–1410). Fig. 14 shows Rayleigh distribution of 6

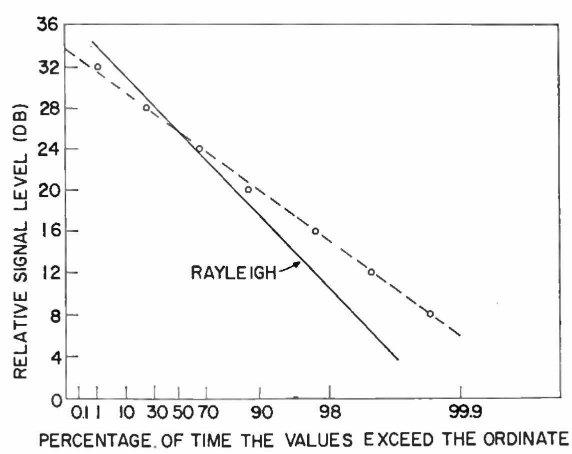

Fig. 13—Probability distribution of received signal level; receiving antenna beam partially obstructed by ship's superstructure and the distance less than 200 miles.

consecutive 50-minute periods. During the total time covered by these samples, the surface path distance varied from 300 to 340 miles, and the median path loss increased about 9 db. Fig. 15(a) and 15(b) show the sum of the first two periods [Fig. 14(a) and (b)] for a

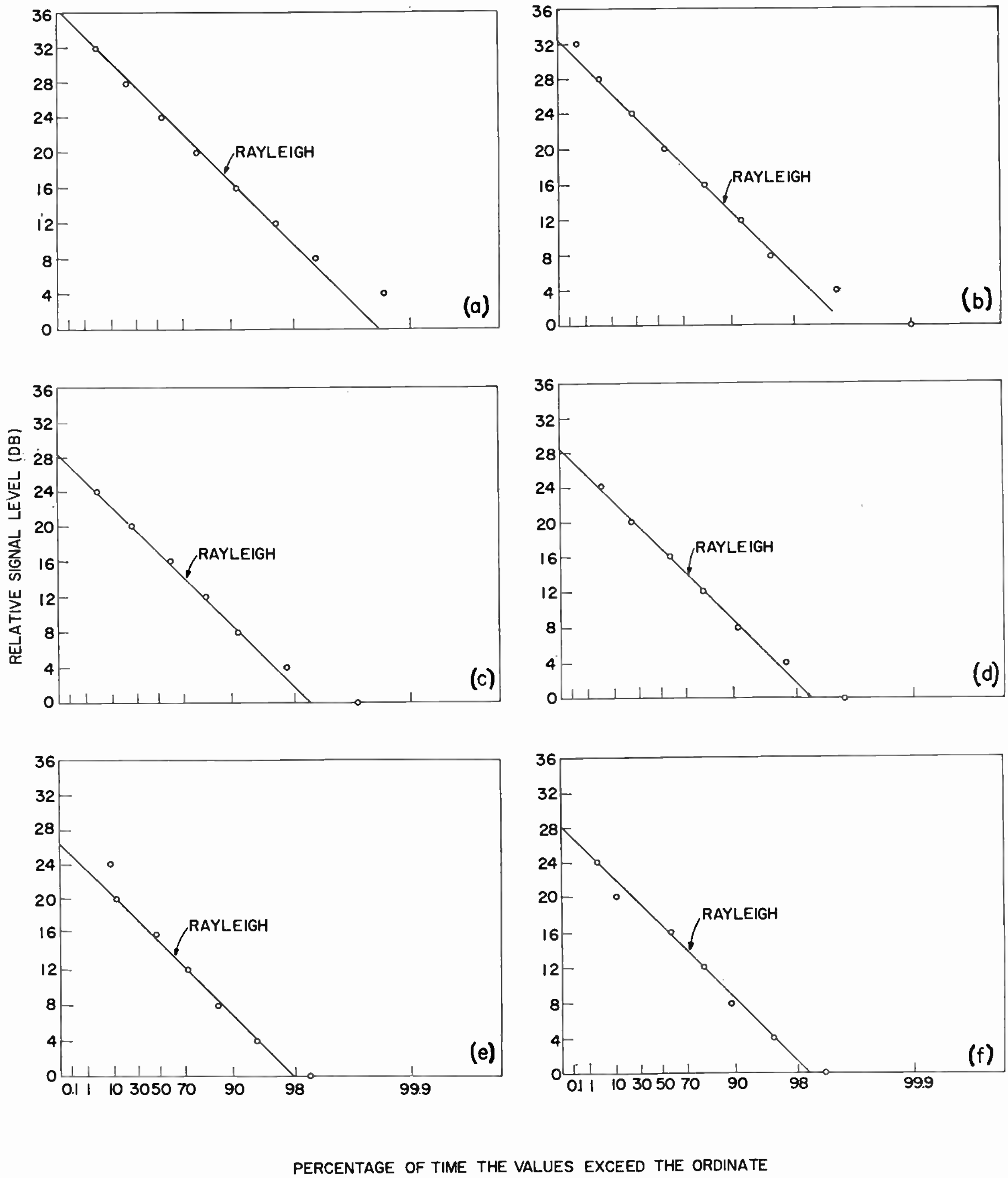

Fig. 14—Probability distribution of received signal level for six consecutive sampling periods; receiving antenna beam unobstructed.

total of 100 minutes plotted on both Rayleigh and log-normal coordinates. Successive summations for longer total periods are shown in the remaining plots of Fig. 15, and the deviation from the Rayleigh distribution becomes more apparent as the period is lengthened.

Discussion

The experimental results reported herein show that the median signal level for all-overwater paths is approximately 5 to 10 db higher than overland measurements reported by Lincoln Laboratory[5] and others.[6,8] The average summer level is approximately 8 db higher than the average winter level over the paths used in this investigation. For signals believed to be unaffected by superrefraction, the loss rate is roughly linear with distance at about 0.16 db per nautical mile. However, the data show a definite cyclic trend with distance which was likewise found in the overland measurements made by Lincoln Laboratory.[5] In over a year of overland observations by Lincoln Laboratory[5] at various distances out to 740 nautical miles, fade rates as fast as those shown in Fig. 11 had never been recorded. The fastest fading that has been observed on the overland paths was of the order of that shown in Fig. 5(a).

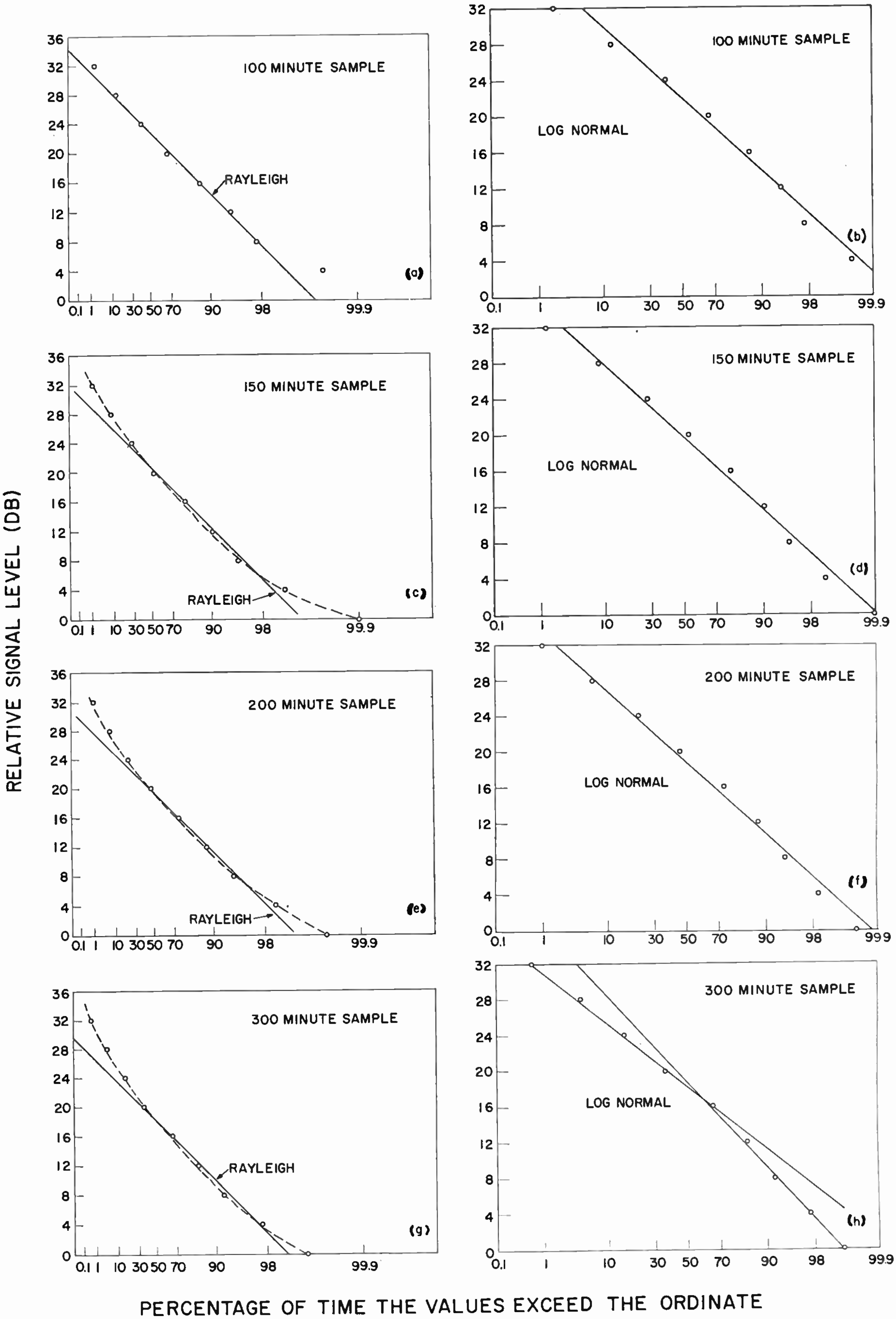

Fig. 15—Summation of probability distributions shown in Fig. 14.

The Hall Effect and Its Application to Microwave Power Measurement*

H. M. BARLOW†, FELLOW, IRE

Summary—**Hall effect and radiation pressure, as different manifestations of the same basic phenomenon, have both been successfully applied to the measurement of microwave power, using semiconductors for the purpose. Attention is called to the part played by displacement current at these frequencies and the conclusion is drawn that such currents are much more significant in relation to radiation pressure than to Hall effect. A wattmeter depending for its operation on the Hall effect is described and it is shown to give accurate measurements whatever the nature of the load.**

INTRODUCTION

THE Hall effect, which was first observed in 1880,[1] has recently found a number of new applications, largely as the result of the development of semiconductors.

One of these applications is to the measurement of power[2] and although this is a comparatively simple matter at low frequencies, its use in the microwave part of the spectrum presents many novel and challenging problems.[3]

As is well known, the effect arises from the distortion of the current streamlines in a material medium when an external magnetic field is applied perpendicular to that current (see Fig. 1). To produce a really significant effect of this kind it is necessary to employ a material which has a large ratio of mobility to conductivity, and in which the mobile carriers are predominantly of one sign (*e.g.*, either n or p type semiconductors), since oppositely directed charge carriers will tend to annul each other's effects in this respect.

At frequencies in the microwave band we have to consider the associated displacement current in the material medium in addition to conduction current. Thus for n-type germanium with a relative permittivity $\epsilon_r = 16$ and a resistivity of 25 ohm/cm we find these two currents are of the same order of magnitude at a frequency $f = 5000$ mc since $\omega(\epsilon - \epsilon_0) = 4.16$, which compares with the conductivity $\sigma = 4$ mhos per meter. The contribution to the Hall effect made by this displacement current in the material medium is thought to be small in most cases, but there are nevertheless conditions under which it might well prove to be quite significant. In good dielectrics like polystyrene where current is carried mainly by the displacement of electrons associated with electric dipoles, one would also expect to find a Hall effect, even though this may be difficult to detect.

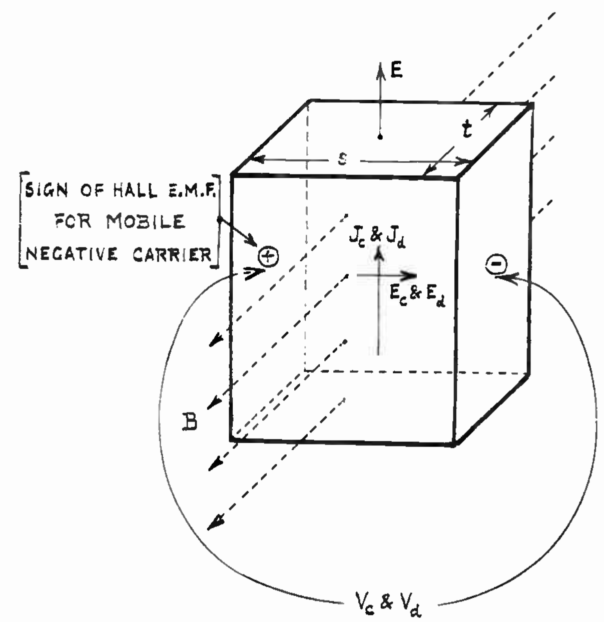

Fig. 1—Semiconductor element.

Associated with the distortion of the current streamlines in a material, arising from the Hall effect, there must be a mechanical force and this is what we know as radiation pressure. Hall effect and radiation pressure are therefore simply different manifestations of the same basic phenomenon. It is interesting, however, to observe that the contribution of the displacement current in the material medium to radiation pressure may frequently be quite important although it is insignificant in relation to Hall effect.

BASIC THEORY

Suppose that a plane wave is incident from the left on a slice of material of infinite extent perpendicular to the paper, of thickness S and having electrical constants μ, ϵ, and σ as shown in Fig. 2.

* Original manuscript received by the IRE, October 24, 1957. Presented at URSI Twelfth General Assembly, Boulder, Colo., August 22–September 5, 1957.

† University College, London, Eng.

[1] E. H. Hall, "On the new action of magnetism on a permanent electric current," *Phil. Mag.*, vol. 10, p. 301; September, 1880.

[2] H. M. Barlow, "The application of the Hall effect in a semiconductor to the measurement of power in an electromagnetic field," *Proc. IEE*, pt. B, vol. 102, pp. 179–185; March, 1955. Also see "The design of semiconductor wattmeters for power-frequency and audio-frequency applications," pp. 186–191; March, 1955.

[3] H. M. Barlow and L. M. Stephenson, "The Hall effect and its application to power measurement at microwave frequencies," PROC. IEE, pt. B, vol. 103, pp. 110–112; January, 1956.

H. M. Barlow, "Hall effect and its counterpart, radiation pressure, in microwave power measurement," *Proc. IEE*, pt. C, vol. 104, pp. 35–42; 1957. Also see Monograph 191R; August, 1956.

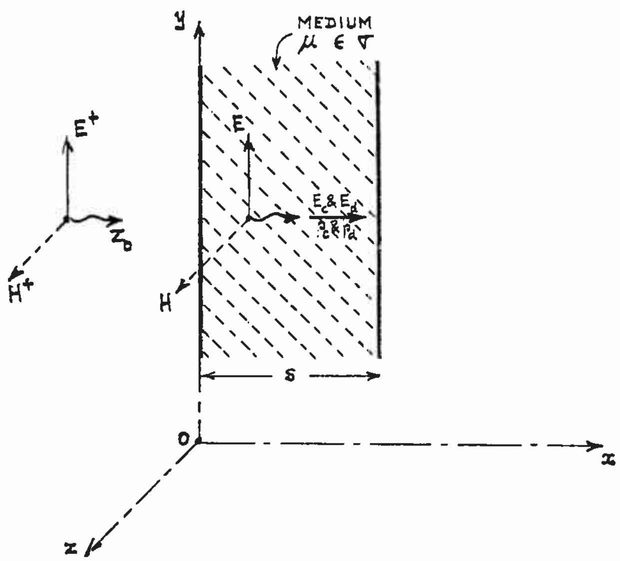

Fig. 2—Hall effect of radiation pressure produced by a plane wave incident on the medium.

The primary electric field E produces in the medium a conduction current density $J_c = \sigma E$ and a displacement current density associated with the material of

$$J_d = (\epsilon - \epsilon_0)\frac{\partial E}{\partial t}\cdot$$

These currents, by interaction with the primary magnetic field $B = \mu H$ of the incident wave, set up the secondary Hall electric fields in the direction of propagation of the wave which for the conduction and displacement currents, respectively, will be represented by the scalar equations

$$E_c = R_c J_c B = R_c \mu \sigma E H$$

and

$$E_d = R_d J_d B = R_d \mu (\epsilon - \epsilon_0) H \frac{\partial E}{\partial t}$$

where R_c and R_d are the Hall coefficients appropriate to the conduction and displacement currents.

It is convenient to measure the Hall emf between the opposite faces of the slice of material of thickness S, and for the two components we have

$$V_c = \int_0^S E_c \cdot dx$$

and

$$V_d = \int_0^S E_d \cdot dx.$$

The average value in time of the total Hall emf $V_{(av)}$ can be used to give a measure of the power incident on the slice. Thus

$$V_{(av)} = V_{c(av)} + V_{d(av)} = R_c \mu \sigma \int_0^S \frac{1}{2} \operatorname{Re}(H^* E) dx$$
$$+ R_d \mu (\epsilon - \epsilon_0) \int_0^S \frac{1}{2} \operatorname{Re}\left(H^* \frac{\partial E}{\partial t}\right) dx$$

where H^* represents the complex conjugate of H and the field components are in terms of maximum values. If the radiation pressures, representing the mechanical forces per unit area of surface normal to the incident wave, are p_c and p_d corresponding to the Hall emf's V_c and V_d, then it is easy to show that

$$R_c = \frac{V_c}{p_c} \quad \text{and} \quad R_d = \frac{V_d}{p_d}$$

from which we deduce that simultaneous measurement of Hall emf and its associated radiation pressure should yield the Hall coefficients for the medium concerned.

Application of Hall Effect to Microwave Power Measurement

For semiconductors like germanium and silicon the contribution of displacement current to the Hall emf even at frequencies as high as 10,000 mc, appears to be relatively small, so that $V_{(av)} \approx V_{c(av)}$. Also, if we choose a thin slice of semiconductor in which both the losses and the phase change are small, we find

$$V_{(av)} \approx (R_c \mu \sigma s) P$$

where P = power consumed in the medium on the far side of the semi-conductor.

The direct application to power measurement in a rectangular waveguide supporting the dominant H_{01} mode is shown in Fig. 3. The coaxial line pistons G_1 and G_2 associated with the Hall leads H_1 and H_2 to the crystal C mounted in the waveguide are adjusted to insure that no significant hf current passes along these leads, while the piston G_3 is used to phase the current through the crystal so that there is no Hall output when the waveguide is terminated in a short circuit. One of the most difficult problems in constructing a wattmeter of this kind is the elimination of residual rectifier action at the metal/semiconductor contacts. The rectifier output at the Hall terminals depends only on the electric field in the guide and does not reverse, as the Hall effect does, with reversal of the direction of the power. It is therefore desirable to place the crystal in a field for which the ratio E/H is as small as possible at any given power level. For a crystal mounted directly in the waveguide we generally have $(E/H) \approx 500$ ohms, which is not particularly suitable. An alternative, and in this respect a much better arrangement, is shown in Fig. 4 where the crystal C is now mounted at the center of a resonant cavity which is magnetically coupled to the main guide.

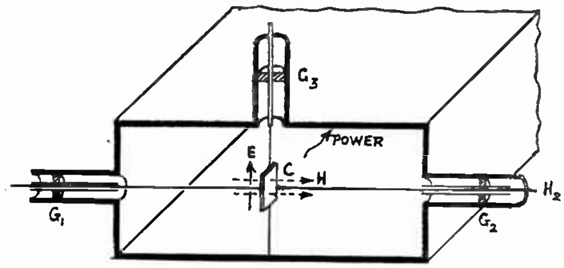

Fig. 3—Transmission type of wattmeter.

The cavity is about one wavelength long, so that the crystal is situated at a point of maximum magnetic field and zero electric field. A wire connected to the crystal projects slightly through the coupling slot into the main guide and thus picks up a small displacement current. Since the magnetic field in the cavity is approximately in quadrature with the corresponding field in the main guide, the Hall output from the crystal should be approximately zero when no power passes along the guide, but this condition can be established precisely by slightly detuning the cavity.

An arrangement of this kind operated at 4000 mc gave a linear calibration curve with a Hall output of about 1 μv for a power of 50 mw. The calibration proved, as expected, to be quite independent of the nature of the load and for a given power the same points were obtained on the curve for standing wave ratios of 0.1 and 1.0. Moreover, the instrument itself consumed only about 5 per cent of the power traversing the guide.

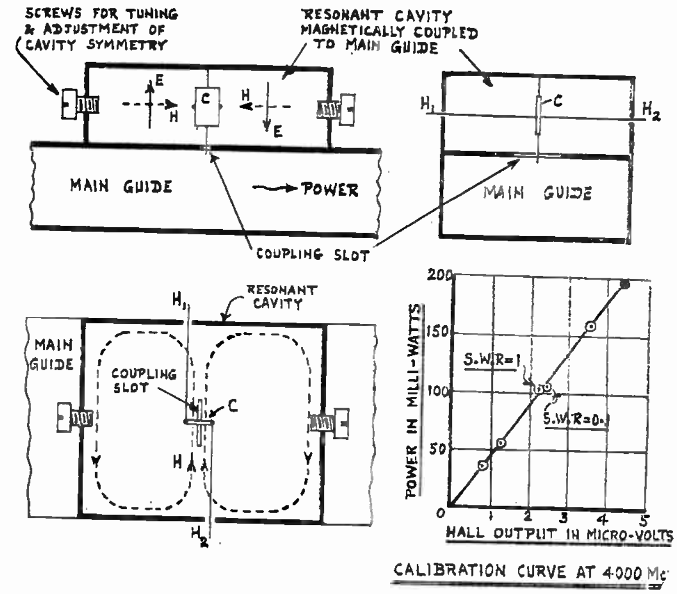

Fig. 4—Coupled resonant cavity type of wattmeter.

Conclusion

This development is only in its early stages and there is clearly much to be learned about the behavior of semiconductors in microwave fields before full advantage can be taken of the Hall effect for the purposes described. With improvement in measurement techniques it may become possible to observe Hall effects in dielectrics and in that event, new information about such materials should be obtainable.

Surface Waves*

H. M. BARLOW†, FELLOW, IRE

Summary—**This paper calls attention to some of the most important and easily recognizable forms of surface wave, pointing out that their essential common characteristic is the evanescent field structure over the wave front, as represented by equiphase planes.**

The problems of launching and supporting surface waves must, in general, be distinguished from one another and it does not necessarily follow that because a particular surface is capable of supporting a surface wave that a given aperture distribution of radiation, *e.g.* a vertical dipole, can excite such a wave.

The paper concludes with a discussion of the behavior of surface waves and their applications.

* Original manuscript received by the IRE, October 24, 1957. Presented at the URSI Twelfth General Assembly, Boulder, Colo., August 22–September 5, 1957.

† University College, London, Eng.

Introduction

In discussing surface waves it is most important to define precisely what is included in that category. Much confusion has arisen from time to time because different interpretations have been placed on what constitutes a surface wave. These misunderstandings seem to have originated largely with Sommerfeld's introduction of the same nomenclature in a different connection, when analyzing ground wave propagation over a flat earth.[1]

[1] A. Sommerfeld, "Über die Ausbreitung der Wellen in der drahtlosen Telegraphie," *Ann. Phys.*, vol. 28, p. 665; 1909.
C. J. Bouwkamp, "On Sommerfeld's surface wave," *Phys. Rev.*, vol. 80, p. 294; 1950.

The surface waves[2] with which we are concerned here are characterized by their ability to propagate along an interface between two different media without radiation, so that the only flow of energy away from the interface is that required to supply the losses in the media concerned.[3] On this basis such waves must possess an evanescent structure over the wavefront, represented by an equiphase plane, and that seems to be the best way of distinguishing them. To comply fully with the conditions required for the support of surface waves, the interface must be straight in the direction of propagation of the wave but transversely it can take a variety of forms, *e.g.*, linear, circular, elliptical, etc.

In examining the behavior of these waves there are two important aspects that have to be considered, and for many purposes it seems preferable to keep these aspects separate. Thus on the one hand we have to identify the kind of surface and the associated conditions required for the support of a given wave, which may therefore be regarded as a mode characteristic of that surface, whereas on the other hand we have to investigate the possibilities of launching such characteristic modes by means of a particular radiating aperture over the appropriate surface. Although an analysis may show that it is feasible to provide for the support of one of these modes over a surface, it does not necessarily follow that the mode can be excited by a given antenna system.

Forms of Surface Wave

To focus ideas it will be helpful to call attention to three distinctive forms of surface wave, each of which is supposed to be propagated in air or in a relatively lossless medium over the associated surface:

1) the inhomogeneous plane wave incident on the surface at the Brewster angle and often known as the Zenneck wave, as in Fig. 1(a),
2) the radial form of 1), as in Fig. 1(b),
3) the axial cylindrical wave, sometimes known as the Sommerfeld-Goubau wave, as in Fig. 1(c).

The first two are supported by flat surfaces and in each case the field decays exponentially with distance from the surface, while the third requires a cylindrical surface and has a field distribution in the radial plane according to a Hankel function. Since there is only one finite boundary condition to satisfy, these surface waves suffer no cutoff and, theoretically at least, they can be employed at any frequency. However, at low frequencies the rate of decay of the field with increasing distance from the surface is generally so small and the corresponding spread of the field so large, that the arrangement becomes of little practical value. It will be observed that the radial forms 2) and 3) of the wave, supported respectively by flat and cylindrical surfaces, both tend at large radii to the inhomogeneous plane wave.

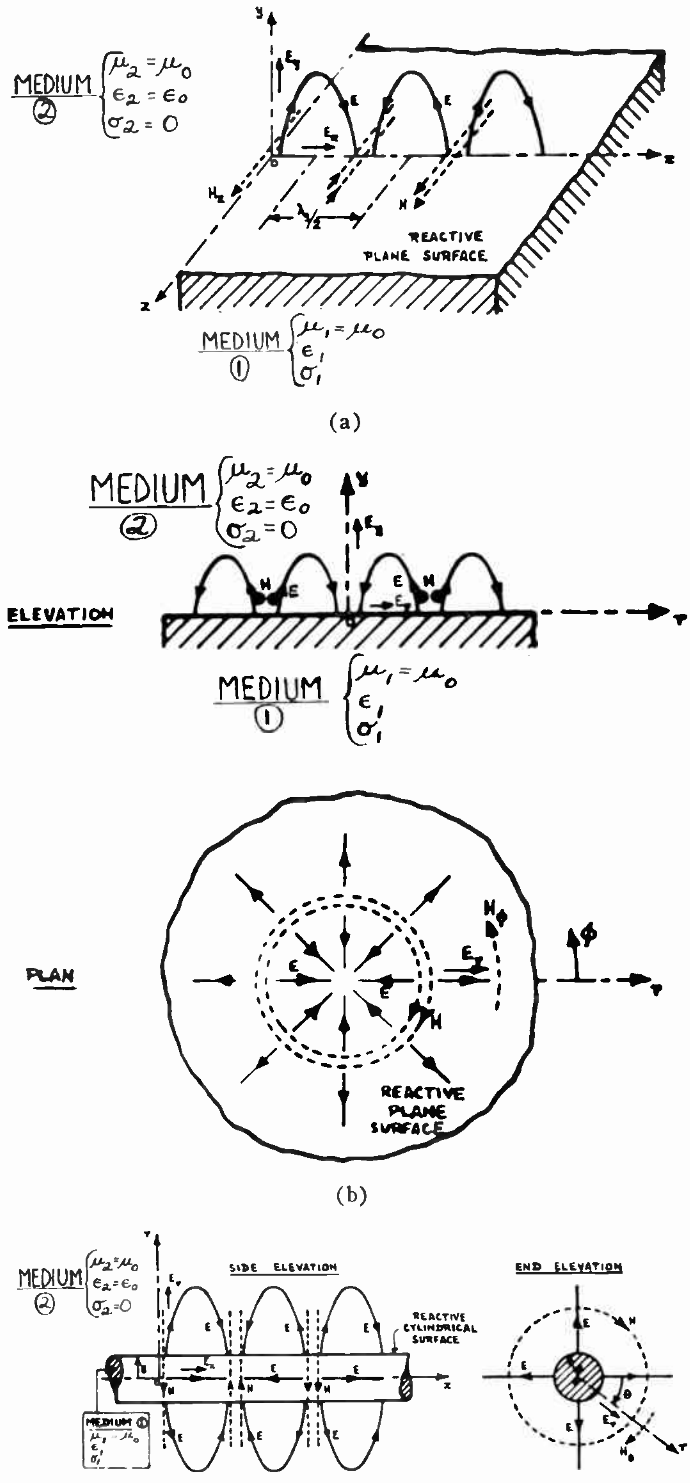

Fig. 1—(a) Zenneck wave (inhomogeneous plane wave). (b) Radial surface wave. (c) Sommerfeld-Goubau wave (cylinder surface wave).

[2] J. Zenneck, "Uber die Footpflanzung ebener elektromagnetischer Wellen längs einer ebener Leiterfläche und ihre Bezichung zur drahtlosen Telegraphie," *Ann. Phys.*, vol. 23, p. 846; 1907.
H. M. Barlow and A. L. Cullen, "Surface waves," *Proc. IEE*, pt. 3, vol. 100, pp. 329–347; November, 1953.

[3] Here radiation is construed to mean energy absorbed from the wave independently of the supporting media.

The Inhomogeneous Plane Wave[4]

It is easy to show that in this case the conditions essential to the support of the wave are satisfied when the surface impedance $Z_s = R_s + jX_s$ includes a finite inductive reactance, X_s. For a homogeneous medium below the surface this implies a finite loss in that medium. In the y direction (outwards from the surface) the field varies according to e^{-uy} where $u = a - jb$ so that with a rate of decay determined by a there is a wave traveling *towards* the surface supplying the losses in it and having a phase coefficient b. The power associated with a traveling wave is directed at an angle of inclination with the normal to the surface represented by the real part ψ_0 of the Brewster angle $\psi = \psi_0 - jx$. Thus the effect of the losses in the surface is to tilt the wavefront forward and to produce a decay of amplitude as the wave progresses over the surface, as shown in Fig. 2.

This situation can be represented by imagining the wave to be propagated without attenuation along a hypothetical surface $x'z$ parallel with the direction of the power.

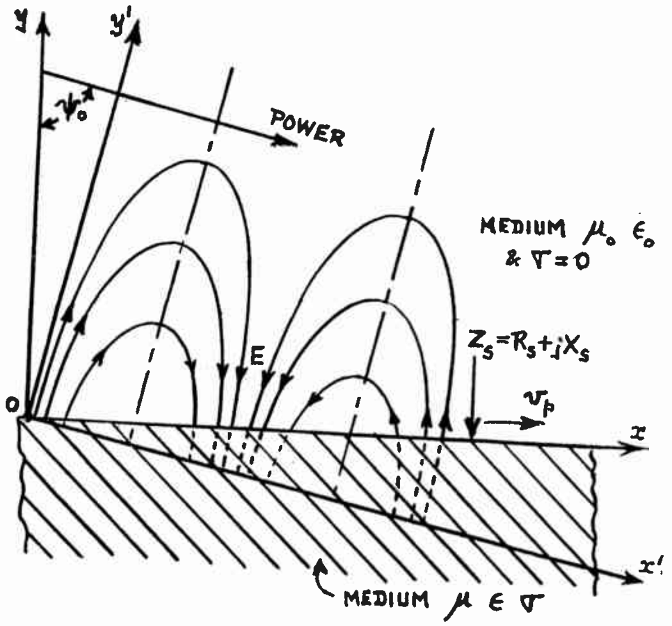

Fig. 2—Inhomogeneous plane wave sinking into a lossy surface.

The phase velocity v_p along the interface exceeds the free-space velocity v_0 for a lossy homogeneous medium below the surface, but when X_s is increased by loading (*e.g.*, a dielectric coating or corrugation) then v_p falls and may become considerably less than v_0. The resistive part R_s of the surface impedance, by tilting the wave forward, tends to increase v_p.

[4] S. Atwood, "Surface-wave propagation over a coated plane conductor," *J. Appl. Phys.*, vol. 22, pp. 504–509; April, 1951.

The Axial Cylindrical Surface Wave[5]

In this case the radial distribution of the field is represented by $H_0^{(1)}(jur)$ for the axial component E_x of the electric field, and by $H_1^{(1)}(jur)$ for the other two components E_r and H_θ where $u = a - jb$ as before. The general behavior of the wave with respect to the surface impedance is very similar to that of the inhomogeneous plane wave, but there is now an additional factor, the radius S of the supporting surface. For values of S normally employed, as for example in the single wire transmission line with an inductive surface, $v_p < v_0$ but as $S \to \infty$ the value of v_p increases, eventually becoming the same as for the corresponding inhomogeneous plane wave. Moreover, with finite values of S, it is quite feasible, over a limited range of phase velocities, to associate this wave with a capacitive surface instead of an inductive one. There has been much discussion about the possibility of supporting an inhomogeneous plane wave above the flat surface of a lossy homogeneous medium.[6] This possibility has frequently been denied on the ground that no surface wave term appears in the ultimate analysis according to Sommerfeld's work on propagation from a vertical dipole over a flat earth. As already pointed out, the radiation problem is quite another matter and should not be confused with the capabilities of a surface as such, for the purposes of supporting a given wave. Theory shows and experiment confirms that a lossy dielectric rod of circular cross section and sufficient diameter to make its surface inductive, will support a surface wave.[7] As the diameter of the rod is increased to infinity there is no apparent discontinuity in the transition from the axial cylindrical wave to the inhomogeneous plane wave, so that on this basis we should expect a flat surface of the same material to be capable of supporting a surface wave, even if it is difficult to identify the wave owing to the slow rate of decay of the field.

Effect of Curvature of the Surface in the Direction of Propagation

As already stated, the surface must be straight in the direction of propagation if a pure surface wave is to be maintained. It is possible, however, in appropriate circumstances, to make gradual bends in the surface with-

[5] G. Goubau, "Surface waves and their application to transmission lines," *J. Appl. Phys.*, vol. 21, pp. 1119–1128; November, 1950.
H. M. Barlow and A. E. Karbowiak, "An investigation of the characteristics of cylindrical surface waves," *Proc. IEE*, pt. 3, vol. 100, pp. 321–328; November, 1953.

[6] N. Marcuvitz, "Guided wave concept in electromagnetic theory," Polytechnic Inst. of Brooklyn, Brooklyn, N. Y., Res. Reps, No. 269 and 208; 1952.
J. R. Wait, "Excitation of surface waves on conducting, stratified, dielectric clad and corrugated surfaces," Natl. Bur. of Standards, Res. Rep. No. 5061; 1957.
G. J. Rich, "The launching of a plane surface wave," *Proc. IEE*, pt. B, vol. 102, pp. 237–246; March, 1955.

[7] H. E. M. Barlow and A. E. Karbowiak, "An experimental investigation of axial cylindrical surface waves supported by capacitive surfaces," *Proc. IEE*, pt. B, vol. 102, pp. 313–322; May, 1953.

out serious radiation. If we consider for simplicity the inhomogeneous plane wave [Fig. 3(a)] and regard its pattern as stationary in space (*e.g.*, within a resonator) then clearly we shall have an evanescent field distribution between adjacent equiphase planes (at which metal plates might be erected without disturbing the field). This evanescent field is in accordance with the condition that no radiation takes place. Now suppose that the surface is bent as in Fig. 3(b), so that the equiphase planes diverge. Although the field remains evanescent in the immediate neighborhood of the surface, the spacing of the equiphase planes quickly becomes sufficient to allow propagation of energy and therefore radiation takes place.

Anything that enhances the surface reactance (such as dielectric coating or corrugating a metal surface) confines the field more closely to the surface enabling the same measure of bending to be applied without producing so much radiation. There is also reason to believe that, as in the case of other forms of waveguide, the successful bending of dielectric coated wires used for single wire transmission lines may be partly attributed to the change of permittivity of the dielectric between the outside and the inside of the bend, helping to keep the wavefront more nearly radial with respect to the center of curvature of the bend.[8] Surface wave antennas using deliberate discontinuities to set up radiation offer considerable scope for future development, but much still remains to be learned about the mechanism and control of the radiation in such circumstances. The part played by surface waves in contributing to hybrid modes between two widely spaced parallel conductors having highly reactive surfaces is now becoming recognized, and it is interesting to observe that they play a part in various mode transducers.

The Launching Problem

The fact that the field of a surface wave extends to an infinite distance from the surface implies that something approaching an infinite aperture is required to launch it efficiently. A horn spreading out the field of a TEM wave can give quite a good approximation to the requirements, particularly for launching over an axial cylindrical surface from a coaxial line.[9] However, for a flat surface supporting, for example, the radial form of surface wave, a launching efficiency of about 80 per cent can be achieved[10] with a point source at a height above the surface corresponding approximately to that at which the field falls to $1/e$ of its surface value. At some

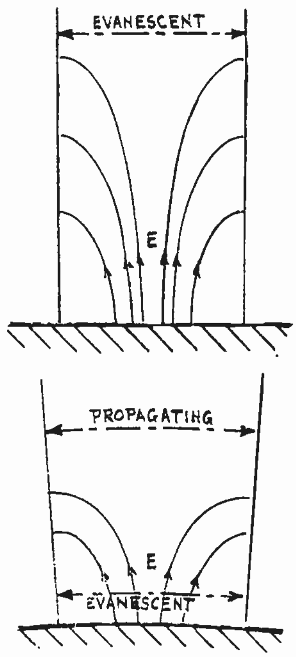

Fig. 3—Effect of curvature of supporting surface. (a) Flat surface. (b) Curved surface.

distance from the radiating aperture and near the surface (where the surface wave field is strong) cancellation of the radiation field by interference between direct and reflected waves occurs in these circumstances, leaving most of the power in the surface wave (Fig. 4). The corresponding concentric line source for launching an axial cylindrical wave is now under investigation, but appears to be less effective.

Some Practical Applications

Whatever arguments can be advanced about the possibility of launching a surface wave over a flat surface forming the boundary with air of a lossy homogeneous medium, there can be no doubt that such a surface when loaded to give an enhanced reactance will not only support the wave but will provide the conditions necessary for launching it from a vertical dipole. In practice we invariably have to deal with rough surfaces and experiment shows[11] that if the electrical wavelength covers at least two or three complete undulations it takes very little irregularity of the surface to add substantially to its effective reactance. It seems reasonable to conclude therefore that it should be possible to launch surface waves of suitable frequency over the earth and that they do indeed exist in appropriate circumstances even though they may be difficult to identify because of the relatively slow decay of the field in the vertical direction. For a perfectly smooth sea at a frequency of 36 mc with a conductivity of 4 mhos per meter and a relative permittivity of 80 we find that the Zenneck wave in

[8] H. E. M. Barlow, "Propagation of the circular H_{01} low-loss wave mode around bends in tubular metal waveguide," *Proc. IEE*, pt. B, vol. 104, pp. 403–409; July, 1957.

[9] G. Goubau, "On the excitation of surface waves," Proc. IRE, vol. 40, pp. 865–868; July, 1952.

[10] A. L. Cullen, "The excitation of plane surface waves," *Proc. IEE*, pt. 4, vol. 101, pp. 225–234; August, 1954. Also see Monograph No. 239 R; May, 1957.
W. M. G. Fernando and H. E. M. Barlow, "The excitation of plane surface waves," *Proc. IEE*, pt. B, vol. 103, pp. 307–318; May, 1956.

[11] H. E. M. Barlow and A. E. Karbowiak, "An experimental investigation of the properties of corrugated cylindrical surface waveguides," *Proc. IEE*, pt. 3, vol. 101, pp. 182–188; May, 1954.

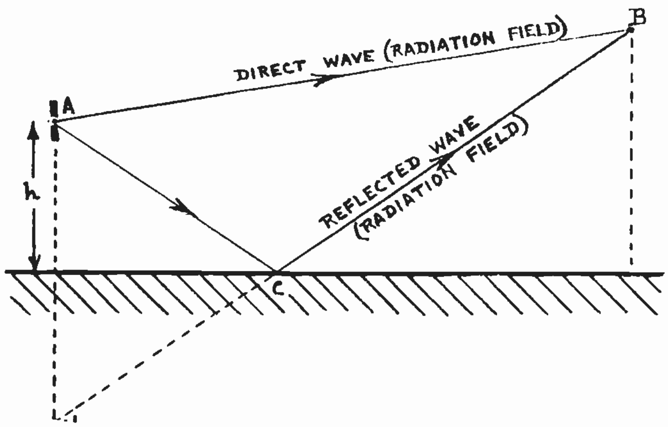

Fig. 4—Cancellation of radiation field near surface.

these conditions would have an attenuation of 2.6 db per mile, the field would fall to $1/e$ of its surface value at a height of 84 meters and the real part of the Brewster angle would be 89.1 degrees. With the rough surface that the sea almost always presents it should be quite feasible to launch the radial form of this wave from a dipole at the appropriate height and perhaps to use the wave for short range communications.

The axial cylindrical wave offers possibilities for application to television links. In Montana, U.S.A., a single-wire transmission line of this kind is now in operation at a frequency of about 200 mc. It consists of a metal conductor approximately $\frac{1}{2}$ inch in diameter, coated with $\frac{1}{4}$-inch thick dielectric and supported at intervals along its length by nylon cords hung from wooden poles. It is claimed that the attenuation of the line is about 10 db per mile over a frequency band of some 100 mc. The unavoidable bends and discontinuities in the line must cause some radiation and interference on a reciprocal basis, but in the conditions of installation this does not appear to be too serious.

Conclusion

The author is only too conscious of the many important omissions from this very brief survey. He hopes, however, that enough has been said to stimulate discussion of this subject, and that many other aspects of the problem will thus be raised.

Correction

In "IRE Standards on Television: Measurement of Luminance Signal Levels, 1958," (Standard 58 IRE 23. S1) which appeared on pages 483–486 of the February, 1958 issue of Proceedings, the horizontal scale in Fig. 2 on page 484 was not drawn correctly below 1 mc. Going back to the primary data with that read from the published curve, the following results were obtained:

Freq. (mc)	Correct Data	Data Read From Curve
0.2	*0.1* db	*0* (marked division)
0.3	0.3 db	0.1 (estimated)
0.4	0.45 db	0.4 (estimated)
0.5	*0.75* db	*0.7* (marked division)
0.6	1.0 db	1.1 (estimated)
0.8	1.6 db	1.8 (estimated)
1.0	*2.5* db	*2.5* (marked division)

This comparison shows that errors of the order of 0.2 db can be made if the scale below 1 mc is used as a purely arbitrary scale. If the curve is read only at the marked divisions along the horizontal scale, the error is of the order of 0.1 db (or less).

Supplement to "IRE Standards on Receivers: Methods of Measurement of Interference Output of Television Receivers in the Range of 300 to 10,000 KC, 1954" (Standard 54 IRE 17.S1)*

58 IRE 27.S1

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* Approved by the IRE Standards Committee, February 13, 1958. Reprints of this Standard, 58 IRE 27.S1, may be purchased while available from the Institute of Radio Engineers, 1 East 79th Street, New York, N. Y., at $0.50 per copy. A 20 per cent discount will be allowed for 100 or more copies mailed to one address.

I. Introduction

The method of measurement of conducted interference from television and FM broadcast receivers is described by two current IRE Standards. These are "IRE Standards on Receivers: Methods of Measurement of Interference Output of Television Receivers in the Range of 300 to 10,000 KC, 1954" (Standard 54 IRE 17.S1[1]) and "IRE Standards on Methods of Measurement of the Conducted Interference Output of Broadcast and Television Receivers in the Range of 300 KC to 25 MC, 1956" (Standard 56 IRE 27.S1[2]).

In the measurement of conducted interference, it has been determined that the network formerly employed to deliver an RF input signal to the receiver under test has been responsible for some inconsistency. Accordingly, this Supplement is issued to describe a new procedure in which the old coupling network is replaced with a resistive pad having properties that are well defined and easily reproduced.

The Standard 56 IRE 27.S1 represented an amendment to the earlier Standard 54 IRE 17.S1.

The present supplement further modifies Standard 54 IRE 17.S1.

II. Deletions

The material of this Supplement replaces paragraph 3.2.6, Section 3.3 and Figs. 6 and 7 of the subject Standard (54 IRE 17.S1).

III. Additions

The following paragraphs should be inserted to replace the old 3.2.6:

"3.2.6 A means of supplying a normal signal for the receiver under test. A length of transmission line shall be connected between the receiver antenna terminals and the output of a 20-db 300-ohm resistive attenuator pad. The output of a suitable signal generator is connected to the input terminals of the 20-db pad. The disposition of the transmission line and coupling pad is important. Fig. 1 shows the standard arrangement. Fig. 2 shows the details of the resistive coupling pad which is designed to have impedance of 300 ohms balanced and 300 ohms unbalanced (impedance between the two output terminals connected together and ground). If the signal generator is not located within the screen room, adequate filters should be installed at the signal input to the screen room to exclude undesired signals in the frequency band of interest."

"If the receiver has a built-in antenna, it shall be disconnected from the antenna terminals during these tests."

[1] Proc. IRE, vol. 42, pp. 1363–1367; September, 1954.
[2] Proc. IRE, vol. 44, pp. 1040–1043; August, 1956.

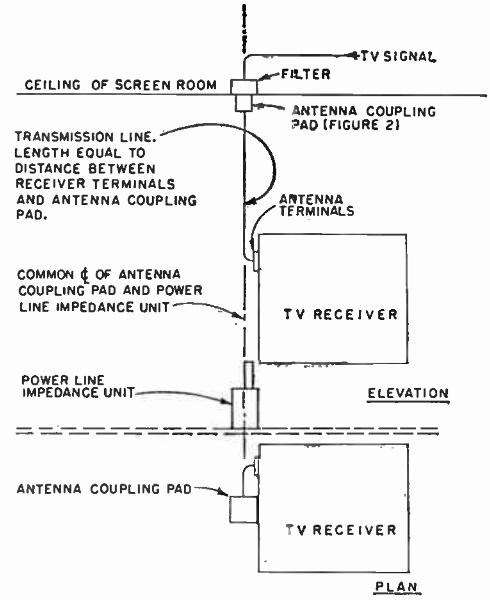

Fig. 1—Signal input system.

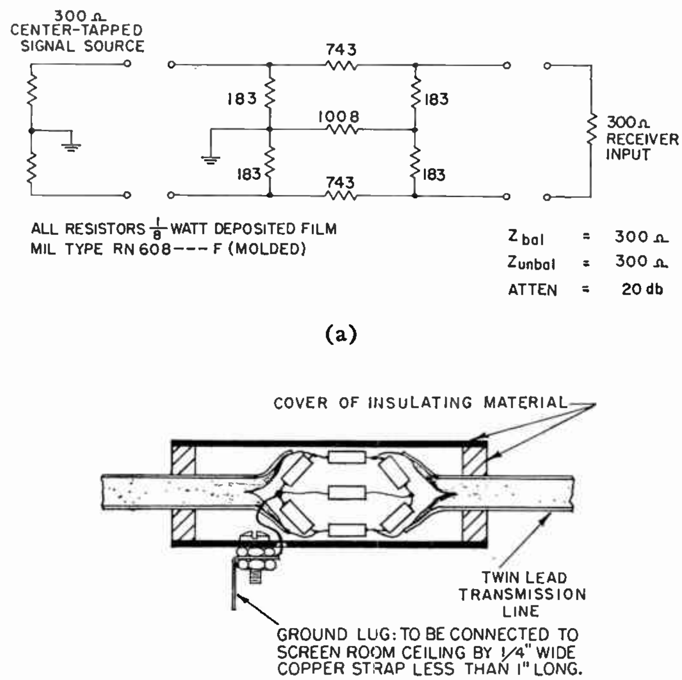

Fig. 2—Antenna coupling pad. (a) Schematic diagram of resistive pad. (b) Drawing of typical construction.

"If the signal generator does not have a 300-ohm center-tapped output impedance, a suitable matching network shall be provided between the signal generator and the coupling pad."

"If the receiver is designed for use with an unbalanced shielded transmission line, a line having the characteristics recommended by the receiver manufacturer shall be used in place of the twin-lead in Figs. 1 and 2.

The input terminals of the transmission line are connected to the output terminals of the resistive pad. In addition, a resistor is connected in shunt with the output terminals of the pad so that the combination of pad and resistor matches the nominal input impedance of the receiver."

The following paragraph should be inserted to replace Section 3.3:

"3.3 With the field strength meter connected to one 50-ohm coaxial connector of the power line impedance unit as described in Section 2.3.4 of Standard 56 IRE 27.S1, measure the voltage appearing at that coaxial connector at the frequencies of interest. Interchange field strength meter and 50-ohm resistive termination and repeat the measurement for the other 50-ohm coaxial connector."

Correspondence

WWV Standard Frequency Transmissions*

Since October 9, 1957, the National Bureau of Standards radio stations WWV and WWVH have been maintained as constant as possible with respect to atomic frequency standards maintained and operated by the Boulder Laboratories, National Bureau of Standards. On October 9, 1957, the U.S.A. Frequency Standard was 1.4 parts in 10^9 high with respect to the frequency derived from the UT 2 second (provisional value) as determined by the U. S. Naval Observatory. The atomic frequency standards remain constant and are known to be constant to 1 part in 10^9 or better. The broadcast frequency can be further corrected with respect to the U.S.A. Frequency Standard as indicated in the table below. This correction is *not* with respect to the current value of frequency based on UT 2. A minus sign indicates that the broadcast frequency was low.

WWV FREQUENCY†

1958 April 1500 UT	Parts in 10^9
1	−2.7
2	−2.7
3	−2.8
4	−2.8
5	−2.9
6	−2.9
7	−3.0
8	−3.1
9	−3.1
10	−3.1
11	−3.1
12	−3.1
13	−3.0
14	−3.0
15	−2.9
16	−2.8
17	−2.6
18	−2.5
19	−2.4
20	−2.4
21	−2.5
22	−2.5
23	−2.6
24	−2.7
25	−2.9
26	−3.1
27	−3.2
28	−3.4
29	−3.5
30	−3.6

† WWVH frequency is synchronized with that of WWV.

The WWV and WWVH time signals are synchronized; however, they may gradually depart from UT 2 (mean solar time corrected for polar variation and annual fluctuation in the rotation of the earth). Corrections are determined and published by the U. S. Naval Observatory.

WWV and WWVH time signals are maintained in close agreement with UT 2 by making step adjustments in time of precisely plus or minus 20 msec on Wednesdays at 1900 UT when necessary; one step adjustment was made at WWV and WWVH on April 9, 1958.

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* Received by the IRE, May 15, 1958.

Pumping to Extend Traveling-Wave-Tube Frequency Range*

By means of pumping with a high-level signal the frequency range for amplification in a traveling-wave tube can be extended substantially. This was demonstrated in some recent experiments on a commercially available traveling-wave amplifier. For example, with an *S*-band tube the small signal gain for an *L*-band signal (1.0 kmc) was increased by 33 db simply by adding to the tube input a saturating *S*-band signal (3.2 kmc). Simultaneously without any readjustment a similar gain enhancement was measured for signals at frequencies well above *S* band.

The measured data are undoubtedly a consequence of a number of different phenomena which may enter into the picture in various complicated ways. These phenomena may well include the parametric effects available in beams as recently enunciated by Louisell and Quate.[1] However, the results may be explained qualitatively, at least, in terms of the mixing effects associated with electron beams.[2] In fact the gain enhancement was first noticed in experiments involving these mixing effects.

Such an explanation proceeds as follows. The nonlinearity present in an overmodulated electron beam permits effective frequency mixing between a high- and a low-level signal if the high-level signal is sufficiently intense to just begin to saturate the beam.[2] The gain enhancement can be looked upon as being due to a double-mixing action. We observe that the high-level signal is in the center of the frequency band of amplification of the traveling-wave amplifier. The low-level signal is outside that band. Nevertheless the low-level signal is capable of inducing at least a small amount of modulation on the beam. Since the beam is made nonlinear by the presence of the high-level signal, a mixing action results and modulation at the difference frequency appears. The difference frequency is within the band of amplification, and this modulation is amplified by the traveling-wave interaction. The traveling-wave interaction is not exclusively that of the conventional traveling-wave tube and probably includes parametric effects. The difference-frequency modulation then remixes with the modulation due to the high-level signal to give back an amplified version of the low-level signal. Consequently, by means of this double-mixing action, amplification becomes available for signals normally outside the frequency band of the tube. The magnitude of the amplification depends upon the gain of the tube at the difference frequency in the presence of a

* Received by the IRE, April 2, 1958. This paper was prepared under Air Force Contract AF19(604)-1847.

[1] W. H. Louisell and C. F. Quate, "Parametric amplification of space-charge waves," Proc. IRE, vol. 46, pp. 707–717; April, 1958.
[2] R. W. DeGrasse and G. Wade, "Microwave mixing and frequency dividing," Proc. IRE, vol. 45, pp. 1013–1015; July, 1957.

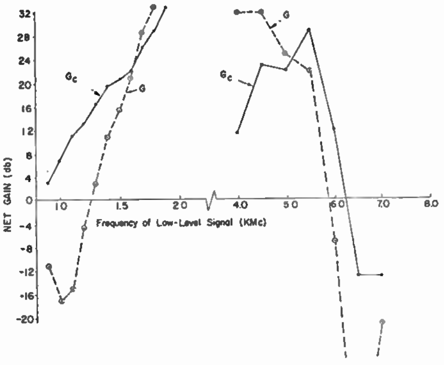

Fig. 1—Double-mixing conversion gain, G_c, and normal low-level signal gain, G, as a function of frequency.

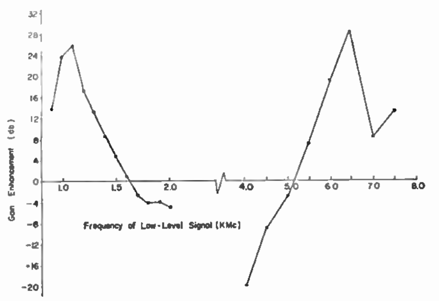

Fig. 2—Gain enhancement, $G_c - G$, as a function of frequency.

saturating signal and also upon the conversion efficiencies of both mixing processes.

Measurements on the bandwidth extension, and other possible desirable effects associated with it, have been started. Fig. 1 shows, as a function of frequency, net gain available for signals outside the normal frequency band when the high-level saturating signal is present, and compares this gain with the net gain available when the high-level signal is removed. In accordance with the previous explanation, the former gain can be looked upon as a double-mixing conversion gain and is given the symbol G_c. The latter gain is just the small signal gain and is symbolized by G. For these data the high-level signal was at 3.2 kmc and had a power level of −14 dbm. This is near the saturation level for the tube. The helix voltage and beam current were set at the rated values for normal broad-band S-band operation.

The input and output couplers were designed for S-band and worked inefficiently at other frequency ranges. Consequently the most significant set of data obtained from this experiment was probably the gain enhancement, $G_c - G$. These data are presented in Fig. 2 as a function of frequency.

It was found that both the double-mixing conversion gain and the gain enhancement could be optimized at any particular low-level signal frequency by adjusting the high-level signal frequency and power, and by adjusting the helix voltage. It was under more optimized conditions that the gain enhancement of 33 db, as indicated previously, was obtained.

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Mixed Garnets for Nonreciprocal Devices at Low Microwave Frequencies*

The frequency range in which ferromagnetic materials may be applied in microwave components, such as isolators and phase shifters, has been extended recently to lower frequencies than was previously possible. This has been accomplished through the use of yttrium iron garnet. YIG has proved so useful primarily because it possesses a very narrow ferromagnetic resonance linewidth. Resonance absorption, therefore, occurs without overlapping magnetic losses at weak field values.

In order to minimize further the deleterious effect of low field losses, the saturation magnetization must be as small as is compatible with narrow linewidth. Polder and Smit[1] have demonstrated that magnetic loss occurs in demagnetized ferrites between the frequencies of γH_a and $\gamma(H_a + 4\pi M_s)$, where H_a is the effective anisotropy field. Thus, the smaller the saturation magnetization, the less extensive is the frequency band in which low field losses override nonreciprocal effects and, hence, prohibit the design of components. In addition to these two design factors, narrow ΔH and small $4\pi M_s$, low-frequency microwave devices require propitious geometry, as further discussed in the last section.

In order to construct particularly L-band and also S-band coaxial isolators, mixed garnets were prepared. Y and Gd ions were chosen to share the c sites in the garnet structure. It was hoped that the narrow ΔH characteristics of YIG would be maintained, while the $4\pi M_s$ would be reduced. The saturation magnetization as a function of temperature for pure YIG, pure GdIG, and the mixtures $(2\frac{1}{2}Y \cdot \frac{1}{2}Gd)IG$ and $(2Y \cdot 1Gd)IG$ is shown in Fig. 1. The curves are for 100 per cent dense material. These theoretical densities were obtained from Debye-Scherrer X-ray diagrams which yielded the following values for the lattice constants:

YIG 12.379 ± 0.004 Å
GdIG 12.469 ± 0.005 Å
$(2\frac{1}{2}Y \cdot \frac{1}{2}Gd)IG$ 12.393 ± 0.004 Å
$(2Y \cdot 1Gd)IG$ 12.409 (estimated).

(The diagrams also showed that the garnets were composed of only one phase.) In the temperature range beyond GdIG's compensation point, approximately 14 degrees C, the net magnetic moment of the Gd ions is oppositely directed to the net magnetic moment of the Fe ions on the d sites, hence the $4\pi M_s$ is reduced as the Gd content is increased.

The full resonance absorption linewidth at one half maximum was measured in a rectangular TE_{103} reflection cavity at 7500 mc. The method involved measuring the SWR in front of the cavity with and without the sample placed in the position of zero electric field and maximum magnetic field (of one component). The external dc magnetic field, perpendicular to the RF magnetic field,

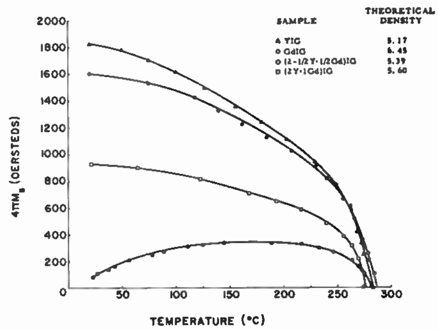

Fig. 1—Saturation magnetization as a function of temperature.

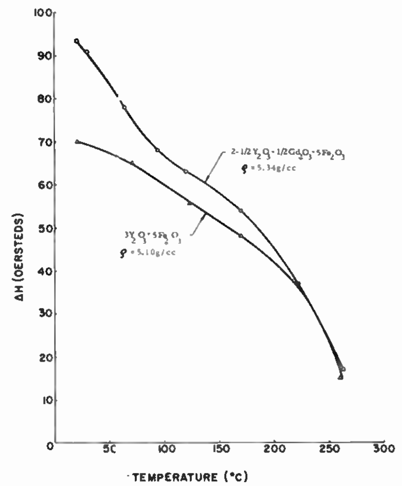

Fig. 2—Linewidth of pure YIG and a mixed Y-Gd garnet as a function of temperature.

could be varied and measured to a fraction of an oersted. Measuring was accomplished with a paramagnetic fluxmeter developed at Sylvania utilizing 1, 1-diphenyl-2-picyrl hydrazyl[2] constructed in 0.16 inch diameter coaxial line.

The linewidth vs temperature curves are shown in Fig. 2. The spherical samples were prepared identically and, therefore, have the same surface texture which was relatively rough. The same material yields narrower linewidths if more carefully polished, but we are interested here only in the relative values. A 34 per cent increase in the linewidth and a 12 per cent decrease in the saturation magnetization are caused by substituting Gd for Y on 17 per cent of the c sites. The replacement of 33 per cent of the ions causes a ΔH of approximately 550 oersteds, comparable with ordinary ferrites and therefore useless at low microwave frequencies.

The samples prepared for this work were extremely dense: 98.8 per cent and 99.1 per cent of theoretical density for the 2 to 1 and 5 to 1 mixtures, respectively. Their loss tangent was ~0.0015 at 20 mc.

An isolator was constructed using the 5 to 1 Y-Gd mixture garnet in $\frac{5}{8}$-inch 50-ohm dielectrically loaded coaxial line. The dielectric subtended an angle of π radians and its relative dielectric constant was ~15.

* Received by the IRE, April 14, 1958.

[1] D. Polder and J. Smit, "Resonance phenomena in ferrites," *Rev. Mod. Phys.*, vol. 25, pp. 89–90; January, 1953.

[2] P. H. Vartanian and J. L. Melchor, "Broadband microwave frequency meter," Proc. IRE, vol. 44, pp. 175–178; February, 1956.

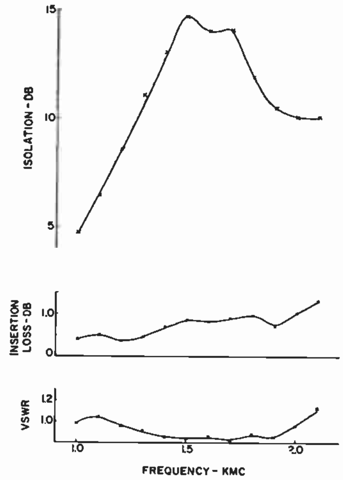

Fig. 3—Characteristics of *L*-band isolator.

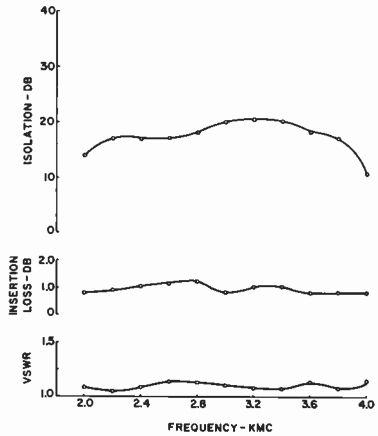

Fig. 4—Characteristics of *S*-band isolator.

The garnet material was ground into relatively long thin slabs and cemented to the flat face of the dielectric. The external magnetic field was applied perpendicular to the broad face of the garnet. This geometry insures that the H applied is greater than the saturation magnetization as seen from Kittel's equation:

$$H_{eff} = \frac{\omega_0}{\gamma} = H_a - 4\pi M_s.$$

Thus stability of operation is assured. Furthermore, magnetic losses are avoided at the weak applied fields required for low-frequency application.

Data for the *L*-band isolation are shown in Fig. 3. The rapid decline of the isolator's properties below 1500 mc possibly may be attributed to the deterioration at low frequencies of the TE mode configuration in coaxial line suggested by Duncan, *et al.*[3] Evidence that such a mode deterioration does occur and hinder the performance below 1500 mc is seen by the excellent performance of the same structure at higher frequencies, Fig. 4. Furthermore, it was not possible to enhance the isolation below 1500 mc by optimizing the magnitude and position of the magnetic field. Additional experiments with this geometry are being conducted using higher dielectric constant loading material in an effort to maintain this TE mode below 1300 mc, and so improve the performance in this region.

As Fig. 4 shows, an isolator made with this garnet material has greater than 10 to 1 isolation to insertion ratio over the octave 2000 to 4000 mc.

The authors are indebted to chemist Rosalie Farrand for preparing all the garnet samples.

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[3] B. J. Duncan, L. Swern, and K. Tomiyasu, "Microwave magnetic field in dielectric-loaded coaxial line," Proc. IRE, vol. 46, pp. 500–502; February, 1958.

Design Theory for Depletion Layer Transistors*

In his very interesting paper, Gärtner[1] mentions a number of possible modifications of the basic DLT principle. These deal with different methods of injecting carriers into the DL (depletion layer) of a reverse biased *p-n* junction, *e.g.*, by irradiation with light or microwaves. It is rather difficult to visualize how light irradiation, whether perpendicular or parallel to the junction, is to accomplish carrier injection into the DL. Consider first the case where illumination is perpendicular to the junction. In silicon, visible radiation is absorbed in a very thin layer of material so that substantially all the electron-hole pairs are produced on the incident side of the junction and not in the DL region. Thus the time response is determined by the rate of diffusion of the electrons to the junction. The difficulty persists if the illumination is parallel to the plane of the junction. The surface layer, in which the radiation is absorbed, is distorted from the condition necessary for the setting up of a DL by the presence of the surface state. In the DLT, the metal electrode contact penetrates through this surface state and injects carriers into the DL region. I should like to point out that carrier injection by irradiation can be accomplished if irradiation is performed by means of a high energy electron beam. A number of years ago I carried out work on the injection of electrons into the high electric field region of a solid-state diode by electron bombardment of the aluminum-doped side of the diode. This device was described in my U. S. Patent No. 2,527,981 (October, 1950). The data indicated that, for one of the designs cited in the patent, the potential across a silicon-aluminum diode could be adjusted to produce current multiplication. This multiplication was generated by strong electric fields across the dielectric, which caused many electrons to be raised into the conduction band of the diode for every electron of the bombarding beam. The energy of the bombarding beam must, of course, be sufficiently high so that the electrons can penetrate beyond the junction into the strong electric field region of the diode. A brief discussion of this early work was recently included in a symposium paper.[2]

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* Received by the IRE, December 19, 1957.

[1] W. W. Gärtner, Proc. IRE, vol. 45, pp. 1392–1400; October, 1957.

[2] A. Bramley and J. E. Rosenthal, "Photoconductive Switching Devices," presented at the Symposium on the Role of Solid-State Phenomena in Electric Circuits, Polytech. Inst. Brooklyn, Brooklyn, N. Y.; April, 1957.

Author's Comment[3]

Dr. Rosenthal has questioned how generation of carriers in a depletion layer by light could lead to useful microwave amplifiers. This point will be briefly discussed in the following.

The device proposed[4] consists of a suitable modulator which modulates a light beam by the microwave signal. This light beam is then detected by what may be called a "depletion layer photocell" (DLPC). In such a photocell optical excitation of carriers takes place only in the depletion layer. If this depletion layer is properly designed[1] the transit time of the generated carriers will be very short, and depletion layer photocells may be expected to exceed any other photocell in response rate. The power gain of such an amplifier which has no internal feedback is given by the ratio of the power required to modulate the light, over the output power from the photocell.

In this discussion we want to concentrate on the design of depletion layer photocells.

The shortest response time will evidently be obtained if the carriers travel the entire distance of the depletion layer at their maximum limiting velocities.[5–9] This may be achieved in a *p-i-n* junction with a high resistivity layer sandwiched between two highly doped regions, and with an applied reverse voltage high enough for the electric field anywhere in the depletion layer to exceed the minimum field strength necessary for the carriers to reach their maximum velocities.[5–9] Modifications of this structure consist of metal contacts instead of one or both highly doped semiconductor regions. The latter case would correspond to a metal semiconductor-metal (MSM) photocell, which has a minimum of internal series resistance.

[3] Received by the IRE, March 6, 1958.

[4] In this connection, see also, K. Lehovec, "New photoelectric devices utilizing carrier injection," Proc. IRE, vol. 40, pp. 1407–1409; November, 1952.

[5] E. J. Ryder and W. Shockley, "Mobilities of electrons in high electric fields," *Phys. Rev.*, vol. 81, pp. 139–140; January, 1951.

[6] W. Shockley, "Hot electrons in germanium and Ohm's law," *Bell Sys. Tech. J.*, vol. 30, pp. 990–1034; October, 1951.

[7] E. J. Ryder, "Mobility of holes and electrons in high electric fields," *Phys. Rev.*, vol. 90, pp. 766–769; June, 1953.

[8] E. M. Conwell, "High field mobility in germanium with impurity scattering dominant," *Phys. Rev.*, vol. 90, pp. 769–772; June, 1953.

[9] E. M. Conwell, "Mobility in high electric fields," *Phys. Rev.*, vol. 88, pp. 1379–1380; December, 1952.

The upper limit for the applied reverse voltage is given by the postulate that nowhere in the depletion layer does the electric field reach a value which produces carrier multiplication[10–14] except for the case where multiplication is desired as a means to enhance the response, similar to the photomultiplier.

When the transit time of the generated carriers through the depletion layer becomes comparable to the reciprocal of the frequency at which the light beam is modulated, then transit time effects will come into play.[15]

The light may strike the depletion layer parallel or perpendicular to the planes of the junctions. In the first case a certain penetration depth must be assured by choosing wavelengths with an absorption coefficient of approximately 3×10^{-4} to 10^{-2} cm^{-1}. For germanium[16] this range lies in the infrared; for silicon[16] it is at the boundary between visible and infrared radiation; and for some wider band-gap semiconductors the absorption edge occurs fully in the visible region. Several intermetallic compounds fall into this category. On the other hand, if a response into the long-wavelength infrared is desired, one will use narrow-band gap semiconductors like InSb, or wide-band gap semiconductors doped so as to possess impurity levels inside the forbidden zone.

More promising, however, than this kind of photocell appears to be one in which the light strikes the depletion layer perpendicular to the junction plane as in a diffused solar battery. This case is illustrated in Fig. 1. The depletion layer may, *e.g.*, be set up between a semiconductor and a metal contact [Fig. 1(a)]. Light penetrates into the depletion layer through a slit in the metal contact. The wavelength range is chosen such that all radiation is absorbed in the depletion layer and none is absorbed in the bulk of the semiconductor, thus preventing any limitation in response time by diffusion of carriers. In this and in the following example, the depletion layers may be made as thin as capacitance considerations permit and transit times of carriers will become extremely short. Instead of the simply slitted metal contact one might also use a comblike structure with multiple slits, if permissible by capacitance considerations. Fig. 1(b) shows a modification of depletion layer photocells on which encouraging experiments have been carried out at the U. S. Army Signal Engineering Laboratories.[17,18]

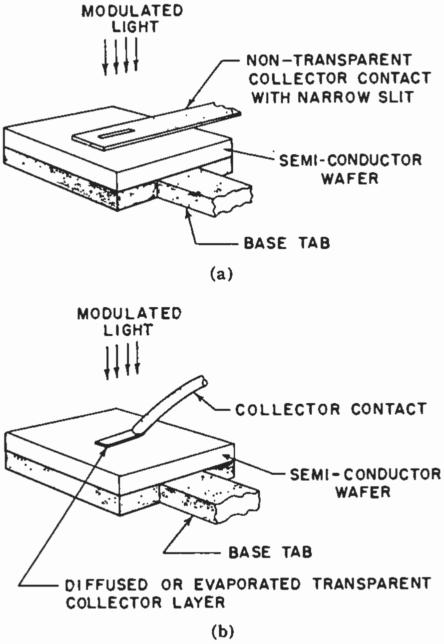

Fig. 1—Conceivable structures for depletion layer photocell with very short response time.

The upper contact consists of a thin and transparent metal or semiconductor layer, evaporated or plated onto the semiconductor wafer. Conventional photocells have been built by this principle in germanium.[19–23] For our specific purposes they must be designed so that the junction capacitance and the internal series resistance as well as the carrier transit time through the depletion layer are small. The wavelength of the incident light must be suitably chosen so that it does not penetrate further than the depletion layer and no carrier diffusion can take place. The evaporated metal contact will not cause any problem in this respect. The upper contact might also consist of a semiconductor with a wider band gap than the base wafer (*e.g.*, silicon on germanium) and one could then use a wavelength at which the contact is already transparent. Diffused surface layers, such as in solar batteries, are suitable only if they are extremely thin and highly doped. A metal-semiconductor-metal photocell has the added advantage that the solid metal contact, if properly chosen, will reflect all light back into the depletion layer, so that the absorbing distance is at least twice the width of the depletion layer.

We have concentrated in this discussion on the short response time of the DLPC. It may be well, however, to point out that for a given response time, τ, and a given photon flux the DLPC will pass more current than any other solid-state photosensitive device with no internal amplification or carrier multiplication simply because in no other device do the carriers travel at their maximum possible velocity[6–9] during their entire active lifetime ($\sim\tau$). The limitations here are the high voltages required for long response times, and the difficulty of making very thick uniform depletion layers, so that the main advantage of the design will be in the range of fast response times.

The current from the DLPC may be delivered into a high resistance load because of the high impedance of the reverse biased *p-n* junction. These features, combined with the possibility of carrier multiplication in properly constructed and biased units, may make the DLPC a very attractive device.

It thus appears that the generation of carriers in a depletion layer by light is a soluble problem and that such depletion layer photocells will have a shorter response time than practically any other existing photosensitive device.

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[10] K. G. McKay and K. B. McAfee, "Electron multiplication in silicon and germanium," *Phys. Rev.*, vol. 91, pp. 1079–1084; September 1, 1953.
[11] K. G. McKay, "Avalanche breakdown in silicon," *Phys. Rev.*, vol. 94, pp. 877–884; May 15, 1954.
[12] P. A. Wolff, "Electron multiplication in silicon and germanium," *Phys. Rev.*, vol. 95, pp. 1415–1420; September 15, 1954.
[13] S. L. Miller, "Avalanche breakdown in germanium," *Phys. Rev.*, vol. 99, pp. 1234–1241; August 15, 1955.
[14] E. Groschwitz, "Zur Stossionisation in Silicium and Germanium," *Z. Physik*, vol. 143, pp. 632–636; January, 1956.
[15] W. W. Gärtner, "Design theory for depletion layer photocells," *Rev. Sci. Instr.*, to be published.
[16] H. Y. Fan, "Infrared absorption in semiconductors," *Rep. Progr. Phys.*, vol. 19, p. 107; 1956.
[17] W. W. Gärtner and H. Mette, "Photoconductive and photovoltaic effects across semiconductor surface depletion layers," presented at APS meeting, Washington, D. C.; May 1–3, 1958.
[18] H. Mette and W. W. Gärtner, "Metal-to-semiconductor interfacial photoeffects on silicon," presented at APS meeting, Washington, D. C.; May 1–3, 1958.
[19] S. Benzer, "High inverse voltage germanium rectifiers," *J. Appl. Phys.*, vol. 20, pp. 804–815; August, 1949.
[20] J. I. Pantchechnikoff, "A large area germanium photocell," *Rev. Sci. Instr.*, vol. 23, p. 135; March, 1952.
[21] E. Simon, "Large Area Photovoltaic Cells," Purdue University Rep. under Signal Corps Contract DA36-039 sc-15339; July 1, 1953.
[22] B. Gossick, J. Mayer, and J. Kemmerly, "Characteristics of a Germanium Surface Barrier Photo-Diode," Purdue University Rep. under Signal Corps Contract DA36-039-sc-63222; November, 1955.
[23] E. Simon, "Germanium Photovoltaic Cell," Transitron Electronic Corp. Rep. under Signal Corps Contract DA36-039 sc-54698; May 1, 1956.

On the Transmission Error Function for Meteor-Burst Communication*

We have shown[1] that the fractional binary error p for meteor-burst communication using narrow-band frequency modulation is approximately proportional to the integral

$$F(a, r_t) = \int_{r_t}^{\infty} e^{-r} r^{-(1+a/2)} dr \qquad (1)$$

where r_t is the threshold signal-to-noise power ratio, and a is a parameter that depends upon the meteor characteristics.[2] The integral has been approximated in the form of a finite series. [The formula for this series is given incorrectly in Montgomery and Sugar;[1] the coefficient under the summation sign in (14) and (22) should read $\Gamma(i+1+a/2)/\Gamma(1+a/2)$.] The approximation is adequate when $r_t > 3$, but for smaller values of r_t a better approximation would be useful.

In a recent note,[3] Gautschi has demonstrated the inequality

$$\frac{1}{2}\left[(2+y)^b - y^b\right] < b e^y \int_y^{\infty} z^{b-1} e^{-z} dz < \frac{1}{c}\left[(c+y)^b - y^b\right] \qquad (2)$$

where $0 < b < 1$, $0 \le y < \infty$, and

$$c = \left[\Gamma(b+1)\right]^{1/(b-1)}. \qquad (3)$$

* Received by the IRE, January 14, 1958.
[1] G. F. Montgomery and G. R. Sugar, "The utility of meteor bursts for intermittent radio communication," Proc. IRE, vol. 45, pp. 1684–1693; December, 1957.
[2] L. L. Campbell, "Bandwidth considerations in a JANET system," Proc. IRE, vol. 45, pp. 1658–1660; December, 1957.
[3] Walter Gautschi, "Some elementary inequalities relating to the gamma and incomplete gamma function," to be published.

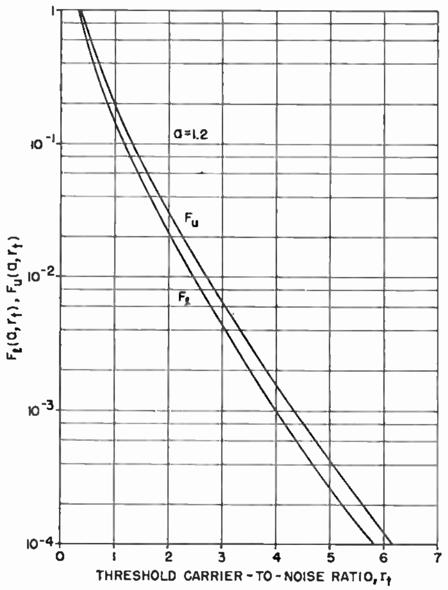

Fig. 1

If (1) is integrated by parts,

$$F(a, r_t) = \frac{2}{a} r_t^{-a/2} e^{-r_t} - \frac{2}{a}\int_{r_t}^{\infty} r^{-a/2} e^{-r} dr. \quad (4)$$

Then, if $b = 1 - a/2$, where $0 < a < 2$,

$$< 1 - \frac{2}{2-a}\left[\frac{1 + r_t/2}{(1 + 2/r_t)^{a/2}} - \frac{r_t}{2}\right]$$

$$\frac{a}{2} r_t^{a/2} e^{r_t} F(a, r_t) \quad (5)$$

$$> 1 - \frac{2}{2-a}\left[\frac{1 + r_t/c}{(1 + c/r_t)^{a/2}} - \frac{r_t}{c}\right]$$

where

$$\frac{1}{c} = [\Gamma(2 - a/2)]^{2/a} \quad 6)$$

and the the lower and upper bounds $F_l(a, r_t)$, $F_u(a, r_t)$ can be calculated easily for small r_t. These functions have been plotted in Fig. 1 for $a = 1.2$. In the range of r_t for which it is plotted, Fig. 6 in Montgomery and Sugar[1] corresponds more closely to F_u than to F_l.

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Harmonic Generation at Microwave Frequencies Using Field-Emission Cathodes*

The possibility of using the nonlinear current-voltage characteristic of field-emission cathodes for harmonic generation has been mentioned by several authors [1], [2].

* Received by the IRE, January 13, 1958. The research reported in this document was supported jointly by the U. S. Army Signal Corps, the U. S. Air Force, and the U. S. Navy (Office of Naval Research).

The progress achieved by the researchers at Linfield Research Institute, toward making the field emitter a practical device [3], makes it important to seriously consider various possible applications such as harmonic generation. Particularly encouraging for high-frequency applications is the extremely high current density emitted. Currents of the order of one ampere can be obtained from point emitters with an area of about 10^{-8} cm^2, and the pulsed powers reported for some cathodes have been as high as half a megawatt [1]. Furthermore, the nonlinear form of the emission characteristic remains true even at very high frequencies, due to the lack of appreciable time-delay effects in the field-emission phenomenon. These facts seem to indicate the possibility of generating appreciable power at high microwave frequencies by starting at fundamental frequencies where high-power drivers are available.

The analysis presented here gives expressions for the harmonic amplitudes in terms of the emission properties of the cathodes and the operating conditions. It is shown that the analytical difficulties presented by the peculiar form of the current-voltage relationship and by the nature of the parameters controlling the operation can be solved by the use of approximations valid under practical operating conditions.

The result is an equation for the harmonic amplitudes in the emission current from a field emitter subjected to rf modulation, from which the effects of the various parameters may be seen directly, and which may be used directly to calculate the performance of any field emitter for which the basic parameters are known. As a check, values calculated from this equation have been found to be consistent with values calculated by Dyke [4] obtained by numerical Fourier analysis of the known emission curve of a particular field emitter.

Fig. 1 shows a sketch of the current-voltage characteristic of a typical field emitter [5], [6]. With the coordinates chosen, the curve is a straight line for low currents, and bends slightly for higher values. If such an emitter is simultaneously subjected to a dc bias voltage V_0 and to a sinusoidal voltage $V_1 \cos \omega_0 t$, the current will vary in a nonsinusoidal manner. To produce a current rich in harmonics, we must use values of V_1 at least as large as the bias V_0 so as to have the current flowing in short pulses, as shown in Fig. 2. In this case, we can make two approximations.

In the first place, the curved characteristic of Fig. 1 can be replaced by a straight line tangent to it at the point corresponding to maximum instantaneous voltages: $V_m = V_0 + V_1$ and current: I_m. This straight line is entirely specified by the two parameters I_∞ and σ shown in the figure. The characteristic can then be expressed by

$$I = I_\infty e^{-\sigma/V}. \quad (1)$$

The portion of the curve where the approximation is not valid corresponds to low currents, that is, to the lower part of the pulses of Fig. 2. Furthermore, the current approximated in this way gives pulses which are wider and so, presumably, of lower harmonic content, at least for small harmonic orders. This means that the straight line gives a

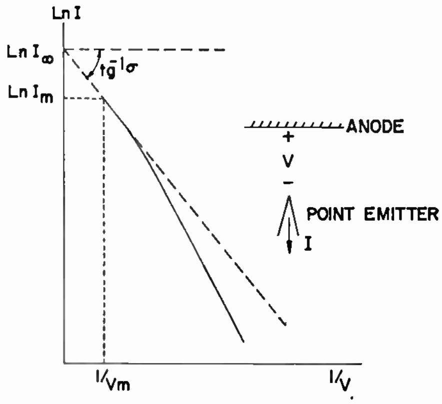

Fig. 1—Schematic emission characteristic (solid curve) and straight line approximation (broken line) for field emission diode sketched in inset.

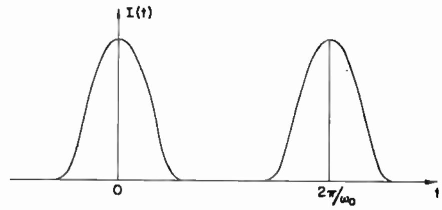

Fig. 2—Schematic representation of current from biased field emitter.

lower limit to the harmonic amplitudes to be expected from the true curve.

In the second place, $\cos \omega_0 t$ can be replaced by the first two terms of its power expansion:

$$\cos \omega_0 t \cong 1 - 1/2(\omega_0 t)^2. \quad (2)$$

To study the range of validity of this approximation, let us define two dimensionless parameters:

$$p = \sigma/V_m \qquad q = V_1/V_m.$$

The values of p from published characteristics [5], [6] are usually between five and ten. q depends on the choice of V_0 and V_1, and should be made as large as possible to increase the harmonic content. We can make V_1 larger than V_m by taking a negative V_0, so as to have $q > 1$.

When p and q are large enough to yield narrow current pulses, the time variation of $\cos \omega_0 t$ is important only near $\omega_0 t = 0$ (or an integer multiple of 2π), because elsewhere the current is zero or negligible. Fig. 3 shows a plot of the current pulses sketched in Fig. 2 for several choices of p and q. The continuous lines are for the two-term approximation, while the broken lines are the exact curves.

Using (1) and (2), we can express the current $I(t)$ produced by the voltage $V(t) = V_0 + V_1 \cos \omega_0 t$:

$$I(t) \cong I_\infty \exp\left[-\frac{\sigma}{V_0 + V_1 \cos \omega_0 t}\right]$$

$$\cong I_\infty \exp\left[-\frac{\sigma}{V_1 + V_0} - \frac{\sigma}{2} V_1 \frac{(\omega_0 t)^2}{(V_0 + V_1)^2}\right]$$

$$= I_\infty \exp\left[-p - \tfrac{1}{2} pq(\omega_0 t)^2\right]$$

$$= I_m \exp\left[-\tfrac{1}{2} pq(\omega_0 t)^2\right]. \quad (3)$$

The values of I_m, and so of V_m, are limited by the maximum tolerable heating

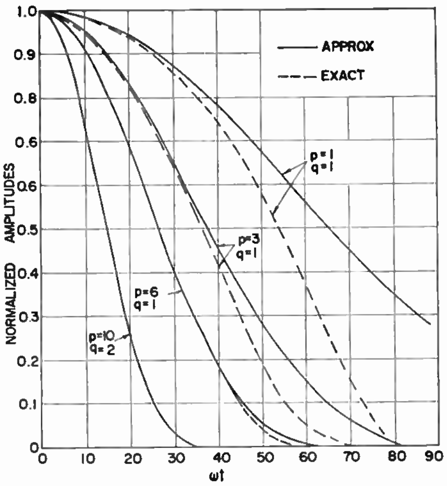

Fig. 3—Instantaneous current normalized to its peak value for various combinations of parameters p and q. Solid curves are using (2).

of the emitter, which depends upon the rms value of the emitted current, I_{rms}. We can relate I_{rms} to the other parameters

$$I_{rms}^2 = \frac{1}{2\pi}\int_{-\pi}^{\pi} I^2(t)d(\omega_0 t)$$
$$= \frac{1}{2\pi}\int_{-\infty}^{\infty} I_m^2 \left[\exp - pq(\omega_0 t)d(\omega_0 t)\right]$$
$$= \frac{I_m^2}{2\sqrt{\pi}\sqrt{pq}} \cdot \quad (4)$$

Substituting the value of I_m from (4) into (3), we have:

$$I(t) = \sqrt{2}\pi^{1/4}(pq)^{1/4}I_{rms}\exp\left[-\tfrac{1}{2}pq(\omega_0 t)^2\right]. \quad (5)$$

This is the current in one pulse. The Fourier transform of this expression gives the envelope of the Fourier coefficients for the periodic sequence of pulses. Letting $F(\omega)$ be the transform of $I(t)$, we have for the nth harmonic current amplitude I_n

$$I_n = \omega_0 F(\omega) = \frac{I_{rms}}{\pi^{1/4}(pq)^{1/4}}\exp - \frac{(\omega/\omega_0)^2}{2pq} \quad (6)$$

where ω/ω_0 can assume only integral values n, equal to the order of the harmonic.

The exponential part of this expression is plotted in Fig. 4 as a function of the variable $n/\sqrt{pq}$, and provides a universal curve of harmonic amplitudes for any emitter and any operating voltages. The broken lines are plots, with the same normalized variables, of Fourier analysis of the corresponding curves of Fig. 3, showing how the approximation improves for higher values of the product pq.

Considering I_n to be a function of pq, we can find the maximum possible amplitude of each harmonic:

$$(I_n)_{max} = \frac{0.492\, I_{rms}}{\sqrt{n}} \quad (7)$$

when

$$pq = 2n^2. \quad (8)$$

This value of n, giving maximum amplitude for each value of pq, is used in Fig. 4 to normalize the harmonic amplitudes.

The maximum amplitude attainable for each harmonic is seen to vary as $n^{-1/2}$. The

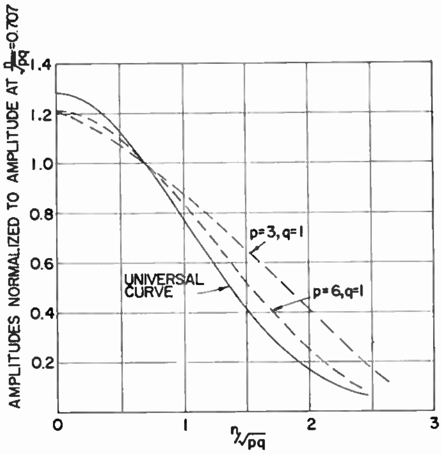

Fig. 4—Curves of normalized current amplitude vs normalized harmonic order.

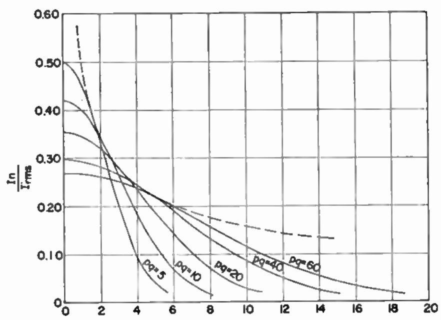

Fig. 5—Current amplitudes for several values of pq vs harmonic order. Broken line is envelope given by (8).

product pq can be controlled by varying V_1/V_0 and keeping V_m so as to satisfy (4). However, the back voltage during the non-conducting half-cycle is $(2q-1)V_m$ and might rapidly acquire unreasonably large values.

Fig. 5 shows current amplitudes for the various harmonic orders n, computed from (6), with pq as a parameter. Maximum possible amplitudes are given by the broken line, using values of pq given by (8).

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First Meeting on Radio Climatology*

The past few years has seen a rapid increase in the amount of research effort on the utilization of standard weather observations for radio propagation studies. Since the data utilized are basic to any radio-meteorological or radio-climatological study, a meeting of government agencies engaged in radio-climatology was held at the Boulder Laboratories of the National Bureau of Standards on January 15, 1958. The following groups were represented:

1) Central Radio Propagation Laboratory of the National Bureau of Standards,
2) Headquarters of the Third Weather Group, Air Defense Command, U. S. Air Force,
3) U. S. Army Signal Radio Propagation Agency,
4) U. S. Army Electronic Proving Ground,
5) U. S. Navy Weather Research Facility,
6) U. S. Naval Electronics Laboratory.

The following composed the agenda:

1) Non-overlapping geographic coverage in climatological calculations.
2) Uniform calculations of basic parameters and presentation of data.
3) Free exchange of data between groups, or the establishment of a central data pool.

The points unanimously agreed upon were:

1) Future calculations should use the constants $K_1 = 77.6$ and $K_2 = 4810$ in the expression for refractivity:

$$N = \frac{K_1}{T}\left(P + \frac{K_2 e_s RH}{T}\right),$$

where P is the station atmospheric pressure in millibars, RH is the per cent of the saturation vapor pressure, e_s, in millibars at the absolute temperature, T, in degrees Kelvin.

2) An immediate listing should be made of past data that are available for general use. It was decided that the most workable method was for each group to submit a listing of their data to the Radio Meteorology Section of the Central Radio Propagation Laboratory and they then would compile the individual lists and issue a report on all available data. Future calculations would be recorded in the same fashion.

3) Since the National Weather Records Center (NWRC) does not keep the IBM cards with the calculated values of refractivity beyond six months, it was agreed to request that all such cards be sent to the Central Radio Propagation Laboratory.

4) Calculation of radio refractivity from significant level radio-sonde data will undoubtedly be done at the National Weather Records Center and thus a uniform presentation of calculations to be adopted is that of NWRC Job No. 8100 which gives a listing

* Received by the IRE, March 3, 1958. A listing of the data available from the participants of this meeting has been compiled and can be obtained from the author.

(in this order) of: station, year, month, day, hour, pressure, temperature, relative humidity, height difference, N gradient, N and station elevation. Any additional information should be added to the end of this listing, thus maintaining the same rows of each card for the same information and reducing the probability of needless error in future calculations based upon these data.

5) Minimum calculations necessary to define the climatology of a station would be five years of daily observations during the months of February, May, August, and November.

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A Possible Simplification of Stereophonic Audio Systems*

Binaural or stereophonic reproduction of speech and music should offer "realism" improved over single-channel systems because of the apparent spatial distribution of the sound source. This note suggests an economy in the design of such multichannel systems—the use of only one full-range channel with the supplementary channel or channels carrying only a restricted bandwidth.

There is considerable experimental evidence that, at least for pure tones, the human observer cannot determine the direction of the source of sounds of frequencies higher than about 1000 cycles.[1] At lower frequencies the distance between the ears is less than a wavelength, and the phase difference in the sound waves arriving at the two ears makes the determination of source direction possible. At frequencies above about 1000 cycles, the phase difference changes so rapidly with frequency as to be confusing, and the information is therefore disregarded. There is presumably some lower cutoff frequency as well, although a casual search of the literature does not show any information about this.

It appears very likely, then, that in a stereophonic system for speech or music there is little point in transmitting and reproducing the full range of audibility in both channels since the audience will not benefit by the spatial dispersion of the high-frequency sounds. Furthermore, it may well be that the lower frequency limit of spatial localization is principally determined by room acoustics and that reproduction of frequencies below 100 cycles or so does not add significantly to the "realism" of the reproduced sound.

If these conjectures are correct, a considerable simplification of stereophonic systems is available. For broadcast transmission spectrum space can be saved by transmitting one full-frequency-range channel and one (or more) reduced-bandwidth channels for stereophonic enhancement of the program. The savings in reproducing equipment, especially transducers, are evident. Stereophonic disk or tape recording and playback equipment should be significantly less expensive than if two full-range channels are necessary; in fact, it might be possible to record the additional channel as a modulated high-frequency subcarrier on disks or tapes, thus requiring only one playback stylus or head, rather than the two currently being used. Alternatively, if two full-range channels are available, part of the second channel might be used for transmitting gain-control signals, so that the dynamic range of the program can be improved.

The savings possible from such a system arrangement should encourage the further investigation necessary. Careful experimental work is needed to indicate whether the presence of frequency components of speech and music above 1000 cycles and below 100 cycles in the supplementary channels of a stereophonic system really contributes to the "realism" of the reproduced program. Such experimental work should result in the setting of standards for the bandwidth and signal-to-noise ratio required of the supplementary channels.

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* Received by the IRE, January 14, 1958.

[1] J. L. Hunter, "Acoustics," Prentice-Hall, Inc., Englewood Cliffs, N. J., pp. 274–276; 1957.

Noise in Mixer Tubes*

It is usually stated without proof, that the noise in mixer tubes can be calculated by averaging over a complete local oscillator cycle.[1] We show here that a rigorous proof can be given if the noise has a white spectrum, whereas it will be indicated with the help of an example that the theorem is incorrect if the spectrum is not white.

First we prove the theorem for the simplest case, *viz.*, the case of zero feedback, since it illustrates the general procedure that has to be followed. The case of a diode mixer, in which an appreciable feedback occurs, can then be treated in the same manner.

The final result obtained is the outcome of an intricate mixing process. This is the reason why the theorem is incorrect if the noise spectrum is not white.

Proof of the Theorem for Zero HF Feedback

Let dI_0 be the emission current due to electrons emitted with an initial energy between V_0 and (V_0+dV_0) volts. Let at the instant τ a small fluctuation δI_0 of duration $\Delta\tau$ occur in dI_0 and let δI_0 have a white spectrum. The corresponding fluctuation δI_a in anode current is then:

$$\delta I_a = \gamma(V_0, t)\delta I_0. \tag{1}$$

Here δI_0 is present under all conditions, but the space charge suppression factor $\gamma(V_0, t)$ is now not only a function of V_0, but also a periodic function of $\omega_h t$ with period 2π, where ω_h is the local oscillator frequency. Considered as a function of $\omega_h t$, we may thus write:

$$\gamma(V_0, t) = \gamma_0(V_0) + 2\gamma_1(V_0)\cos\omega_h t + 2\gamma_2(V_0)\cos 2\omega_h t + \cdots. \tag{2}$$

Furthermore the conductance (or transconductance) $g(t)$ of the tube is a periodic function of $\omega_h t$ with period 2π, so that:

$$g(t) = g_0 + 2g_{c1}\cos\omega_h t + 2g_{c2}\cos 2\omega_h t + \cdots. \tag{3}$$

We now make a Fourier analysis of δI_0; thus:

$$\delta_0 I = \sum_{n=0}^{\infty} a_n \cos\omega_n(t-\tau) \tag{4}$$

where $\overline{a_n^2}$ is independent of ω_n, since the spectrum is white. We may thus write $a_n = a$ for all frequencies ω_n of practical interest.

We now substitute (4) and (2) into (1) and take along all terms in δI_0 that can give the IF frequency ω_0. These frequencies are:

$$\omega_n = \omega_0 \text{ and } \omega_n = |m\omega_h \pm \omega_0|. \tag{5}$$

Multiplying out the various terms in (1) we obtain after some calculation:[2]

$$\begin{aligned} &b\cos\omega_0(t-\tau) \\ &= a[\gamma_0(V_0) + 2\gamma_1(V_0)\cos\omega_h\tau \\ &\quad + 2\gamma_2(V_0)\cos 2\omega_h\tau + \cdots]\cos\omega_0(t-\tau) \\ &= a\gamma(V_0, \tau)\cos\omega_0(t-\tau). \end{aligned} \tag{6}$$

We now take averages and integrations in the following order:

1) Average over an ensemble of identical systems, all having a fluctuation δI_0 at the instant τ.

2) Summation over all instants τ for which $(\omega_h\tau - 2\pi m)$ $(m = 0, 1, 2, \cdots)$ has the same value. This sums over equivalent pulses of different periods.

3) Integration over all values of V_0.

4) Summation over a full cycle of the local oscillator.

The first averaging gives:

$$\overline{b^2} = \overline{a^2}[\gamma(V_0, \tau)]^2. \tag{7}$$

The second step (summation over equivalent instants) gives:

$$\Delta(\overline{di_a^2}) = 2edI_0 df \cdot \frac{\Delta(\omega_h\tau)}{2\pi}[\gamma(V_0, \tau)]^2 \tag{8}$$

where

$$dI_0 = I_s e^{-V_0/V_T} d(V_0/V_T) \tag{9}$$

is the emission current due to electrons emitted with initial energies between V_0 and (V_0+dV_0) electron volts.[3] The third step yields:

$$\overline{\Delta i_a^2} = \epsilon 4kTg(\tau)df\frac{\Delta(\omega_h\tau)}{2\pi} \tag{10}$$

* Received by the IRE, January 7, 1958.

[1] Compare, *e.g.*, A. van der Ziel, "Noise," Prentice-Hall Inc., Englewood Cliffs, N. J., ch. 9; 1954.

[2] The term $2\gamma_m(V_0)\cos m\omega_h t\{a\cos(m\omega_h+\omega_0)(t-\tau)+a\cos(m\omega_h-\omega_0)(t-\tau)\}$ in (1) gives the following terms of frequency ω_0: $a\gamma_m(V_0)\cos[\omega_0(t-\tau)+m\omega_h\tau]+a\gamma_m(V_0)\cos[\omega_0(t-\tau)-m\omega_h\tau]=2a\gamma_m(V_0)\cos m\omega_h\tau\cos\omega_0(t-\tau)$. This proves (6).

[3] This result is easily seen, for one should obtain:

$$\overline{di_a^2} = 2edI_0 df\gamma^2(V_0)$$

if $\gamma(V_0, t)$ is independent of t and (8) is integrated over a complete cycle.

where $g(\tau)$ is the value of $g(t)$ at $t=\tau$ and ϵ has the usual meaning.[4] The validity of (10) is easily seen, since it must give the well-known diode and triode formulas if $g(t)$ is independent of t. Finally the last step gives:

$$\overline{i_a^2} = \epsilon 4kTdf\frac{1}{2\pi}\sum_{\Delta\tau} g(\tau)\Delta(\omega_h\tau)$$

$$= \epsilon 4kTdf\frac{1}{2\pi}\int_{-\pi}^{\pi} g(\tau)d(\omega_h\tau) = \epsilon 4kTg_0 df \quad (11)$$

where the summation is carried over all intervals $\Delta\tau$ of a complete cycle; the summation can, of course, be replaced by an integration. Since g_0 is the average of $g(t)$ taken over a complete cycle, the theorem has thus been proved for the case of zero feedback.

Proof for Diode Mixer Tubes with an Appreciable Amount of HF Feedback

We now treat the case of the diode mixer. Here we have to take into account both the IF and the hf signal caused by the mixing process. Looking at current pulses in the time interval $\Delta\tau$, caused by electrons emitted with an energy between V_0 and (V_0+dV_0) volts, we obtain an IF noise current:

$$b_0 \cos\omega_0(t-\tau) = a\gamma(V_0,\tau)\cos\omega_0(t-\tau) \quad (12)$$

and an input noise current:

$$b_i \cos\omega_i(t-\tau) = a\gamma(V_0,\tau)\cos\omega_i(t-\tau) \quad (13)$$

where the notation is the same as before.

We now observe that the noise figure of the mixer is independent of the output impedance. It is thus allowed to short-circuit the output; this removes all interaction between output and input. The hf noise signal gives rise to an input noise voltage of frequency ω_i, which by mixing gives an IF output noise current (frequency ω_0):

$$-F_c a\gamma(V_0,\tau)\cos[\omega_0(t-\tau)-\omega_h\tau] \quad (14)$$

where F_c is the current amplification factor (output noise current divided by input noise current) of this mixing process. Adding (12) and (14) and averaging over an ensemble gives the mean square amplitude:

$$\overline{b^2} = \overline{a^2}[\gamma(V_0,\tau)]^2(1-2F_c\cos\omega_h\tau + F_c^2). \quad (15)$$

We now have to sum again carefully. We first sum over all equivalent intervals $\Delta\tau$.[5] This gives in analogy with (8):

$$\Delta(\overline{di_a^2}) = 2edI_0 df\frac{\Delta(\omega_h\tau)}{2\pi}[\gamma(V_0,\tau)]^2$$

$$\cdot(1-2F_c\cos\omega_h\tau+F_c^2) \quad (16)$$

where dI_0 has the same meaning as before. Integration over all V_0 gives in analogy with (10):

$$\Delta\overline{i_a^2} = \epsilon\cdot 4kTg(\tau)df\frac{\Delta(\omega_h\tau)}{2\pi}$$

$$\cdot(1-2F_c\cos\omega_h\tau+F_c^2) \quad (17)$$

[4] That is, $\epsilon=\theta T_c/T$ for a diode and $\epsilon=\theta T_c/\sigma T$ for a triode, where T is room temperature, T_c is cathode temperature, and θ and σ are constants introduced in the regular noise theory of diodes and triodes.

[5] They are the intervals for which $(\omega_h\tau-2\pi m)$ $(m=0, 1, 2)$ has the same value.

where $g(\tau)$ is the conductance (or transconductance) at the instant τ. Taking the sum over all intervals $\Delta\tau$ of a complete cycle gives:

$$\overline{i_a^2} = \epsilon\cdot 4kTdf\frac{1}{2\pi}\int_{-\pi}^{\pi} g(\tau)[1-2F_c\cos\omega_h\tau$$

$$+F_c^2]d(\omega_h\tau)$$

$$= \epsilon\cdot 4kTg_0 df\left(1-2F_c\frac{g_{c1}}{g_0}+F_c^2\right). \quad (18)$$

Putting

$$\epsilon\cdot 4kTg_0 df = 4kTR_{nc}df;$$

$$\overline{i_a^2} = 4kTR_{nc}'g_{c1}^2 \quad (19)$$

we have:

$$R_{nc}' = R_{nc}\left[1-2F_c\frac{g_{c1}}{g_0}+F_c^2\right]. \quad (19a)$$

The averaging theorem is now proved for a diode mixer. In addition we have given a rigorous proof of (9.35) of van der Ziel's book.

A similar proof can be given for the feedback mixer. The proof proceeds along the same lines as in the diode mixer case.

An Example of a Nonwhite Spectrum for Which the Theorem Is Not Valid

We note from the proofs in the previous sections that the result is the outcome of an intricate mixing process. The theorem is a consequence of the fact that the spectrum was white, for we assumed that the individual Fourier amplitudes a_n were independent of frequency. It will now be shown with the help of an example that the theorem becomes incorrect if the spectrum is not white.

Consider a vacuum tube showing a flicker effect that is due to a true fluctuation δI_s in the emission current I_s. In that case the fluctuation δI_a in anode current is:

$$\delta I_a = \frac{kT_c g_m}{eI_s}\delta I_s \quad (20)$$

where g_m is the transconductance of the tube and T_c is the cathode temperature.[6]

If the tube is used as a mixer, the emission current I_s and the fluctuation δI_s will not be affected by the mixing, but *the mixing process will generate two flicker noise sidebands around the local oscillator frequency* ω_h. For

$$\delta I_s = \sum_n a_n\cos\omega_n t \quad (\omega_n = 2\pi f_n) \quad (21)$$

where $\overline{a_n^2}$ varies as $1/f_n$ (as is usual in flicker effect), and

$$g_m = g_{m0} + 2g_{mc1}\cos\omega_h t$$

$$+ 2g_{mc2}\cos 2\omega_h t + \cdots. \quad (22)$$

Substituting into (20) we obtain for $\omega_h \ll \omega_n$:

$$\delta I_a = g_{mc1}\left[\sum_n a_n\cos(\omega_h-\omega_n)t\right.$$

$$\left.+\sum_n a_n\cos(\omega_h+\omega_n)t\right] \quad (23)$$

plus sidebands of frequencies $2\omega_h$, $3\omega_h$, etc.

If mean square values are now taken for frequencies around the local oscillator frequency, we obtain a result that cannot be deduced from the averaging theorem. This theorem should thus only be applied if the noise spectrum is white. Moreover, the above proof shows that the theorem is by no means obvious and that it is worthwhile to prove it before applying it.

[6] van der Ziel, *op. cit.*, ch. 8.

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The Forward Switching Transient in Semiconductor Diodes at Large Currents*

It was pointed out in a letter by Salzberge and Sard[1] that previous papers have not given an adequate theory for the forward switching transient in a semiconductor diode. (See Fig. 1.) This switching transient, which is most troublesome at high currents, can be explained in terms of the current modulation of the resistance of the bulk of the semiconductor diode.

The resistance of the bulk of the semiconductor diode can be calculated to a first approximation from a rather simple model of the diode shown in Fig. 2. The form of the resistance is the same in both the p and the n region; however, the p region is usually so heavily doped that its resistance is negligible. In this case, the resistance of the bulk of the diode can be calculated from the distribution of the minority carriers in the n region. The resistivity of a semiconductor is given by:

$$\rho = \frac{1}{q(\mu_p p + \mu_n n)} \quad (1)$$

where q is the charge on an electron, μ_n is the electron mobility, n is the density of electrons, μ_p is the hole mobility, and p is the density of holes. The distribution of holes in the n region is given approximately by:

$$p = p_n(e^{qv/kT}-1)e^{-x/L_p} \quad (2)$$

where p_n is the equilibrium density of holes in the n material, v is the voltage across the junction, k is Boltzmann constant, T is the absolute temperature, x is the distance from the center of the junction into the n region, and L_p is the diffusion length for holes. Space-charge neutrality requires that the majority carrier distribution is given by $n=n_n+p-p_n$ where n_n is the equilibrium density of electrons in the conduction band.

The steady-state resistance of the bulk of the diode is obtained by integrating the resistivity ρ over the bulk of the diode. In the case where the dimensions of the bulk of the

* Received by the IRE, October 28, 1957. This work was supported by joint services contract N6onr 251(07).

[1] B. Salzberg and E. W. Sard, "Fast switching by use of avalanche phenomena in junction diodes," Proc. IRE, vol. 45, pp. 1149–1150; August, 1957.

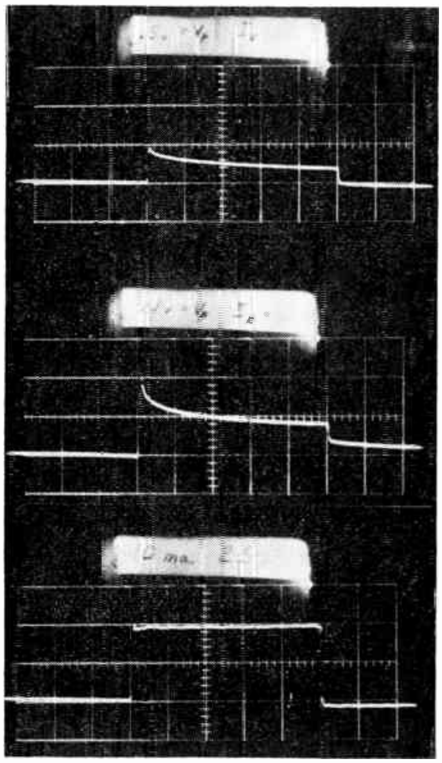

Fig. 1—The forward switching transient for a constant current pulse as a function of the bias for a Raytheon in 307 made from N-type material with $\rho_s \approx 5$ ohm cm.

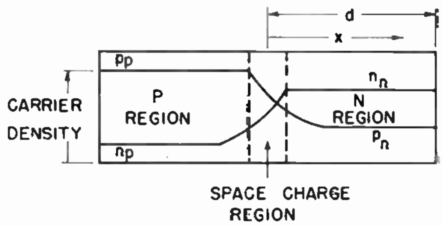

Fig. 2—The distribution of carriers in a semiconductor diode.

diode are large compared to the diffusion length L_p, $R(I)$ is given approximately by:

$$R(I) \approx \frac{\rho_0}{A}\left[d - L_p \ln \cdot \left(1 + \frac{(p - p_n)(\mu_p + \mu_n)}{(\mu_n n_n + \mu_p p_n)}\right)\right]. \quad (3)$$

Converting (3) to measurable parameters one gets

$$R(I) = R_0 - \alpha \ln (1 + \rho_0 \psi I \quad (4)$$

where

$$R_0 = \frac{\rho_0}{A} d, \quad \rho_0 = \frac{1}{q(\mu_n n_n + \mu_p p)}.$$

$$\psi I = q(p - p_n)(\mu_p - \mu_n)$$

and A is the area of the junction.

This resistance $R(I)$ can be seen to decrease rapidly at large steady-state currents.

The distribution of carriers in the bulk of the semiconductor cannot change instantaneously. In switching a diode to a large forward current, there is initially a resistance R_0 in series with the junction so that

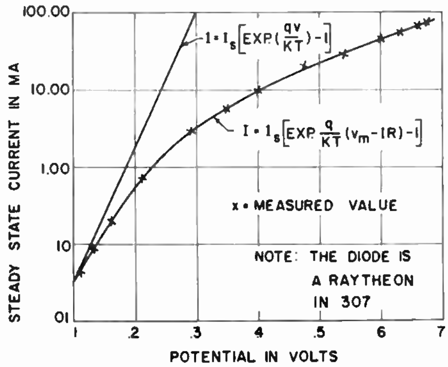

Fig. 3—The dc characteristics of a semiconductor diode.

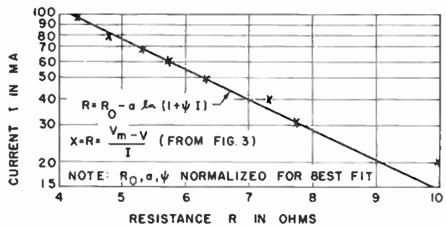

Fig. 4—The bulk resistance of a semiconductor diode as a function of current.

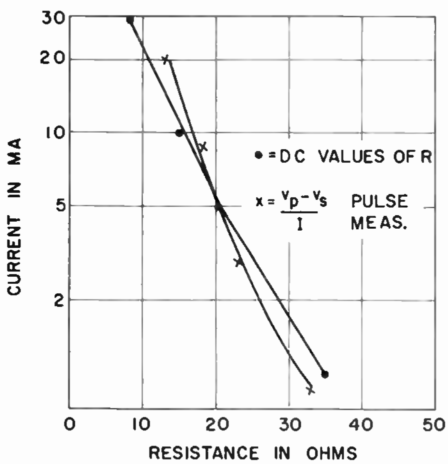

Fig. 5—A comparison of the values of $R(I)$ as measured by dc and pulse methods.

the voltage-current relation across the diode may be described by

$$I = I_s(e^{q/kT(V_m - IR_0)} - 1) \quad (5)$$

where I_s is the saturation current and V_m is the measured voltage across the diode. At a later time in steady state R_0 must be replaced with $R(I)$.

Values for R which can be compared with (4) may be measured easily in two ways. The difference between the simple theory for p-n junction diode,

$$I = I_s(e^{qv/kT} - 1), \quad (6)$$

and the measured voltage-current relation may be used to compute an effective $R(I)$ for (5). For the diode described in Fig. 3 it may be seen in Fig. 4 that this value of R agrees well at large currents with the value of R predicted by (4). A second approximate method of measuring $R(I)$ is to assume that the voltage across the junction proper is constant during a current pulse. In this case $\Delta R(I)$ may be defined by $(V_p - V_s)/I$, where V_p is the initial voltage, V_s, the steady-state voltage, and I, the constant current. This $\Delta R(I)$ is the change in resistance due to current modulation of the diode. If the current is large enough, then $R(I)$ steady state can be assumed to be small compared to the initial $R(I)$. By varying the bias on the diode and assuming that $R(I)$ steady state is negligible, one can obtain a rough estimate for $R(I)$ at $t = 0^+$.

For the diode described in Fig. 3, a comparison of the values of $R(I)$ as measured by the two methods is made in Fig. 5. Although the approximation for the distribution of carriers at large currents is not as accurate as might be desired, the experimental results appear to be sufficiently good to justify the use of (4). Experiments on a series of diodes showed the voltage transient is minimized by using diodes with low bulk resistance, or by biasing the diode with a small forward current.[2]

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[2] F. S. Barnes, "A Representation of DC Characteristics and Transient Response of Commercial Semiconductor Diodes," Signal Eng. Lab., Tech. Rep. No. 8; August, 1956.

On the Codification of Lagrangian Formulation*

Lagrange's equations and the concepts of energy represent much of what is referred to as classical mechanics. Lagrangian techniques for formulating dynamical equations of motions are generally assumed as fundadamental, and as having universal application to physical systems. Presentation of the Lagrangian techniques in the compact notation of matrix algebra for linear systems is helpful in clarifying what is meant by generalized coordinates. More important, matrix notation places in evidence a fundamental limitation of the Lagrangian technique.

Energy and Related Functions

The Lagrangian formulation technique is based on the premise that the physical system can be resolved into a collection of smaller and less complex subsystems, for each of which an energy function can be defined. The smaller and less complex subsystems are frequently referred to as components of the physical system and are identified by such names as spring, mass, resistor, inductor, transistor, rotating machine, etc. In nuclear physics the subsystems are the various particles of the nucleus.

The energy functions associated with each system component are invariably defined in terms of two fundamental observations or measurements. In the case of electrical components the fundamental observa-

* Received by the IRE, January 13, 1958.

tions are realized through the use of the voltmeter and ammeter, and in translational mechanical components through the use of the force and displacement meters. To establish the energy variables to be associated with the components, a knowledge of the mathematical relationship between the two fundamental variables is necessary. There is no loss of generality, as far as central core of the technique is concerned, when the components are considered linear; *i.e.*, the fundamental variables are related by a linear mathematical function.

If the two fundamental variables associated with the components of the physical system are represented by the elements of the column matrices $\mathfrak{X}(t)$ and $\mathfrak{F}(t)$, then the set of equations showing the linear mathematical relationship between the fundamental variables of each component can be written in the form

$$\mathfrak{F}(t)=\mathfrak{K}\mathfrak{X}(t)+\mathfrak{B}\dot{\mathfrak{X}}(t)+\mathfrak{M}\ddot{\mathfrak{X}}(t)+\mathfrak{F}_0(t). \quad (1)$$

The coefficient matrices $\mathfrak{K}$, $\mathfrak{B}$, and $\mathfrak{M}$ are, of course, square but need not be diagonal.

The potential energy function, $V(t)$, for the entire system, expressed as a function of the component variables in $\mathfrak{X}(t)$ is the quadratic form

$$V(t) = \tfrac{1}{2}\mathfrak{X}'(t)\mathfrak{K}\mathfrak{X}(t) \quad (2)$$

where $\mathfrak{X}'(t)$ is the transpose of $\mathfrak{X}(t)$.

In a similar manner the kinetic energy function $T(t)$ and the dissipation factor $D(t)$ for the entire system are given by

$$T(t) = \tfrac{1}{2}\dot{\mathfrak{X}}'(t)\mathfrak{M}\dot{\mathfrak{X}}(t) \quad (3)$$

$$D(t) = \tfrac{1}{2}\dot{\mathfrak{X}}'(t)\mathfrak{B}\dot{\mathfrak{X}}(t). \quad (4)$$

The Lagrangian function, $L(t)$ is defined as

$$L(t) = T(t) - V(t). \quad (5)$$

In addition to the energy and dissipation factors defined above, a fourth function, $E(t)$, is required in the Lagrangian technique of formulation to include the specified component variables, such as regulated voltage or current sources, and displacement and force drivers. The $E(t)$ function for the entire system is defined as

$$E(t) = \mathfrak{F}_0'(t)\dot{\mathfrak{X}}(t). \quad (6)$$

Lagrange's Equations

In the usual presentation, a special form of Lagrange's equations for a dissipationless system with no specified driving functions (forces, displacements, voltages, currents, etc.) is derived from some other basic principle of mechanics such as the Hamiltonian principle. Additional terms or corrections are then injected into the equation to include the so-called dissipation effects and specified driving forces. An alternate starting point, and one which appears to be no more or less fundamental is simply to accept Lagrange's equations as a basic postulate of classical mechanics in the same way that Maxwell's field equations are taken frequently as the basic postulates of electromagnetic field theory.

Such a postulational statement of Lagrange's equation is:

Let the $L(t)$, $D(t)$, and $E(t)$ functions for a linear system be defined as in (4) through (6), then there exists a set of n independent generalized coordinates (variables, $q_1(t)$, $q_2(t) \cdots q_r(t) \cdots q_n(t)$ such that

$$\frac{d}{dt}\left(\frac{\partial L(t)}{\partial \dot{q}_r(t)}\right) - \frac{\partial L(t)}{\partial q_r(t)} + \frac{\partial}{\partial \dot{q}_r(t)}(D(t)+E(t)) = 0. \quad (7)$$

Dynamical Equations of Motion

Note that the partial differentiation required in (7) cannot be realized until the $L(t)$, $D(t)$, and $E(t)$ functions for the system are expressed as explicit functions of the generalized coordinates $q_1(t)$, $q_2(t) \cdots q_r(t) \cdots q_n(t)$. These required explicit relations can only be established by expressing the component variables in $\mathfrak{X}(t)$ as *explicit* functions of the generalized coordinates $q_1(t), q_2(t) \cdots q_r(t) \cdots q_n(t)$. This implies the relation

$$\mathfrak{X}(t) = \mathfrak{A}'\mathfrak{Q}(t) \quad (8)$$

where $\mathfrak{Q}(t)$ represents some set of variables (generalized coordinates). Success of the Lagrangian technique depends upon the determination of the transformation matrix, $\mathfrak{A}$. Although it is asserted in classical mechanics that at least one such transformation exists, no statement is made as to the number of variables in $\mathfrak{Q}(t)$ and no general procedures are given for establishing the $\mathfrak{A}$ matrix. If the system is not too complex, $\mathfrak{A}$ can be obtained from inspection. However, for a complex system, such as a control system or complex electrical network, the problem of establishing the $\mathfrak{A}$ matrix in (8) is one of major proportions to say the least.

Proceeding for the moment on the basis that the transformation matrix in (8) can be established, the $L(t)=T(t)-V(t)$, $D(t)$, and $E(t)$ functions for the system are expressed in terms of the generalized coordinates by simply substituting (8) into (2), (3), (4), and (6) with the result

$$L(t) = T(t) - V(t) = \tfrac{1}{2}\dot{\mathfrak{Q}}'(t)(\mathfrak{A}\mathfrak{M}\mathfrak{A}')\dot{\mathfrak{Q}}(t) - \tfrac{1}{2}\mathfrak{Q}'(t)(\mathfrak{A}\mathfrak{K}\mathfrak{A}')\mathfrak{Q}(t) \quad (9)$$

$$D(t) = \tfrac{1}{2}\dot{\mathfrak{Q}}'(t)(\mathfrak{A}\mathfrak{B}\mathfrak{A}')\dot{\mathfrak{Q}}(t) \quad (10)$$

$$E(t) = \mathfrak{F}_0'(t)\mathfrak{A}'\dot{\mathfrak{Q}}(t). \quad (11)$$

These functions can now be differentiated successively with respect to the variables in $\mathfrak{Q}(t)$ as required by Lagrange's equation, to establish the dynamical equations of motion for the system. This can be accomplished systematically by the application of the following two theorems which are stated without proof.

Theorem I: Let $\mathfrak{G}$ be an $n\times n$ symmetric matrix, and $\mathfrak{Y}$ a column matrix of n elements. When the quadratic form $\tfrac{1}{2}(\mathfrak{Y}'\mathfrak{G}\mathfrak{Y})$ is differentiated successively with respect to the elements of $\mathfrak{Y}$, $(y_1, y_2, \cdots, y_n)$ the result is a linear form

$$\mathfrak{G}\mathfrak{Y}. \quad (12)$$

Theorem II: Let $\mathfrak{X}$ and $\mathfrak{Y}$ be column matrices with n and m elements, respectively, and $\mathfrak{H}$ be an $m\times n$ constant-coefficient matrix. If the bilinear form

$$\mathfrak{Y}'\mathfrak{H}\mathfrak{X}$$

is differentiated successively, with respect to the elements of $\mathfrak{X}$, then the result is a linear form

$$\mathfrak{H}'\mathfrak{Y}. \quad (13)$$

Upon applying the above theorems to each partial differentiation required in Lagrange's equation, (7), for the $L(t)$, $D(t)$, and $E(t)$ functions appearing in (9) through (11), the dynamical equations of motion in terms of the generalized coordinates, $\mathfrak{Q}(t)$, are obtained. They are of the form,

$$\mathfrak{A}\mathfrak{M}\mathfrak{A}'\ddot{\mathfrak{Q}}(t)+\mathfrak{A}\mathfrak{B}\mathfrak{A}'\dot{\mathfrak{Q}}(t)+\mathfrak{A}\mathfrak{K}\mathfrak{A}'\mathfrak{Q}(t) + \mathfrak{A}\mathfrak{F}_0(t) = 0. \quad (14)$$

The Lagrangian technique for formulating the equations of motion for physical systems is contingent upon one's ability to determine the number of generalized coordinates required to describe the system. The variables used to define the energy function of the system must be explicitly related to these generalized coordinates. Apparently a general procedure for establishing this relationship has not been set down in classical mechanics. Consequently, it appears that Lagrangian techniques of classical mechanics are not self-sufficient for the analysis of complex physical systems such as those encountered in automatic control.

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Michigan State University
East Lansing, Mich

Comment on "A Mathematical Analysis of the Kahn Compatible Single-Sideband System"*

To the Editor:

I am submitting this letter in response to your request for my comments on Dr. J. P. Costas' paper.[1]

I found this paper to be quite interesting and in some respects gratifying in that it confirms our original analysis of our *simplified* block diagram.

However, in view of the fact that Dr. Costas' analysis is based upon the simplified system and not on what we consider an up-to-date technique, I wonder whether his limited analysis might tend to confuse the issue. I feel that it would be interesting to the readers of the Proceedings to learn about some actual tests which were made on broadcast transmitters adapted to CSSB operation.

Measurements have been made by a number of highly competent engineering organizations, including Westinghouse Broadcasting, WSM Broadcasting, independent consulting engineers, and others. Mr. Harmon, who is Vice-President for Engineering of Westinghouse Broadcasting, in a recent paper given at the National Association of Broadcasters in Los Angeles, reported that the Compatible Single-Sideband Adapter,

* Received by the IRE, June 3, 1958.
[1] Pp. 1396–1401, this issue.

now operating at Radio Station KDKA, measured total harmonic distortion of 2.4 per cent at 100 per cent modulation at 1000 cycles, while the transmitter alone measured 2.2 per cent. The desired to undesired sideband ratio at 1000 cycles was approximately 30 db. These are actual off-the-air measurements using a 50-kw Westinghouse transmitter which produces a peak envelope power of 200 kw. Other measurements made by WMGM indicate figures of up to 32 db of desired to undesired sideband radiation at 100 per cent modulation with low over-all distortion. Clearly, these measurements, as well as others made by highly competent engineering groups, prove that the system does produce results far better than those indicated in the Costas analysis.

By the way, it is interesting to note that this is Dr. Costas' second attempt to analyze this system. The first written analysis was proven incorrect on two counts: first, the mathematics, and second, the fact that it was also based on the simplified block diagram.

It is quite evident that any system analysis must start with a full understanding and knowledge of the system involved. This we believe is the fundamental error in this second attempt at analysis and not the accuracy of the mathematical techniques employed.

Please refer to the "Scanning the Issue" section of this issue, page 1349, where the editors of the PROCEEDINGS point out that "the limitation of the analysis stems primarily from the fact that the full details of the system are not known and from certain simplifying assumptions made by the author."

In fairness to Dr. Costas, we should point out that we reached conclusions similar to those of Dr. Costas concerning the simplified block diagram a number of years ago. However, at that time we recognized means for reducing the undesired to desired sideband ratio to a point which we have now demonstrated in actual use.

I would also like to take this opportunity to point out that the Compatible Single-Sideband system which we have recently developed for communications purposes is quite different from the broadcast Compatible Single-Sideband system. The communications system has theoretically no undesired sideband output but it has approximately 3 per cent harmonic distortion. Of course, as is presently true with all practical single-sideband equipment, economic limitations restrict the sideband ratio to some 35 to 40 db. We, of course, have included all undesired sideband radiation components in these figures.

As a final thought, in response to your invitation for my comments, I would suggest that the publication of this article would be premature at the present time, and its publication should instead be withheld at least until I publish a full disclosure upon approval of our patent attorneys.

LEONARD R. KAHN
Pres., Kahn Res. Labs., Inc.
Freeport, L. I., N. Y.

On the Mass Education of Scientists*

Our President and Congress are now, as an aftermath of the Soviet satellite excitement, embarking on a crash program of mass education. But, it is nothing short of fallacious and dangerous nonsense to assume that the expenditure of billions for a mere, if great, increase in our annual crop of B.S., M.A., and Ph.D. graduates will keep us astride or ahead of our ideological and mortal enemies abroad; the kind of brains we need cannot be bought with all the world's billions.

You can dump, into every willing mind in the country, all the separate bits of physical knowledge which man has accumulated through the ages, but there is scant assurance that they will retain them; nor can you assume that those minds will have and will add that mysterious catalyst which we call creativeness.

This requires something more than putting known *A* and *B* and *C* together in ways already done by others to produce old or new and useful combinations of knowledge. More often than not, it requires a still higher degree of creativeness: the addition of a new, hitherto-unknown ingredient, *X*, which he himself must invent. Even before this there must be in that mind a nonconformity which is ever dissatisfied with the status quo, dreaming and scheming of better ways and means to solve man's problems.

Only a few have the rare ability. These are the inventive-minded pioneers who chart the courses of the future highways of progress. These are the uncommon men. Educating, to the *n*th degree, as many as you like of the others, can never give them that magic touchstone of creative passion.

* Received by the IRE, February 10, 1958.

Archimedes had it; Fulton and Eli Whitney and Singer had it; Morse, Bell, Tesla, Goodyear, Edison, Ford, the Wrights, DeForest, and a few others also had it. But they were hardly a handful among millions, equally or better trained in science.

Our quest then, as Harvard's Dr. Pusey and du Pont's Greenewalt have emphasized, must be for these uncommon, creatively-endowed men, these very special "geese who lay the golden eggs" of technological progress, without whom we would still be living like the Neanderthal man.

Our great industrial laboratories would have us (and their stockholders) believe that their project teams of so-called experts can and do solve all of our scientific and engineering problems, but this is only wishful thinking. For one thing, "too many cooks spoil the broth." For another, history belies this commercial propaganda.

Examine the records of all the great milestones along the road of our progress, and you will find that practically all were planted there by sheer outsiders. In science, literature, painting, sculpture, music, architecture, it is always the same; the uncommon, ofttimes frenzied, single mind, with nary a thought of money, has created the greatest of man's accomplishments. No group of experts in any field ever *created* anything great, or ever will.

From all reports, the U.S.S.R. has had sense enough to search out, and to provide every conceivable stimulus and reward, for its creatively endowed citizenry. But we, in sharp contrast, have been sitting complacently on our bottoms, secure in the delusion of our scientific omniscience. We have allowed to drift, into a miserably inadequate, even hostile, climate, what once was a fertile and flourishing one for invention. Our patent output has fallen to almost one half in thirty years. Who hasn't heard that a patent is only an invitation to a tremendously expensive law suit?

Educating our talented young men in science is fine, for the facts of science and the ability to use them are some of the building blocks of tomorrow's jig-saw puzzle, but all the trained seals of that type can, without creativity, do no more than the old tricks.

What is far more important is a vast improvement in the inventive climate. That means working facilities, recognition, and rewards. With such proper encouragements we need never fear for our security today or our leadership tomorrow.

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Contributors

Harold M. Barlow (SM'54–F'56) was born in London, England, on November 15, 1899. He was educated at the City and Guilds Engineering College and University College London, where he is now Pender Professor of electrical engineering. He served during World War I with the British Navy as a Sub-Lieutenant R.N.V.R., and during World War II he was Superintendent of the Radio Department, Royal Aircraft Establishment. He has a special interest in microwave engineering.

H. M. Barlow

Professor Barlow is a member of the Council of the British Institution of Electrical Engineers and a Fellow of University College London.

❖

Stanley Bloom was born on October 18, 1924, in Plainfield, N. J. He received the B.S. degree in physics and mathematics from Rutgers University, New Brunswick, N. J. in 1948, and the Ph.D. degree in theoretical physics in 1952 from Yale University, New Haven, Conn. His dissertation work was on pressure broadening of spectral lines.

S. Bloom

In 1952, Dr. Bloom joined the RCA Laboratories, where he has worked on traveling-wave tubes, molecular amplification, plasmas, and parametric amplification.

He is a member of the American Physical Society, Sigma Xi, and Phi Beta Kappa.

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Detlev W. Bronk was born in New York, N. Y. He holds the degrees of A.B., M.S., Ph.D., Sc.D., LL.D., Eng. D., D. Med., D. Litt., M.D. (honorary), and D. of Humane Letters. Among these are 27 honorary degrees, including three conferred by Queen's University, Belfast, Ireland, Cambridge University, England, and the Royal Caroline Medico-Surgical Institute, Stockholm, Sweden.

D. W. Bronk

He was president of Johns Hopkins University, Baltimore, Md., 1948–1953; president, American Association for the Advancement of Science, 1952; foreign secretary, National Academy of Sciences, 1946–1951; chairman, National Research Council of the National Academy of Sciences, 1946–1951; director, Johnson Research Foundation for Medical Physics, University of Pennsylvania, Philadelphia, Pa., 1929–1949, and coordinator of research, Office of the Air Surgeon, U. S. Army, 1942–1946.

He is president of the National Academy of Sciences, president of The Rockefeller Institute, chairman of the National Science Board, National Science Foundation, and vice-chairman of the National Advisory Committe for Aeronautics.

Dr. Bronk is a trustee of Johns Hopkins University, University of Pennsylvania, Rockefeller Foundation, Rockefeller Brothers Fund, and many other institutions. He is a member of the President's Science Advisory Committee, Defense Science Board (Department of Defense), the Science Advisory Board to the Chief of Staff, U. S. Air Force, and the Science Advisory Panel, U. S. Army. He holds foreign membership in the Royal Society of London, French Academy of Sciences, Royal Danish Academy of Sciences and Letters, and the Swedish Academy.

❖

Kern K. N. Chang was born in Shanghai, China, on September 9, 1919. He received the B.S. degree from the National Central University, Nanking, China, in 1940; the M.S. degree in electrical engineering from the University of Michigan, Ann Arbor, Mich. in 1948, and the D.E.E. degree from the Polytechnic Institute of Brooklyn, Brooklyn, N. Y. in 1954.

K. K. N. Chang

From 1940 to 1945, he was associated with the Central Radio Manufacturing Works, Kunming, China, working on radio receivers and from 1945 to 1947, he was a radio instructor in the Office of Strategic Service, U. S. Army, China Theater. Since 1948, he has been at RCA Laboratories, Princeton, N. J., where he has engaged in research on magnetrons, traveling-wave tubes, beam-focusing devices, and parametric amplifiers.

Dr. Chang is a member of Sigma Xi.

❖

John P. Costas (S'46–A'51–SM'56) was born on September 16, 1923, in Wabash, Ind. He received the degree of Bachelor of Science in electrical engineering from Purdue University, Lafayette, Ind., in 1944. He then served with the U. S. Navy as radar officer and attended the Harvard and M.I.T. radar schools.

In 1946, he returned to Purdue, and received the degree of Master of Science in electrical engineering in 1947. He then entered M.I.T. and received the degree of Doctor of Science in 1951.

Dr. Costas has been employed by the General Electric Company since 1951 and is presently a consulting engineer in the Heavy Military Electronic Equipment Department of the Defense Electronics Division at Syracuse, N. Y.

J. P. Costas

He is a member of Eta Kappa Nu, Tau Beta Pi, and RESA and is a licensed Professional Engineer in the State of New York. Dr. Costas also serves as a consultant to the Assistant Secretary of Defense (R&E) on problems of long-range Air Force Communications.

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Frederic H. Dickson (S'38–A'43–M'55) was born in Bristol, Colo., on January 10, 1916. He received the B.S. degree in electrical engineering from Oregon State College in 1939, where he was a graduate assistant in electrical engineering until 1940. Prior to entering the military service in 1942, he was an instructor in the Air Corps Technical Schools. He served as an assistant radio officer, Allied Forces Headquarters and as Assistant Signal Officer, Fifteenth Army Group, European Theater, and returned from overseas as Executive Officer and later Commanding Officer of the Signal Corps Radio Propagation Unit.

F. H. Dickson

After being discharged from the military service in 1946, he joined the Office of the Chief Signal Officer and became Chief of the Radio Propagation Section in 1950. In 1954, he became chief of the U. S. Army Signal Radio Propagation Agency, which is engaged in application engineering and operational research in the field of radio wave propagation.

Mr. Dickson is a member of the U.S.A. National Committee of URSI, and is International Vice-Chairman of Commission IV. He is a registered professional engineer in the District of Columbia.

❖

Harold E. Dinger (A'27–M'43–SM'43–F'58) was born on May 7, 1905, in Barberton, Ohio. He studied at the University of Akron and the University of Maryland. From 1929 to 1939, Mr. Dinger was chief instructor at the McKim Technical Institute and during 1939 and 1940, he was transmitter engineer for the Ohio Broadcasting Company. Since 1940, he has been associated with the Naval Research Laboratory, specializing in radio wave propagation and radio interference problems. In 1947 he received the Navy's Meritorious Civilian Service Award and the ASA Achievement Award for his work in that field. He has also received letters of commendation from the Research and Development Board and the Department of State.

H. E. Dinger

Mr. Dinger has served on numerous panels and committees and has been a U. S. delegate to international assemblies of the International Electrotechnical Commission in Lucerne, 1947, and Paris, 1950; the International Radio Consultative Committee in London, 1953, and Warsaw, 1956; and the International Scientific Radio Union in Sydney, 1952, and Boulder, 1957.

He is a member of the Navy Frequency Allocation Board, the U. S. Executive Committee of the CCIR, and a past chairman of the U. S. Commission IV, URSI. Mr. Dinger is also a member of the American Institute of Electrical Engineers and the Scientific Research Society of America, and a Fellow of the American Association for the Advancement of Science.

❖

W. E. Garner (M'55) was born in Washington, D. C., on July 19, 1923. He received the B.E.E. degree from the Catholic University of America in 1944 and immediately joined the staff of the Naval Research Laboratory working in the field of radio interference. Shortly after, he was commissioned an Ensign in the U. S. Navy and was assigned to the Naval Research Laboratory, where he remained as a staff member following his discharge from active duty in 1945.

W. E. Garner

He has been engaged in research in radio interference, and in instrumentation and calibration methods for field strength measuring equipment.

More recently, he has been engaged in propagation studies and the associated instrumentation, and in atmospheric "whistler" research.

He is a member of the Scientific Research Society of America.

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F. T. Haddock, for a photograph and biography, please see page 367 of the January, 1958 issue of Proceedings.

D. H. Hamilton, Jr. (A'47) was born in New York, N. Y., on April 10, 1918. He attended the University of Virginia from 1936 to 1939. During World War II, he served with the 2nd Armored Division in field communications.

D. H. Hamilton, Jr.

He attended Capitol Radio Engineering Institute from 1946 to 1949. From 1949 to 1954, he was an engineer at the Boston television station of Westinghouse Electric Corporation. Since 1954, he has been a staff member of M.I.T. Lincoln Laboratory, where he has been engaged in research on tropospheric propagation and the development of scatter communication systems.

❖

Edward C. Jordan (S'36–A'39–SM'45–F'53) was born in Edmonton, Alberta, Canada, on December 31, 1910. He received the B.S. and M.S. degrees in electrical engineering from the University of Alberta and the Ph.D. degree from The Ohio State University, Columbus.

E. C. Jordan

He was chief operator of station C.K.U.A. for seven years while attending school, and then worked for two years as an electrical engineer for the International Nickel Company.

Since 1940 he has taught electrical engineering at Worcester Polytechnic Institute, Ohio State University, and the University of Illinois.

He was consultant on the antenna research program at Ohio State University from 1941–1945, and supervisor of research on antennas and radio direction finding at the University of Illinois from 1945 to 1954.

Dr. Jordan is presently professor and Head of the Department of Electrical Engineering at the University of Illinois.

He was chairman of U.S.A. Commission VI of URSI from 1953 to 1955, and chairman of Subcommission VI.III from 1955 to 1958 He has been a member of the Panel on Antennas and Propagation of the Research and Development Board, Department of Defense, and chairman of the Subpanel on Ground and Ship Antennas.

He is a member of the AIEE, ASEE, Sigma Xi, Eta Kappa Nu, and Tau Beta Pi.

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L. A. Manning (S'43–A'45–SM'54) was born in Palo Alto, Calif., on April 28, 1923. After receiving the A.B. degree in electrical engineering from Stanford University in 1944, he joined the wartime Radio Research Laboratory at Harvard University as a special research associate. The following year he returned to Stanford, and received the M.Sc. and Ph.D. degrees in 1948 and 1949, respectively.

He is now an associate professor of electrical engineering; his principal interests are in the field of ionospheric radio propagation.

L. A. Manning

Dr. Manning is a member of Sigma Xi, Phi Beta Kappa, the American Geophysical Union, the American Meteorological Society, and is serving on the U.S.A. National Committee of the International Scientific Radio Union.

❖

Kenneth M. Poole (A'54) was born in Staffordshire, England on September 27, 1927. He received the Bachelor of Arts degree in physics in 1948, and the M.A. and Ph.D. degrees in 1951, all from Oxford University, Oxford, England.

K. M. Poole

Since 1953, he has been a research physicist at Bell Telephone Laboratories, Murray Hill, N. J., where he has specialized in the fields of physical electronics and microwave research.

❖

William G. Shepherd (A'42–SM'49–F'52) was born August 28, 1911, in Fort William, Canada. He received the B.E.E. degree in 1933, and the Ph.D. degree in physics in 1937, both from the University of Minnesota, Minneapolis.

W. G. Shepherd

From 1937 to 1947 he was with Bell Telephone Laboratories. He then joined the faculty of the Department of Electrical Engineering of the University of Minnesota, where he worked on problems in electron emission. He was appointed Associate Dean of the Institute of Technology in 1954, a position he resigned in 1956 to become head of the Department of Electrical Engineering.

Dr. Shepherd is a member of the American Physical Society, Sigma Xi, and the Advisory Group on Electron Tubes. He is a member of the U.S.A. National Committee of URSI and has served as National Chairman of Commission VII. He is currently President of International Commission VII.

❖

John B. Smyth (SM'52–F'56) is a native of Georgia. He received the Bachelor's degree and the Master's degree from the University of Georgia and the Ph.D. degree from Brown University.

Dr. Smyth's experience includes one year as research physicist at Tennessee Eastman Corp. and ten years as director of the radio wave propagation research program for the Navy Electronics Laboratory. Since 1955, he has been president and technical director of Smyth Research Associates.

J. B. Smyth

Dr. Smyth's activities have also included contributions to the educational field. He helped organize the UCLA off-campus graduate program at NEL and acted as graduate advisor. He holds appointments as lecturer in engineering at the University of California at Los Angeles, and lecturer in physics at San Diego State College.

Dr. Smyth is a member of the American Acoustical Society, the American Association for the Advancement of Science, the American Physical Society, and the U.S.A. National Committee of URSI. He is editor of the Transactions of the IRE Professional Group on Antennas and Propagation and is the recipient of the 1954 IRE Seventh Regional Achievement Award. He is a member of Phi Beta Kappa, Phi Kappa Phi, Pi Mu Epsilon, Xi Phi Xi, and Sigma Xi.

❖

A. E. Teachman (A'27–VA'39–SM'49) was born in New Bedford, Mass., on July 23, 1904. He attended Eastern Radio Institute in 1924, completed the radio engineering course of National Radio Institute in 1928, and attended the post-graduate school of Capitol Radio Engineering Institute in 1934.

A. E. Teachman

From 1924 to 1937, he was engaged in the radio service business and was a consultant to Weston Electrical Instrument Corporation on the design of radio service test equipment. He joined the Columbia Broadcasting System in 1937 and became assistant supervisor in charge of maintenance and construction at their Boston outlet. As a commissioned officer in the Army Air Corps, he served during the war years at the Aircraft Radio Laboratory, Wright Field, where he was in charge of the radio noise research unit and was responsible for major improvements to aircraft engine ignition shielding systems. He was chairman of the Army-Navy committee on radio noise filters.

Since January, 1953, he has been a staff member of M.I.T. Lincoln Laboratory, where he has been engaged in research on medium frequency propagation and more recently on long-distance tropospheric propagation.

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Ping King Tien, for a photograph and biography please see page 791 of the April, 1958 issue of Proceedings.

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Ernst Weber, for a photograph and biography, please see page 34A of the March, 1958 issue of Proceedings.

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H. W. Wells, for a photograph and biography, please see page 373 of the January, 1958 issue of Proceedings.

Scanning the Transactions

How thin is thin? The human hair, long a favorite standard of comparison when speaking of minute objects, is looking bigger every day. Transistor fabrication techniques are producing dimensions that are incredibly small by any standard. Consider the base width of a transistor. For an alpha cutoff frequency of 50 megacycles the base width must be 0.2 mil or less, 200 mc calls for 0.1 mil, and 800 mc requires 0.05 mil. (Human hairs range from 7 mils to 0.2 mil.) Now, if you want to use an alloy process to form an emitter and collector on this already ultra-thin base, the alloy cannot penetrate the base by more than 0.01 mil without adversely affecting the base width. As a matter of fact, jet electrochemical techniques have now been developed for forming alloy contacts which will limit the depth of penetration to a mere 0.001 mil, or one-millionth of an inch. This is only one order of magnitude larger than the size of a corpulent molecule, and threatens to make obsolete another standard of comparison—the proverbial "skin of your teeth." The miracle of it all is that infinitesimal dimensions such as these can be made a regular part of a manufacturing operation involving a quantity produced item. (A. D. Rittman, *et al.*, "Microalloy transistor," IRE TRANS. ON ELECTRON DEVICES, April, 1958.)

How loud is loud? The answer depends not only on the physical magnitude of sound waves but also on the hearing process of the listener. The average person is considerably more sensitive to the intensity of sounds in the 1000 to 5000 cps range than at lower or higher frequencies. Thus a 1000 cycle tone sounds decidedly louder than a 100 cycle tone having the same sound pressure level. Work on gathering so-called psychoacoustical data, relating the physical characteristics of sound to their effects on the listener, has been going on for a quarter of a century. Experimenters have subjected numerous people to sounds of various intensities and frequencies to determine the relative apparent loudness of different sounds. These tests have made it possible to construct charts of sound intensity vs. frequency which show curves connecting points of apparent equal loudness.

More extensive tests recently carried out in England have yielded equal-loudness curves of greater accuracy and range than before, and have provided important additional data related to sex and age. For one thing, the results show that above 1 kc men judge the loudness of sounds differently than women, with men hearing "better" in the 1 to 5 kc range associated with speech. One is tempted to conclude that men hear speech better than women because (unfortunately) they get more practice listening. This doesn't turn out to be the right explanation, though. In fact, it has nothing at all to do with the hearing process itself. It is simply a case of men having bigger heads than women, and big heads diffract sound waves differently than little heads.

Who uses these equal-loudness curves? To cite one example, the New York City Fire Department. Concerned over the number of accidents between fire apparatus, they found that units approaching an intersection from different directions could not always hear one another over the noise of their own engines and sirens. The same noise made it difficult to hear radio messages in the cab. Detailed sound measurements were made which with the aid of the loudness curves established the maximum sound pressure levels that could be tolerated. These studies have led to the design of appropriate engine mufflers, the installation of air horns with better directivity, and the specification of important improvements in mobile radio equipment. (D. W. Robinson, "A new determination of equal-loudness contours," IRE TRANS. ON AUDIO, January-February, 1958; N. J. Reinhardt, "Acoustic noise in vehicles," IRE TRANS. ON VEHICULAR COMMUNICATIONS, April, 1958.)

The future of industrial electronics, until recently a somewhat overlooked stepchild in the electronics family, looks rosy indeed. Economic circumstances in industry have literally forced the use of electronic techniques in so many cases that this new field of service has already quietly grown to surprising proportions. Industrial electronics has now risen to be a business doing well over $1 billion a year, and seems assured of reaching $2 billion by 1965. It passed the older and well-established business of radio six years ago. It is smaller than the other two major segments of the electronics industry, television and military electronics, but it is growing considerably faster than either of them and is already better than half as large as television. It is not at all improbable that we are now witnessing the beginnings of what will, in time, become the industrial electronics era. (E. D. Cook, "The economic and technical aspects of industrial electronics," IRE TRANS. ON INDUSTRIAL ELECTRONICS, April 1958.)

The study of man-machine systems is becoming increasingly important as machinery becomes more complex and the demands placed on the human operator increase. One of the principal problems is that of "language" differences among machines, and between machines and humans, giving rise to a somewhat Babylonian communication situation. Appropriate translators are needed at the input or output in order that the various parts of the system may function together. Where there is a choice, the best language must be decided on. In this connection it is interesting to note that although a digital counter indicator may avoid all possible errors in time reading, most watches continue to use the vectorial analog display of time.

Another problem in combining machines and men is determining and matching their information handling rates. Studies of the human indicate that his auditory channel capacity is about 10,000 bits per second, his visual channel capacity is about 4,000,000 bits per second, but the capacity of his brain to handle this information is only 30 to 40 bits per second. However, this apparently gross mismatch is offset by the brain's remarkable ability to scan incoming information rapidly and discard irrelevant information. The human being also has another outstanding ability, that of being able to adjust himself to changing situations. Although the machine approaches the human in storage capacity, it falls far short of the human in these capabilities. This raises a third consideration, namely, deciding which function should be performed by machine and which by a human operator.

Finding the optimum solutions to these problems in practical situations is difficult, but the motivation for finding them is great. It is an area of study that has become a field of engineering in its own right—a field, incidentally, that is now served by IRE's newest Group, the Professional Group on Human Factors in Engineering. (H. B. Ziebolz, "Communication problems between instruments, controls, and man," IRE TRANS. ON INDUSTRIAL ELECTRONICS, April, 1958; J. C. Groce, "General design considerations for man-machine systems," IRE TRANS. ON INSTRUMENTATION, March, 1958.)

What were the highpoints of computer progress in 1957? In the digital computer field the most noticeable development was the continuing trend toward larger, more complex and more ambitious computer systems, as typified by the Sperry-Rand LARC, the IBM STRETCH, and the RCA BIZMAC. These electronic monsters can operate 100 to 200 times faster than any previous general-purpose computer, multiplying 15 digit numbers at a rate of 500,000 a second and performing additions at about 2 million a second. It is significant that two of the newest entries in the large-scale computer field are completely tubeless: the LARC and Philco's TRANSAC.

The big news of 1957 regarding analog computers is the advent of the digital control unit. All of the major computer manufacturers now offer a method of setting up, programming, checking and reading out information by means of electric typewriter and punched paper tape. (R. P. Castanias and J. E. Sherman, "Review of computer progress in 1957," IRE TRANS. ON ELECTRONIC COMPUTERS, March, 1958.)

With transhorizon communication links flourishing from the Arctic to the Caribbean, it is interesting to note that scatter propagation is still far from being as well established in theory as in practice. In fact it now appears that the better known theories dealing with the role of atmospheric turbulence in scatter propagation, which seemed to be substantiated by experimental data, must be discarded. Meanwhile other descriptions of beyond-horizon propagation which are tenable from a theoretical standpoint are not supported by operational results. It is evident that our understanding of the role that turbulence plays in scatter propagation is as yet far from complete. (R. Bolgiano, Jr., "The role of turbulent mixing in scatter propagation," IRE TRANS. ON ANTENNAS AND PROPAGATION, April, 1958.)

The thermistor is quietly becoming a component of considerable importance, both as a versatile circuit element and a commercial product. The thermistor is a thermally sensitive resistor, the resistance of which decreases sharply as temperature increases. Over the past dozen years nearly a score of important uses have been found for it in connection with temperature and power measurements, temperature compensation and amplifier stabilization, and time delay and surge suppression circuits. As an example of the latter application, thermistors are being used in vacuum tube filament supply circuits in order that the heater voltage may be applied gradually. The purpose is to extend tube life by preventing thermal shocks to the filaments caused by the large inrush currents upon the sudden application of power. This idea, which has been used to some extent in television receivers, has now found important use in a large scale computer, where the long life of tens of thousands of tubes is a necessity. (J. J. Gano and G. F. Sandy, "Thermistors for the gradual application of heater voltage to thermionic tubes," IRE TRANS. ON ELECTRONIC COMPUTERS, March, 1958.)

Books

Propagation Tropospherique by Georges Boudouris

Published (1957) by Centre de Documentation Universitaire, 5, Place de la Sorbonne, Paris 5, France. 457 pages +5 bibliography pages. Illus. 6¾×9½.

This book covers the problems of radiowave propagation near the surface of the earth. It considers successively the case of the flat earth, the spherical earth, the mixed paths, and finally the effect of a nonhomogeneous troposphere. The title is perhaps misleading since it properly applies only to the last sixty pages of the book.

This book gives an orderly account of these various problems starting from fundamentals (Maxwell equations, plane waves, reflection coefficients, stationary phase, reciprocity principle . . .) and carries the deduction to the final formulas, to graphs and careful discussion of the approximations involved. It does therefore fill a gap in the literature where books have been written only on special aspects of these problems and reference to original articles is often necessary.

A casual glance at the book gives an impression of complicated mathematics. This comes from many deductions carried out explicitly and also from a justified respect for the notations of original papers. It is unfortunate, however, that the author did not try to simplify some of these notations. A judicious representation, by a single letter, of complicated but often repeated expressions can greatly simplify the typography and the understanding. The concept of surface impedance for example could have been introduced profitably when discussing approximate boundary conditions.

After two chapters of generalities, the flat earth problem is considered in Chapters III and IV. Approximate boundary conditions are used from the start and the Norton formulation is obtained. A short account of the Zenneck, Sommerfeld and Weyl theories is also given. Chapter V, on the spherical earth problem, follows the work of Van der Pol, Bremmer and Norton but also discusses briefly contributions by V. A. Fock. Chapter VI gives a good account of propagation over nonhomogeneous earth (mixed path problem). It reviews empirical methods and describes in some details the integral equation method introduced by Feinberg. The effect of distributed or isolated obstacles is also considered. Chapter VII on tropospheric propagation discusses the effect of a nonhomogeneous atmosphere: ducts, scatter propagation, absorption and diffusion of microwaves.

A few numerical examples are worked out illustrating each method and showing the proper concern for practical applications. Many important graphs and tables can be found in the text. On the whole the book is carefully written, and it should prove a useful reference to engineers working in this field.

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Fundamental Principles of Transistors by J. Evans

Published (1958) by D. Van Nostrand Co., 257 Fourth Ave., N. Y. 10. N. Y. 229 pages+15 appendix pages+1 bibliography page+5 index pages+xii pages. 139 figures. 8¼×5½. $6.75.

This text presents an elementary discussion of transistor electronics together with a good deal of information on transistor fabrication. Transistor circuitry or applications is not dealt with at all. The author states that the subject matter is intended mainly for newcomers in the field of transistors, even though it should also be of interest to the specialist in metallurgy, chemistry or electrical engineering who is also working on transistors and who wants a descriptive survey of the other branches of the art. The strongest aspect of the text is the disscussion of semiconductor device fabrication and the testing of semiconductor materials. The author explains clearly and simply the growing, alloying and diffusion technique for manufacturing *p-n* junction transistors. Point contact, grown, alloy, surface barrier, diffused base, tetrode, *p-n-i-p* and unipolar field-effect transistors are described. Techniques for measuring the resistivity, mobility and lifetime of semiconductor materials are discussed in some detail.

The development of semiconductor physics, though very lucid and readable, is entirely too brief. It is felt that any reader who desires more than a superficial understanding of the physics, would have to refer to other sources. The operation of the *p-n* junction and the junction transistor is described qualitatively without the use of the Fermi level concept. Only a few of the high frequency properties of the device are discussed. The author, except for one equivalent circuit, does not consider the problem of transistor representation at high frequencies. The material describing the measurement of transistor four-pole parameters is inadequate. The discussion of transistor noise, in addition to being incomplete, is actually misleading since it is based on obsolete junction transistors for which excess noise is the dominant source of noise in the device. Fundamental noise sources such as thermal, shot and partition, are not discussed.

It is felt that this book should be of interest to engineers who desire a description of transistor fabrication techniques as well as a very simple discussion of transistor electronics.

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Synthesis of Passive Networks by E. A. Guillemin

Published (1957) by John Wiley & Sons, Inc., 440 Fourth Ave., N. Y. 16, N. Y. 731 pages+9 index pages+xviii pages. Illus. 9¼×6¼. $15.00.

Network synthesis means many things to many people. To some, it is a collection of design techniques, for rather special electrical apparatus. To others, it is a theoretical discipline, which gives a deeper insight into many different engineering problems. To still others, it is an intellectual pursuit, interesting for its own sake. This book by Professor Guillemin is of real interest to all three of these network theory addicts. Design techniques are described in detail, but only after a sound development of concepts and ideas, derived from fundamental physical principles.

Network synthesis is usually divided into two parts. "Realization techniques" deal with the determination of networks which have assigned external characteristics, when the assigned characteristics can be realized exactly. "Approximation techniques" deal with the choice of exactly realizable characteristics which approximate more general assigned characteristics. For both kinds of techniques, mathematical characterizations of realizable external characteristics are essential.

Five chapters develop characterizations of realizable driving-point and transfer impedances, including brief accounts of equivalent and reciprocal networks and of relations between real and imaginary parts. Four chapters are devoted to the synthesis of circuits which contain only two kinds of elements (LC, RC, RL). Four chapters describe a number of the more complicated realization techniques, appropriate for networks which contain all three kinds of elements (RLC). One chapter develops approximation techniques for frequency functions, including Butterworth, Tschebycheff, and potential analogue methods. Finally, one chapter develops approximation techniques for time functions, including a Fourier method, use of "standard parts" or "building blocks," and other methods. The text relies heavily on two of the author's previous books: *The Mathematics of Circuit Analysis*, Wiley, 1949, and *Introductory Circuit Theory*, Wiley, 1953. A sequel to the present volume is promised for the future, on *Special Problems in Network Synthesis*.

While this is a thorough, comprehensive, and penetrating book for network theory addicts, it does not strike this reviewer as an inspiring book. It does not seem well calculated to make new network theory addicts out of normal mortals. This is surprising, since Professor Guillemin is an inspiring teacher, and has, in fact, done a very great deal to further interest in network theory. Perhaps the difficulty may be blamed on the point of view. The author conducts a fine guided tour of occupied territory, but he makes little effort to point out new territory, which is now being opened up or is likely to be in the future. As a single example, the chapter on equivalent networks describes linear transformations in terms of their present limited usefulness, without pointing out that new concepts or ideas may sometime make it possible to realize their full potential usefulness.

On the other hand, from any point of view, the book remains a thorough, reliable treatise on many existing network synthesis techniques, developed from underlying mathematical and physical principles.

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The Ultra High Frequency Performance of Receiving Tubes by W. E. Benham and I. A. Harris

Published (1958) by McGraw-Hill Book Co., 330 W. 42 St., N. Y. 36, N. Y. 169 pages+15 appendix pages+3 index pages+ix pages. 65 figures. 8½×5½. $6.50.

In this book, the authors have presented a complete and concise theoretical account of the behavior of space charge controlled tubes throughout the VHF and UHF regions. A new vacuum tube equivalent circuit is developed which includes the effects of lead inductance, transit time loading and interelectrode capacitance and its utility in small signal circuit analysis is demonstrated. The topics of large signal transit time theory and noise factor calculations are also briefly presented.

It has been assumed by the authors that the reader already has a basic knowledge of physics, vacuum tube electronics and circuit analysis and has a normal command of mathematics, including calculus. The publication would be a good reference book for the advanced student and practicing electrical engineer.

Approximately the first two thirds of the book is used to acquaint the reader with the differences between actual and ideal tubes and rigorously develop the theory and equivalent circuits for diodes, triodes and tetrodes.

The development begins with the accepted equivalent vacuum tube circuits and establishes how through the use of a "mesh circuit" approach displacement currents due to inter-electrode capacitances and the effect of the time varying electric field of the moving space charge need be and can be incorporated into the equivalent circuit. Included in this portion is a detailed study of the equations of motion for movement and how the total current flow can be divided into two components, the convection current (conventional electron flow from cathode to anode) and an induced current. The latter having a dependence upon frequency and thus contributing to the departure between ideal and actual as frequency increases.

In the latter third of the book the authors show application of the equivalent circuit, as a two-terminal-pair, to circuit analysis, as well as discuss the noise factor calculations and large signal transit time theory.

In general, the book is well written, rigorous and contains an adequate supply of references for those persons desiring to delve deeper into a particular phase of the presentation. The book adequately fulfills two needs. Firstly, it provides the VHF-UHF circuit designer with a mathematical model of a vacuum tube that can be used in the design and analysis of circuits, and secondly it helps the tube designer in better understanding and predicting the behavior of tubes designed for VHF and UHF operation.

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Analysis and Control of Nonlinear Systems by Y. H. Ku

Published (1958) by The Ronald Press Co., 15 E. 26 St., N. Y. 10, N. Y. 321 pages+27 bibliography pages+10 index pages+vii pages. Illus. 9¼×6¼. $10.00.

Seeing an announcement of this book or picking it up for the first time, a person familiar with Professor Ku's papers might expect to find only an expanded discussion of his work with simultaneous phase-plane equations. If so, the prospective reader will be pleasantly surprised. Although this subject is fully treated, the book also contains a great variety of other material.

The book begins with a discussion of the phase plane as a means for representing the transient behavior of linear and nonlinear systems. Isoclines and energy curves are introduced, and brief descriptions of graphical methods due to Lienhard, Hsia, Tumura, Buland, and Paynter are included. A number of analytic methods are mentioned, but the descriptions are too sketchy to be very useful.

In subsequent chapters, Ku discusses techniques for writing equations for electrical and mechanical systems, and he gives some rules for predicting the order of the system equations. In most cases, his rules give an upper limit on the order of the equations, not as valuable as an exact answer but nevertheless helpful.

A number of classic problems in nonlinear mechanics are treated, frequently by more than one method. These problems include the pendulum with and without damping, synchronous motor pull out, oscillators described by Van der Pol's equation, fluid dynamics, nuclear reactor kinetics, and various nonlinear circuits. Phenomena uncovered in these analyses include self-sustained oscillations, jumps in the frequency response curves, and subharmonic response. Power series, iteration, pertubation, singular points, Van der Pol's method of slowly varying magnitude and phase, and graphical techniques are used.

This book is unusual among its competitors in the amount of space devoted to high-order and multi-loop systems. In addition, two final chapters are devoted to feedback control systems containing either incidental or deliberate nonlinearities. Both phase-space and describing function methods are employed. Transfer functions and block diagrams are used to state the problems, a welcome contrast to the differential equation approach usually found in books on nonlinear mechanics.

The final pages of the text contain a few

Technical Report Writing by J. W. Souther

Published (1957) by John Wiley and Sons, Inc., 440 Fourth Ave., N. Y. 16, N. Y. 58 pages+10 appendix pages+2 index pages+xi pages. 25 figures. 8½×10¾. Paperbound. $2.95.

Most books on report writing "make abundant suggestions regarding the finished product . . . but offer amazingly little information about how reports are written or about the relation between the industrial function of the report and the final form." Thus the author describes a situation which he hopes to correct with this new addition to the rapidly increasing list of books on this same subject. The author then proceeds to liken the report writing function to an engineering design problem and divides his book accordingly into four principal chapters: analysis, investigation, design and application. There is also an introduction which, in the space occupied, presents a good case for the design approach to technical writing.

The four principal chapters are a mixture of theory and practice, yet the practical always seems to predominate. He does devote some space to certain aspects of grammar and English usage but he devotes even more space to determining and analyzing the motivations behind a report. Although he refers frequently to " the technical writer" he does seem to mean an engineer who is assuming for the time being the function of report writer. Incidentally, there are exercises at the end of each section which suggest strongly that this book is also directed at the student engineer in an undergraduate course in technical report writing, a commendable direction in which to point.

If the typical engineer will sit down and read entirely through this text there is no doubt that he will profit by it. Necessarily, if his background should be electronic he may find the mechanical illustrations taken from mechanical engineering to be perhaps less meaningful than if they had been from his own field. Yet, any author attempting a book on this subject must choose examples from some field and perhaps the mechanical examples can be more universally understood than could equivalent electrical ones. Also, this book tends to lie somewhat awkwardly between a pure reference text and the more readable essay-style of discussion. As a result, the engineer, like most human beings, would probably find the essay-style more interesting and may find the sections which report largely reference material of less interest even though no less valuable. There are four appendixes which the author might have enlarged so as to include some of the reference material included in the main text.

The value of this book to the engineer who must write a report will depend largely upon how objectively he views his own writing. If asking the questions, "Is the identity of the subject clear from the beginning?" or "Is the content adequate?" will force the engineer to reread his writing and edit it so as to reach affirmative answers, then this book should be useful. It certainly seems to ask all of the right questions and is quite complete in the subjects discussed. The author has succeeded in raising his questions and discussing them in a very modest 58 pages.

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The Encyclopedia of Radio and Television

Published (1958) by Philosophical Library, Inc., 15 E. 40 St., N. Y. 16, N. Y. 712 pages+23 appendix pages. Nearly 800 figures. 9×6. $12.00.

It is an ambitious undertaking to compile an encyclopedia, in one volume, of not only radio, but also television. This book represents the second edition of such an effort. According to the preface, the book is to provide "easy reference to all the major aspects of modern radio and television," and is designed for "students and practising engineers, as well as . . . all radio amateurs."

It is remarkable how well this book does that. It covers a vast amount of instrumentation. It summarizes many ramified sections of technology whose development has been prolific over the years. It gives generally good notions, if distinctly qualitative, of radio propagation over a variety of conditions.

The editor indicates that "the steady advance of electronic engineering inevitably renders a book such as this out-of-date fairly soon." This has been solved by introducing an appendix to cover more important recent developments.

The book has a certain nostalgic flavor. For example, nineteen lines and a figure are devoted to the "coherer," and six more lines to the "decoherer." In contrast, only five lines are given to "homodyne reception," though an additional twelve lines are given to the "synchronous detector," without noting any relationship between them. The word "troposphere" or a derivative is not listed. Much of the material on television dates somewhat. However, color television is included, if quite sketchily.

It is disappointing that no literature references are given. A second appendix contains a number of useful formulae and tables, with examples on their use.

The book will be useful for quick reference, particularly to older material.

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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.

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Antennas & Propagation

Vol. AP-6, No. 2, April, 1958

News and Views (p. 159)

Contributions—The Role of Turbulent Mixing in Scatter Propagation—Ralph Bolgiano, Jr. (p. 161)

The Villars-Weisskopf-Wheelon theory describing turbulent mixing of an established gradient is shown to contain a contradiction which necessitates its being discarded. To fill the gap thus created, the theory of isotropic mixing is extended to account for the presence of a gradient. The results indicate that "mixing-in-gradient" cannot be employed to explain the wavelength dependence characteristic of much of the radio data. On the other hand, it is shown that experimentally determined spectra of refractive index fluctuations lend strong support to the mixing theory herein set forth. Hence, the conclusion is reached that scatter theory, as it is currently based on atmospheric turbulence, can provide, at best, an incomplete description of transhorizon propagation.

feedback capacitors used in the integrators of a differential analyzer cannot be considered ideal, but their capacitance must be considered a variable. Methods of representing the complex capacitance are discussed and a model is selected which is conveniently suited to the analysis. Experimental methods of measuring the complex capacitance are described. The phenomenon of dielectric absorption is interpreted in terms of the capacitor model and it is shown that an integrator having such a feedback capacitor will experience a change in effective initial conditions after a solution is started on the computer. It is also shown that when such integrators are used to solve linear differential equations with constant coefficients, the locations of the roots of the characteristic equation are changed slightly; these changes can be evaluated when the properties of the capacitor model are known.

A Study of Refill Phenomena in Williams' Tube Memories—J. M. Maughmer and H. D. Huskey (p. 23)

A dot-circle scheme is proposed which will permit the distinction between binary "0" and "1" signals when the stored information has been destroyed approximately 90 per cent by refill. This unusual recovery of stored information is accomplished by making proper choices of operating parameters and using discharging effects instead of the charging effects as has been done in the past.

Basic relationships are developed from Coulomb's law and the equivalent circuit of the Williams' memory to predict the binary output signals. The agreement between these theoretical signals and the actual experimental signals is remarkably good. A 5JP11 cathode-ray tube was used in the experimental work.

Computing and Error Matrices in Linear Differential Analyzers—Amos Nathan (p. 32)

Matrix formulation permits the compact analysis of a very general computing scheme based on operational amplifiers. The computer solves an equation in which a computing matrix and an error matrix can be distinguished. Programming a differential equation consists of writing it in an appropriate matrix form. The computing setup is in immediate mutual correspondence with the computing matrix. The error matrix can be written down by inspection.

Scanners for Ferroelectric Memory Capacitors—C. F. Pulvari and G. E. McDuffie, Jr. (p. 34)

Many references are available on the properties and characteristics of ferroelectric materials and their memory application. The purpose of this paper is to present several scanning systems by which binary information can be stored and recalled from ferroelectric capacitor configurations. The circuitry to be described here was originally designed for testing of ferroelectric elements and employs an ordered or nonrandom scanning pattern. Most of the circuitry presented is, however, adaptable to random access application.

A Transistorized Four-Quadrant Time-Division Multiplier with an Accuracy of 0.1 Per Cent—Hermann Schmid (p. 41)

This article describes a four-quadrant time-division multiplier with an over-all accuracy of better than 0.1 per cent of full scale. The circuit is independent of the transistor characteristics, requires no complicated balancing adjustments, exhibits excellent stability and uses only simple, noncritical circuitry. The maximum output voltage is 10 v when both input voltages are 10 v.

New Applications of an Electronic Function Generator—Rajko Tomovich (p. 48)

In previous papers a new technique for performing in a single electronic computing unit all nonlinear mathematical operations in a differential analyzer was described.

The field of application of this technique is extended to include the generation of functions of several variables.

Synthesis of N-Valued Switching Circuits—R. D. Berlin (p. 52)

The concept of a functionally complete set is defined and examples are given in the familiar field of 2-valued logic and switching circuits.

Several functionally complete sets, already known to investigators in n-valued logic, are discussed, with particular emphasis on applications to the synthesis of n-valued switching circuits.

It is noted that much of the switching in a base-n computer will be, in a sense, binary, permitting the use of relatively simple elements in the synthesis. As an example, an n-valued switching matrix is synthesized.

Synthesis of Electronic Circuits for Symmetric Functions—George Epstein (p. 57)

This paper develops a systematic method for the synthesis of electronic circuits which must realize symmetric Boolean functions. The "fold-down" method, originated by Shannon, solves the problem nicely for relay circuits. The electronic circuit, however, composed of "and," "or" and "not" elements, does not seem to incorporate the feature of symmetry as readily.

It is shown that for symmetric functions a minimal-not condition exists, and that this form is a powerful tool for synthesis. The minimality is not actually proven, except for the case of fundamental symmetric functions. As with the minimal-or circuit, a minimal-not circuit does not necessarily imply the most economical realization, and the design procedure should take account of this fact.

Correction (p. 60)

Thermistors for the Gradual Application of Heater Voltage to Thermionic Tubes—J. J. Gano and G. F. Sandy (p. 61)

Thermistors which are thermally-sensitive resistors having large negative temperature coefficients of resistance can be aptly used for the gradual application of heater voltage to thermionic tubes, thereby diminishing thermal transients and reducing mechanical failures. Full voltage is first applied to the thermistor and load in series and after temperature equilibrium is reached, the thermistors are shorted out. From a cold start thermistor resistance decreases by a factor of approximately 100 and heater resistance increases by a factor of 5 to 10. By selecting a set of series-connected thermistors to limit the current to a maximum of 120 per cent of the operating value during the voltage application, the initial voltage on the heaters will be less than 5 per cent of rated, and the voltage before shorting out, about 75 per cent of rated. Peak currents occur twice, once while the thermistors are in the circuit and again when the thermistors are shorted out at 90 seconds. One set of thermistors can be used to limit the current satisfactorily over a wide range of loads. The most favorable number of thermistors to connect in series is determined experimentally. Commercially available units in washer form can accommodate heater loads up to 1100 watts.

Review of Computer Progress in 1957—R. P. Castanias and J. E. Sherman (p. 65)

Contributors (p. 73)

PGEC News (p. 75)

Reviews of Current Literature (p. 77)

Industrial Electronics

PGIE-5, April, 1958

Combined Abstract of Conference Papers (p. 1)

Basic Instrumentation—W. A. Wildhack (p. 4)

Communication Problems Between Instruments, Controls, and Man—H. Ziebolz (p. 9)

The Economic and Technical Aspects of Industrial Electronics—E. D. Cook (p. 13)

Application of Magnetic Amplifiers in Industrial Instrumentation and Control—W. A. Geyger (p. 23)

Principles and Techniques for Direct-Reading Digital Transducers—W. H. Kliever (p. 37)

Electronics in a Chemical Company—R. C. McMillen (p. 45)

Some New Aspects of Nuclear Instrumentation in Industrial Electronics—N. Anton and M. Youdin (p. 51)

Process Monitoring by Dielectric Constant—W. H. Howe (p. 56)

Automatic Card Programmed Control of Reversing Mills—E. H. Browning (p. 64)

Some Applications of Analog-Computer Techniques to Control System Design—E. C. Goggio (p. 70)

Selection of Reliability Levels in Equipment Design—H. L. Garbarino (p. 76)

Transcript of Panel Discussion (p. 82)

Analysis of a Motor Speed-Control System with an Analog Computer—W. J. Bradburn (p. 94)

In order to obtain maximum productivity, longest tool life, and high-quality surface finish on a lathe, it is necessary that the machining be done at a constant surface cutting speed. This is particularly true with the use of carbide cutting tools where deviations from optimum cutting speed must be maintained within extremely close limits.

A system was proposed using a direct current motor in conjunction with a multistage field regulator in a closed loop system to provide constant cutting speed on an automatic copy lathe. An analog study of the system was made in order to determine what performance could be expected and how performance could be improved. This paper presents a qualitative discussion of the analog study, together with the results obtained and the conclusions reached.

Conference on Magnetic Amplifiers Proceedings Available (p. 103)

Contributors (p. 104)

Instrumentation

Vol. I-7, No. 1, March, 1958

Abstracts of Papers (p. 2)

Instrumentation for the C-130 Static Test—W. W. Hartsfield (p. 5)

During the static tests conducted for the Air Force on the C-130A Hercules at the Lockheed plant in Marietta, Ga., an instrumentation job was undertaken that spanned more than three years. This paper describes the various techniques employed in coping with the many requirements of the tests, and observations by the writer on possible variations intended to simplify and expedite the data collection and processing task.

The major requirement, by far, in connecwith this static test was strain gauge instrumentation. This task included installation and wiring of over 750 strain gauges with which more than 50,000 static strain measurements were made. Several types of SR-4 resistance wire strain gauges were used as the sensing element in this application. Strain gauges were also used in several other special applications as required. Other phases of the tests included the use of failure wire for determining characteristics of crack propagation and failures, vibration and sound pickups for pin-pointing minor failures from remote locations, and various special purpose monitoring and indicating devices. The majority of the data collection problem was handled by an analog-to-digital conversion system designated SADIC I, manufactured by the Consolidated Electrodynamics Corporation. Three other types of equipment were used to supplement the SADIC in the data processing job.

Several of the test conditions encountered during the test program presented quite a challenge to the instrumentation engineer. Uncontrolled temperature and humidity in the test area, submersion of the test article in water, and hydrostatic pressures to fifteen pounds per square inch are but a few of these conditions.

In-Flight Recording for System Malfunction Detection—J. Jamgochian and T. K. Speer (p. 12)

The full utilization of modern aircraft is seriously handicapped by the unpredictable failures which frequently occur in portions of the complex airborne subsystems. This handicap can be eliminated only by improved design for increased reliability. However, the amount of time required to repair the subsystems, as presently designed, *can* be reduced by improved troubleshooting techniques.

A system is described which has been successfully employed to reduce the time required to prepare modern military aircraft for delivery to the United States Air Force.

A Semidigital Process Simulator—M. Terao and K. Tamura (p. 18)

A new process simulator has been accomplished by the combined use of digital and analog techniques.

The transient response of processes to be imitated can be set in the simulator graphically. The simulator represents dynamic behaviors of various industrial processes which may have remarkable dead time.

All data are quantized by a sampling period Δ, which is adjustable in a wide range through a programming mechanism, so that the simulator can behave in the real time. This has great advantages over the usual electronic analog computer and the high-speed delay type process simulator in acquiring experimental data with an actual controller, especially a digital controller, and for training a human operator.

The layout and the behaviors of the simulator are presented with a discussion of a simplified method for obtaining the frequency response from the transient response data.

A Transistorized Digital-to-Analog Converter—W. D. Rowe (p. 22)

An essential device in digitalized automatic control systems is one that performs the function of digital-to-analog conversion. In order to fill the requirements of such a device, a highly reliable, highly accurate converter has been designed using transistors. This device takes a digital signal in binary, decimal, binary coded decimal, biquinary, and other codes and presents a current or voltage at its output directly proportional to numerical input.

The device discussed here is binary as required in the accompanying application, an oscilloscope output display unit for the IBM-704 Electronic Data Processing Machine. This converter in binary form is accurate to better than 0.1 per cent at a sampling rate of better than 10 kc. The designs of the circuit and required gates are discussed in detail. The oscilloscope display application requires two of the converters to present an *X*- and *Y*-coordinate display on the face of the cathode-ray tube by internal programming of the electronic computer.

Logical Detenting in Cathode-Ray Coding Tubes—Bernard Lippel (p. 29)

The first published cathode-ray voltage digitizing tubes detented the electron beam, but they were soon superseded by tubes which used unit-distance codes (*e.g.*, the Gray code). Surprisingly, the principle of logical detenting (*e.g.*, V scan) does not seem to have been applied, despite its special importance for crt's attributable to the liberal construction tolerances. Other advantages arising from this method are the presentation of data in natural codes directly (without use of a translator), and fine-digit-first transmission when the data is read off serially.

Logically-detented cathode-ray digitizers are expected to be simple, inexpensive, reliable, and very fast in operation, but they cannot compete with slower and more complex apparatus where high resolution is needed. They may find wide application in automatic recording of electrical measurements within the accuracy range of electrical indicating meters and in some digital computer input operations.

Serial voltage digitizers are described, which were designed and constructed at USASEL from suitable cathode-ray coding tubes and from very simple control circuitry. These digitizers give outputs in either selected binary-decimal codes or the conventional binary language.

The principle may be even more advantageous in the case of tubes constructed for parallel reading.

Irregular Lines by Standard Teletype—John Brown (p. 38)

A system for transmitting irregular lines by standard teletype has been designed and experimentally tested by one of the Project Michigan groups of the University of Michigan Engineering Research Institute. The system is primarily for transmitting military map overlays, but has a variety of other applications. The automatic *X-Y* plotter, required to receive and display the lines, is also used in the coding. The operator coding at the teletype keyboard selects, from a grid mounted on the moving head of the plotter, the coordinates of the next line segment to be transmitted and types them on the keyboard. The plotter then traces the line segment to check the coding and to indicate the origin of the next line segment.

Data Handling for a Reliability Test Program—V. W. Walter and F. I. Bien (p. 44)

A philosophy of data handling in a large-scale life test program is presented. The program involves the testing of one parameter on each of 30,000 resistors, five parameters on each of 20,000 diodes, and nine parameters on each of 9000 transistors, on an average of twice a week. The purpose of the program is to learn more about the life of the components, so that the reliability of the end product can be improved. To properly satisfy this purpose, it is necessary to emphasize the reliability and accuracy of the instrumentation and recording equipment. A thorough analysis of the program, its purpose, and requirements revealed four basic factors of prime importance: 1) the accuracy of the measurements; 2) identification of individual components and their related data; 3) the time that could be allotted for making a measurement; and 4) the recording, reproduction, and processing of the test data. The manner in which these factors were satisfied through the design of the instrumentation, coding equipment, and application of data recording equipment is thoroughly discussed. The end result of the study and design work was the fabrication of six test consoles which would perform the required test, convert the analog data to digital data, and record this data on punched cards for future processing on commercial computers.

Dynamic Data System—B. J. Fister and C. A. Woodcock (p. 48)

Instrumentation for jet engine testing in the General Electric Company Aircraft Gas Turbine Division has undergone drastic changes over the past several years due to both developments of new measurement systems and a backlog of data and experience which has been accumulated. Of particular significance in improved mechanical designs and safety of operation has been measurement and analysis of dynamic operating conditions, such as stress, vibration, and pressure fluctuations, by means of a multichannel magnetic tape recording, playback and data reduction system which has been in operation in AGT for the past three years. The operation consists of a permanently installed playback and data reduction system which processes data from a number of portable recorders which can record as many as 28 tracks simultaneously on 1¾-inch tape.

Magnetic tape has several important advantages over other methods of recording, including wide dynamic amplitude and frequency ranges, and storage of the data in "live" form so that the signal produced by the transducer during the test can be reproduced at a later time for detailed study.

Signals in the frequency range of dc to 5000 cps are recorded by means of frequency modulation, whereas higher frequencies are recorded by means of direct recording amplifiers which are interchangeable with the fm units. Signals of each channel are continuously monitored by means of a multichannel oscilloscope to assure proper recording level, good signal quality, and safe operation of the test vehicle.

After a test run has been recorded, the tape is taken to the laboratory installed playback system, leaving the recorder for subsequent tests. In the data reduction system, the signals are reproduced for study and analysis. Oscilloscopes, direct writing oscillographs, voltage level recorders, frequency recorders, cameras, filters, and other equipment are used to determine the required data from the signals. Data processing is accomplished primarily by analog techniques with results typically presented in the form of charts or graphs. A data folder, including data analysis, graphs, waveform photographs, conclusions, and a discussion of the test, is prepared for project engineers.

On the basis of the results obtained from this system, previously undetected dangerous operating conditions now can usually be detected and corrected before failures occur.

A New Six-Channel *X-Y* Recorder and Point Plotter—H. C. Craddock (p. 53)

The continuing desire for faster graphic displaying of analog or discrete-value data in two variables from either in-line instruments or storage media has prompted the development of a new *X-Y* recorder with several unique qualifications.

The new recorder may be operated with its plotting surface in either a horizontal or vertical plane and will accommodate 11×16½-inch or 8½×11-inch standard graph paper held securely in place on the plotting area by an internal vacuum system. Line recordings are made by an inked pen and automatic point plotting is done by a solenoid operated print wheel and inked ribbon. The print wheels are easily changed and are available with six symbols in any combination which, with a self-indexing feature, allows recording of up to six separate graph plots on the same sheet. Digital data may be plotted with an accuracy of 0.1 per cent of full scale and at a maximum rate of six points per second. A speed of 50 inches per second is the nominal slewing rate of the recorder.

Design of Oscillographic Recorders for Efficient Use—V. E. Payne (p. 58)

The data reduction facility of the Naval Ordnance Unit, Key West, Fla., has encountered difficulties which stem from the necessity of reducing complex oscillograms by personnel with little technical training or experience. These difficulties could be alleviated by design of data recorders from the viewpoint of the data reduction personnel.

Examples of poor recorder design are taken from actual experience and the deleterious effects of these designs upon the data reduction process are explained, both for manual and semiautomatic reduction methods.

A number of specific suggestions are made for those who must design recorders. These include the avoidance of ambiguities, restrictions in the use of nonlinear calibrations, and the standardization of traces and calibrations.

Some controversial points of recorder philosophy are discussed. A preference is expressed for visual records even if these are digital in nature. Some advantages of the record which is digital by increments of the measured param-

Abstracts and References

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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 number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number and is not to be confused with the Decimal Classification used by the United States National Bureau of Standards. The number in heavy type at the top right is the serial number of the Abstract. DC numbers marked with a dagger (†) must be regarded as provisional.

U.D.C. NUMBERS

Extensions and changes in U.D.C. numbers published in P.E. Notes, up to and including P.E. Note 609, will be introduced in Abstracts and References where applicable, notably the subdivisions of 621.372.8 waveguides published in P.E. Note 594. U.D.C. publications are obtainable from The International Federation for Documentation, Willem Witsenplein 6, The Hague, Netherlands, or from The British Standards Institution, 2 Park Street, London, W.1, England.

JOURNAL REFERENCES

References to Russian publications will henceforth be based on the Russian title which will be abbreviated on the principles of The World List of Scientific Periodicals. The main changes are as follows:

Dokl. Ak. Nauk S.S.S.R. (formerly *C.R. Acad. Sci. U.R.S.S.*),

Izv. Ak. Nauk S.S.S.R. (formerly *Bull. Acad. Sci. U.R.S.S.*).

The Index to the Abstracts and References published in the PROC. IRE from February, 1957, through January, 1958, is published by the PROC. IRE, May, 1958, Part II. It is also published by *Electronic and Radio Engineer*, incorporating *Wireless Engineer*, and included in the March, 1958, issue of that journal. Included with the Index is a selected list of journals scanned for abstracting with publishers' addresses.

ACOUSTICS AND AUDIO FREQUENCIES

534.613 **1611**
Radiation Force on Bodies in a Sound Field—H. Olsen, W. Romberg, and H. Wergeland. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 69–76; January, 1958.)

534.75 **1612**
Proposed Laboratory Standard of Normal Hearing—J. F. Corso. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 14–23; January, 1958.) Report and discussion of laboratory measurements to determine the normal monaural threshold of hearing for pure tones.

534.782 **1613**
Sound Synthesizer with Optical Control—O. Fujimura. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 56–57; January, 1958.) Brief description of a system based on a bank of ADP crystals, polarized light beams, and a photocell. See also 1822 below.

534.84 **1614**
Applications of the Monte Carlo Method to Architectural Acoustics—J. C. Allred and A. Newhouse. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 1–3; January, 1958). "The Monte Carlo method of numerical analysis is applied to the determination of mean free paths and acoustic weighting factors relating probability of collision with walls in rectangular parallelopipeds. The method of calculation is discussed and its extension to determination of reverberation times in coupled rooms and auditoria is evaluated."

534.84:534.62 **1615**
Output of a Sound Source in a Reverberation Chamber and Other Reflecting Environments—R. V. Waterhouse. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 4–13; January, 1958.) Expressions are derived for the sound-power output for various source/reflector systems of interest in architectural acoustics, including the case of a dipole source near a reflecting plane, and a simple source near a reflecting edge and corner. In general, the power output differs significantly from the free-field value if the distance of the source from the reflector is less than one wavelength. See also 2513 of 1955.

621.395.61+621.395.62 **1616**
Dynamic Mechanical Stability in the Variable-Reluctance and Elecrostatic Transducers—C. H. Sherman. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 48–55; January, 1958.) An analysis of the stability of these types of transducer for high-power applications. The limiting displacements for typical values of mechanical Q, polarization and frequency are shown.

621.395.625.3:778.5 **1617**
Further Data on Infrared Transparency of Magnetic Tracks—G. Lewin. (*J. Soc. Mot. Pic. Telev. Eng.*, vol. 66, pp. 760–763; December, 1957. Discussion, p. 763.) The dependence of the transmittance upon the thickness of the magnetic oxide deposit and the intermodulation effects on a converted 35-mm reproducer are examined.

ANTENNAS AND TRANSMISSION LINES

621.372.2.011.1:518.4 **1618**
Transmission-Line Calculator—J. H. Andreae. (*Wireless World*, vol. 64, pp. 191–193; April, 1958.) A graphical device for finding the length of terminated lines at specific frequencies is described. It has been found useful for calculations on low-loss resonant lines used in ultrasonic research above 50 mc.

621.372.2.011.21:517.54 **1619**
The Calculation of Characteristic Impedance by Conformal Transformation—J. C. Anderson. (*J. Brit. IRE*, vol. 18, pp. 49–54; January, 1958.) The theory is applied to a line with cylindrical-outer and strip-inner conductors.

621.372.21 **1620**
Calculation of a Lossy Line—V. S. Mel'nikov. (*Radiotekhnika, Moscow*, vol. 12, pp. 28–30; January, 1957.) Analysis for the case where energy absorption per unit length is constant along the line.

621.372.821:621.3.049.75 **1621**
The Application of Printed-Circuit Techniques to the Design of Microwave Components—J. M. C. Dukes. (*Proc. IEE*, vol. 105, pt. B, pp. 155–172; March, 1958. Discussion, pp. 180–181.) The basic theory of strip-transmission lines is reviewed and the relative merits of the techniques and materials used are discussed. An adjustable short circuit and a wide-band precision attenuator are described, together with other components for the band 2500–4300 mc. Details are given of an RF head for two-way communication equipment.

621.372.821:621.3.049.75 **1622**
Developments in Printed Microwave Components—D. R. J. White. (*Electronic Indus. and Tele-Tech*, vol. 16, pp. 63–66, 146; November, 1957.) A general description is given of the mechanical construction and electrical properties of high-Q microwave transmission lines used for connecting printed components.

621.372.821:621.372.832.43 **1623**
Broad-Band Slot-Coupled Microstrip Directional Couplers—J. M. C. Dukes. (*Proc. IEE*, vol. 105, pt. B, pp. 147–154; March, 1958. Discussion, pp. 180–181.) The two strip-transmission lines are mounted back to back and coupled through slots in the common ground plane. A 3-db coupler with 50 transverse slots is described. By grading the phase velocity in one line, a power split equal within 1 db over the band 2800–4300 mc is achieved.

621.372.821:621.372.852.1 **1624**
Re-entrant Transmission-Line Filter using Printed Conductors—J. M. C. Dukes. (*Proc. IEE*, vol. 105, pt. B, pp. 173–179; March, 1958. Discussion, pp. 180–181.) A novel procedure is described for the design of microwave low-pass filters having a relatively high stop-band insertion loss over a 3:1 bandwidth. The filters can be produced in microstrip or triplate line using printed circuit techniques.

621.372.83:621.372.6 1625
Scattering Equivalent Circuits for Common Symmetrical Functions—W. K. Kahn. (IRE TRANS. ON CIRCUIT THEORY, vol. CT-3, pp. 121–127; June, 1956. Abstract, PROC. IRE, vol. 44, p. 1492; October, 1956.)

621.372.831 1626
Design of a Conical Taper in Circular Waveguide System Supporting H_{01} Mode—L. Solymar. (PROC. IRE, vol. 46, pp. 618–619; March, 1958.)

621.372.852.1 1627
Wide-Band Waveguide Filters with Short Linear Tapers—G. Craven. (*Proc. IEE*, vol. 105, pt. B, pp. 210–212; March, 1958.) Details are given of broad-band filters which are matched to standard waveguides. In a typical example, the amplitude of the variations in the transmission loss in the band 3800–4200 mc is not more than 0.25 db, with a voltage SWR less than 1.6.

621.372.852.323:621.318.134 1628
Field-Displacement Isolator in Microwave Communications—S. Weisbaum and H. Boyet. (*Bell Labs. Rec.*, vol. 35, pp. 456–461; November, 1957.) A general summary is given of the theory and uses of ferrite slabs in rectangular waveguides, in which a dc magnetic field is applied to the ferrite at right angles to the direction of wave propagation. Reflected waves are dissipated greatly in the ferrite, but forward-going waves only slightly. Typical performance figures in the 10.7–11.7-kmc band are: forward loss 1 db, reverse loss 70 db, with H = 1045 oersteds.

621.396.67:537.226 1629
Polar Diagrams of Surface-Wave Antennas—K. I. Grinëva. (*Radiotekhnika, Moscow*, vol. 11, pp. 3–14; December, 1956.) An infinite metal surface covered with a thin layer of a dielectric is considered, over which a surface wave is propagated. The polar diagram of the surface-wave antenna is calculated by an approximate method based on Kirchhoff's formula. The effects of attenuation in the dielectric and of antenna length and phase velocity on the polar diagram are discussed. Conclusions are compared with experimental results and a procedure for the design of the antenna is proposed.

621.396.67:621.396.712 1630
The Planned Medium-Wave and Television Antenna of the N.D.R. at Flensburg—E. Mohr. (*Rundfunktech. Mitt.*, vol. 1, pp. 139–142; August, 1957.) Details of an antenna installation erected by the Norddeutsche Rundfunk, which consists of a mast 205 m high divided into two sections by an insulator at a height of 110 m. It incorporates television and VHF transmitting antennas as well as serving as a mast radiator for medium waves in the range 500–1600 kc.

621.396.674.3:621.396.11 1631
Excitation of Surface Waves on Conducting, Stratified, Dielectric-Clad, and Corrugated Surfaces—Wait. (See 1852.)

621.396.677 1632
Antenna Applications in Two-Way Radio Systems—T. J. McMullin. (*Radio TV News*, vol. 58, pp. 37–40; December, 1957.) Practical information is given on the performance of directive antennas in the wavebands for mobile use, 25–50 mc, 72–76 mc, and 148–174 mc.

621.396.677.3:621.372.51 1633
Three Antennas on One Lead—C. Woodard. (*Radio TV News*, vol. 58, pp. 48–49, 157; December, 1957.) Discussion of a method of connecting three Yagi antennas operating on Channels 6, 8 and 13, to one lead.

621.396.677.43 1634
Investigations of the Large Rhombic Antenna at the Overseas Receiving Station Eschborn—W. Kronjäger, E. Mark, and K. Vogt. (*Nachr-Tech.*, vol. 10, pp. 382–384; August, 1957.) Report of comparative tests carried out at 5, 7.5 and 10 mc with the Eschborn antenna which has sides of length 300 m. The advantages over antennas of normal size include a relative gain of about 15 db at the lower frequencies.

621.396.677.832:621.396.96 1635
V-Reflex Antenna for an Information Radar Station—G. von Trentini and E. J. Kirkscether. (*Rev. telegr. Electrónica, Buenos Aires*, vol. 46, pp. 637–641; November, 1957.) A discussion of the design and application of V-shaped reflectors with a partially reflecting surface across the mouth of the V; their advantage over curved reflectors lies in greater simplicity and consequent cheapness. Tests on a scale model working at 32 cm λ and coastal installations for operation at 144 cm λ are described. See also IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-4, pp. 666–671; October, 1956. (von Trentini.)

621.396.677.833:523.16 1636
The 45-ft Radio Telescope at the Royal Radar Establishment, Malvern—(*Nature, London*, vol. 180, pp. 1225–1228; December 7, 1957.) The parabolic reflector has a focal length of 20 feet and may be elevated between 5 degrees and 85 degrees at all azimuths. The telescope may be used to detect galactic radiation at 91 cm λ, or as a radar transmitter and receiver. Radar echoes from the first Russian earth-satellite rocket and also from the moon have been recorded.

AUTOMATIC COMPUTERS

681.142 1637
Basic Magnetic Logic Circuits in Computers—K. Ganzhorn. (*Elektronische Rundschau*, vol. 11, pp. 229–34; August, 1957.) Classification of fundamental circuits which can be realized by means of square-loop ferromagnetic cores.

681.142 1638
The Design of the Control Unit of an Electronic Digital Computer—M. V. Wilkes, W. Renwick, and D. J. Wheeler. (*Proc. IEE*, vol. 105, pt. B, pp. 121–128; March, 1958. Discussion, pp. 144–146.) The design of the control or sequencing unit is discussed. In one system the order code is determined by the arrangement of the diodes in a diode matrix, and in another by the threading of wires through a matrix of ferrite cores.

681.142:537.311.33:538.632 1639
Analogue Multiplier Based on the Hall Effect—L. Löfgren. (*J. Appl. Phys.*, vol. 29, pp. 158–166; February, 1958.) Discussion of the application of the Hall effect for electronic multiplication of voltages. An investigation of semiconductors shows Si to be the best for accurate multiplication. The choice of crystal dimensions is discussed with reference to the solution of a potential problem with skew boundary condition which determines the Hall voltage.

681.142:621.3.087.6:535.376 1640
An Accurate Electroluminescent Graphical-Output Unit for a Digital Computer—T. Kilburn, G. R. Hoffman, and R. E. Hayes. (*Proc. IEE*, vol. 105, pt. B, pp. 136–144; March, 1958. Discussion, pp. 144–146.) The unit is fabricated from a uniform layer of electroluminescent phosphor with 512 parallel conducting strips on either side, these sets of strips being at right angles to form a matrix of conductors. A changing electric field between selected strips of both sets causes fluorescence at their intersection. Intersections are selected in turn and the pattern is recorded photographically. Details of some phototype matrices are given.

681.142:621.316.86 1641
The Design of Function Generators using Silicon Carbide Nonlinear Resistors—E. Brown, and P. M. Walker. (*Electronic Eng.*, vol. 30, pp. 154–157; March, 1958.) The effective current/voltage characteristics of SiC resistors are modified by linear resistors placed in series and parallel. Such modified resistors are then used as input or feedback components in amplifiers to give nonlinear functions. Design details are given of square-law and sine-function generators using this device.

681.142:621.318.57:538.221 1642
Magnetic Switching Circuits for the Representation of Logical Relations—H. Gillert. (*Nachr-Tech.* vol. 10, pp. 391–402; August. 1957.) A design method is derived for obtaining the number of cores and the number of turns required on each core for a given switching function. Results of a systematic investigation are given for switching functions with two and three variables.

681.142:621.318.57:621.314.7 1643
A New Bistable Element Suitable for Use in Digital Computers: Parts 1 and 2—C. D. Florida. (*Electronic Eng.*, vol. 30, pp. 71–77; February, 1958, and pp. 148–153; March, 1958.) The development of a trigger circuit using *p-n-p* and *n-p-n* transistors is described. Switch-on and switch-off times of 0.2 μsec are achieved with a high-current carrying capacitance enabling several other circuits to be driven from it. The transient response of the circuit to a voltage-ramp input at either the turn-on or turn-off terminals is analyzed mathematically. The results thus obtained, assuming certain operating conditions, show good agreement with experimental observations.

681.142:621.374.32 1644
A Decimal Adder using a Stored Addition Table—M. A. Maclean and D. Aspinall. (*Proc. IEE*, vol. 105, pt. B, pp. 129–135; March, 1958. Discussion, pp. 144–146.) A description of a serial decimal adder which accepts numbers in binary-coded form. The binary digits are decoded into a set of pulses which actuate a built-in addition table storing all the possible sums.

681.142.001.4 1645
Word Generator for Digital Testing—R. R. Hartel. (*Electronics*, vol. 31, p. 71; February 28, 1958.) "A beam-switching tube supplies arbitrary nine-bit words at pulse rates from a few cps to 1 mc for testing and evaluating digital systems. Pulse shape can be varied from spike to square wave by changing plug-in capacitors."

CIRCUITS AND CIRCUIT ELEMENTS

621.3.011.3:621.376.32.029.3:621.385.1 1646
The Reactance Valve at Audio Frequencies—B. J. Alcock. (*Electronic Eng.*, vol. 30, pp. 86–88; February, 1958.) "The reactance-tube circuit is analyzed to derive circuits producing an inductive impedance at AF with particular reference to obtaining a large Q factor."

621.3.012:[621.3.015.3+621.3.018.4 1647
Approximate Relations between Transient and Frequency Response—H. H. Rosenbrock. (*J. Brit. IRE*, vol. 18, pp. 57–64; January, 1958.) An existing graphical method for deriving the transient response of a linear net-

work from the sinusoidal frequency response and vice versa is extended to cover certain difficult cases. Typical examples are illustrated.

621.3.049.75:621.372.821 1648
The Application of Printed-Circuit Techniques to the Design of Microwave Components—Dukes. (See 1621.)

621.3.049.75:621.372.821 1649
Developments in Printed Microwave Components—(See 1622.)

621.3.072.6:621.372.54 1650
The Locking Band for the Automatic Phase Control of Frequency—M. V. Kapranov. (*Radiotekhnika, Moscow*, vol. 11, pp. 37–52; December, 1956.) Formulas are derived relating the locking band to the filter parameters and the delay time of the circuits.

621.314.2:621.373.431.2 1651
Design Transformers for Blocking Oscillators—R. D. McCartney. (*Electronics*, vol. 31, pp. 78–80; February 28, 1958.) Design procedure, based on four common circuits, is given; the pulse shape is calculable, and a 6:1 size reduction over previous units is obtained with a Type-L-1 core.

621.314.6 1652
An Extended General Network Theorem on Rectification—H. Stockman. (Proc. IRE, vol. 46, pp. 615–616; March, 1958.) Extension of Gewartowski's theorem (48 of 1958).

621.318.435.3.042.143 1653
A New Type of Construction for High-Grade Transductor Cores—U. Krabbe and G. H. Giesenhagen. (*Elektrotech. Z., Ed. A*, vol. 78, pp. 712–716; October 1, 1957.) Improvements of laminated-core design and assembly are discussed, which permit a better utilization of the qualities of the material.

621.318.57:621.373.431 1654
Calculation of the Duration of a Quasi-Equilibrium State in a Phantastron Circuit—G. I. Perov. (*Radiotekhnika, Moscow*, vol. 11, pp. 61–74; December, 1956.) A formula is derived, and typical operating conditions of phantastron circuits are considered.

621.318.57:621.387:621.314.7 1655
Transistor Circuits for Use with Gas-Filled Multicathode Counter Valves—J. B. Warman and D. M. Bibb. (*Electronic Eng.*, vol. 30, pp. 136–139; March, 1958.) Transistors are used in conjunction with dekatrons to provide a logical circuit; the combination is run off a low-voltage supply, the hv to the dekatrons being supplied by a transistor dc converter. A block of these circuits is made to function successfully in a telephone exchange register.

621.319.4 1656
Ceramic Capacitors—a Complete Substitute for Paper and Mica Capacitors—C. V. Ganapathy, R. Krishnan, and T. V. Ramamurti. (*J. Inst. Telecommun. Eng., India*, vol. 4, pp. 2–11; December, 1957.) The electrical characteristics of paper, mica, and ceramic capacitors are compared. Performance tests on receivers before and after substituting ceramic for paper capacitors show no significant difference.

621.372.4 1657
The Sense of Rotation and Curvature of the Impedance Loci of Real and Ideal Two-Poles—N. Wolter. (*Arch. elekt. Übertragung*, vol. 11, pp. 359–365; September, 1957.) The impedance of a two-terminal network, as represented on the Gauss number sphere, describes a closed curve revolving completely, at least once, in a clockwise direction for a frequency variation from $-\infty$ to $+\infty$. A method is given for synthesizing two poles which have impedance loci turning anticlockwise in places.

621.372.414 1658
Design of Complex Resonators—A. I. Zhivotovskiĭ. (*Radiotekhnika, Moscow*, vol. 12, pp. 22–27; January, 1957.) An investigation of resonators consisting of several uniform coaxial-line sections with different characteristic impedances.

621.372.414:621.372.8 1659
Microwave High-Power Simulator—H. Heins. (*Electronic Indus. and Tele-Tech*, vol. 16, pp. 78–81; 155; November, 1957.) "By periodically injecting energy from a directional coupler into a waveguide cavity made in the form of a closed loop, much higher-power levels can be achieved than are available from microwave-power generators. Energy is stored in a circulating or traveling wave." See also 1325 of 1956 (Sferrazza).

621.372.5/.6 1660
The Scattering Matrix in Network Theory—H. J. Carlin. (IRE Trans. on Circuit Theory, vol. CT-3, pp. 88–97; June, 1956. Abstract, Proc. IRE, vol. 44, pp. 1491–1492; October, 1956.)

621.372.54 1661
Frequency Transformations in Filter Design—A. Papoulis. (IRE Trans. on Circuit Theory, vol. CT-3, pp. 140–144; June, 1956. Abstract, Proc. IRE, vol. 44, p. 1492; October, 1956.)

621.372.54 1662
Optimum Filters with Monotonic Response—A. Papoulis. (Proc. IRE, vol. 46, pp. 606–609; March, 1958.) The amplitude characteristic has no ripple in the pass band and a high rate of attenuation in the stop band and combines the desirable features of the Butterworth and Tchebycheff response.

621.372.54 1663
A Twin-T Variable-Slope Filter—G. B. Miller. (*Electronic Eng.*, vol. 30, pp. 143–145; March, 1958.) "By suitable modification a twin-T notch filter is converted into a low-pass filter in which the rate of attenuation up to a specified upper frequency is controlled by a single potentiometer. Design data are given and a detailed circuit is described."

621.372.54:621.315.212 1664
Filters, Built from Coaxial Conductors—T. J. Weijers. (*Philips Telecommun. Rev.*, vol. 18, pp. 186–206; November, 1957, and vol. 19, pp. 23–54; January, 1958.) Zobel's method of filter design is applied to coaxial-line filters considering the impedance of the line as a function of frequency. Characteristics can then be determined for the entire frequency range. Design data are shown in a series of tables, and four types of filter section are discussed in detail.

621.372.542.2 1665
A Filter with Characteristics Approximating to those of an Ideal Low-Pass Filter—J. Remer. (*Rundfunktech. Mitt.*, vol. 1., pp. 151–158; August, 1957.) The design and construction of a filter are described whose characteristics conform closely to those of the ideal low-pass filter specified by Küpfmüller. The variations of its amplitude response up to cutoff at 5.5 kc are less than ± 0.5 per cent. At cutoff the response is 9 per cent of its maximum value, and the fluctuations of group delay are less than 0.025 msec.

621.372.543:621.375.126 1666
***RC* and *LC* Resonant Filters and their Application in Selective Amplifiers**—H. H. Rabben. (*Elektronische Rundschau*, vol. 11, pp. 265–268; September, 1957 and pp. 314–318; October, 1957.) The design of a narrow-band amplifier with a center frequency of about 200 cps is discussed following a comparison of circuits using different types of filter elements. A two-stage circuit with negative feedback and incorporating a RC band-stop filter was the design adopted for use in the measurement of the solar magnetic field.

621.372.552 1667
An Approach to the Design of Constant-Resistance Amplitude Equalizer Networks—J. S. Bell. (*Proc. IEE*, vol. 105, pt. B, pp. 185–189; March, 1958.) A method of designing constant-resistance amplitude equalizers to give a desired frequency response characteristic over a given range is suggested. A typical example illustrates the method of adjusting the response of a velocity-type pickup over part of the AF spectrum.

621.372.57:621.314.7 1668
A Treatment of Cascaded Active Four-Terminal Networks, with Application to Transistor Circuits—H. L. Armstrong. (IRE Trans. on Circuit Theory, vol. CT-3, pp. 138–140; June, 1956. Abstract, Proc. IRE, vol. 44, p. 1492; October, 1956.)

621.373.42 1669
Self-Oscillator with Large Circuit Attenuation—A. Z. Khaĭkov. (*Radiotekhnika, Moscow*, vol. 12, pp. 63–72; January, 1957.) The optimum operating conditions for power transfer to the load and the efficiency of the oscillator are discussed. Equations are derived and graphs show the grid-voltage variations for different values of attenuation.

621.373.42.029.42 1670
Amplitude-Stabilized Low-Frequency Oscillator—A. K. Choudhury and B. R. Nag. (*J. Inst. Telecommun. Eng. India*, vol. 4, pp. 36–45; December, 1957.) The performance of a VLF oscillator for the range 0.01–10 cps with the output stabilized by biased diodes or lamps, is analyzed. Formulas for the harmonic content with different initial damping are deduced and means of reducing it are indicated. A circuit for measuring the harmonic content is described.

621.373.421.029.62/.63 1671
Double-Tetrode Oscillator—J. H. Andreae and P. L. Joyce. (*Wireless World*, vol. 64, pp. 173–177; April, 1958.) The oscillator covers a frequency range of 150–500 mc and can be anode modulated with 3-μsec 3-kv pulses repeated at a rate of about 300 per second. Constructional details are given.

621.373.421.13 1672
Crystal Oscillator has Variable Frequency—G. A. Gedney and G. M. Davidson. (*Electronics*, vol. 31, pp. 118–119; February 14, 1958.) A maximum frequency deviation of 5 cps is obtained from a two-stage crystal feedback amplifier operating at 9.1 kc with a long-term frequency stability within a few parts per million.

621.373.421.13 1673
Frequency Stabilization of U.S.W. Oscillators by using Harmonics for the Excitation of the Quartz Crystal—M. M. Pruzhanskiĭ. (*Radiotekhnika, Moscow*, vol. 11, pp. 15–27; December, 1956.) Modern methods of direct stabilization of USW oscillators by quartz crystals are reviewed. Circuits are described in which the static capacitance of the crystal is compensated by inductance. Simple bridge circuits for operation over a range of frequencies are also described, in which the crystal is excited by high-order harmonics. Uncompensated circuits are also considered, and comparison is made between the various types of circuit.

621.373.431.1 1674
A Three-Phase Three-Valve Multivibrator—W. F. Lovering. (*Electronic Eng.*, vol. 30, pp. 94–95; February, 1958.) A three-tube circuit in which each anode is capacity-coupled to the other two grids is described. Frequencies up to 50 kc are obtained using miniature RF pentodes.

621.373.44 1675
Generation of Bell Shaped Pulses—L. I. Kastal'skiĭ. (*Radiotekhnika, Moscow*, vol. 12, pp. 73–75; January, 1957.) A pulse-generating circuit is described for producing pulses 2.5 to 8 msec long at a repetition frequency of 25 kc.

621.373.44:621.314.7 1676
Transients in Pulse Circuits with Point-Contact Transistors—O. G. Yagodin. (*Radiotekhnika, Moscow*, vol. 12, pp. 43–57; January, 1957.) Analysis based on the dynamic characteristics of transistors. Transient processes in relaxation oscillators and triggering circuits are examined.

621.373.5 1677
A Carrier-Energized Bistable Circuit using Variable-Capacitance Diodes—E. O. Keizer. (*RCA Rev.*, vol. 18, pp. 475–485; December, 1957.) A variable-capacitance junction diode [see 2559 of 1956 (Giacoletto and O'Connell)], when used in a simple circuit driven from a high-frequency source, can cause that circuit to have a bistable characteristic suitable for dynamic storage, or to have a sensitive output /input characteristic suitable for control or detection purposes.

621.374.3 1678
Adjustable Electronic Delay Circuit for the Microsecond Range—J. F. Vervier and P. C. Macq. (*J. Phys. Radium*, vol. 18, p. 603; October, 1957.) A modification of a pulse-discriminator circuit of a type, described by Moody *et al.* (2730 of 1952) using Type-EFP60 secondary-emission pentodes, is described. By means of an adjustable capacitance coupling dynode and grid, the time interval between successive negative and positive pulses derived in the circuit can be adjusted between 2×10^{-6} and 2×10^{-5} s. For an application of the method in a delayed coincidence circuit, see *Rev. Sci. Instr.*, vol. 28, pp. 843–844; October, 1957. (Macq and Vervier).

621.374.32 1679
Binary Frequency Divider with Junction Transistors—A. R. Luminskiĭ and N. M. Trakhtenberg. (*Elektrosvyaz'*, pp. 33–39; April, 1957.)

621.375.13 1680
Limited-Gain Operational Amplifiers—A. W. Keen. (*Electronic Radio Eng.*, vol. 35, pp. 141–143; April, 1958.) The effect of finite gain can be allowed for by assuming infinite amplifier gain and then adding fictitious elements to the feedback network to reduce the gain to its actual value. This leads to a more convenient equivalent network, of which simple examples are given.

621.375.13:621.372.54 1681
Parallel-T *RC* Selective Amplifiers—J. J. Ward and P. V. Landshoff. (*Electronic Radio Eng.*, vol. 35, pp. 120–124; April, 1958.) The operation of a less familiar form of selective amplifier, with low-impedance input, is analyzed, in which the signal is injected at the null point of the parallel-*T* network in the feedback loop. Design equations are derived and applied as an example to a 50-cps fixed-tuned amplifier with a 10-cps square-wave input.

621.375.2.029.3:621.372.552 1682
Electronic Equalizer—S. Subramanian. (*J. Inst. Telecommun. Eng., India*, vol. 4, pp. 12–17; December, 1957.) Description of an AF amplifier with variable boost or attenuation at both the low- and high-frequency ends of the response characteristic. Typical response curves of the amplifier are shown.

621.375.2.029.3:621.396.82 1683
Hum in Audio Stages—R. S. Babbs and M. E. Mason. (*Mullard Tech. Commun.*, vol. 3, pp. 209–213; December, 1957.) A design procedure, based on measurements on typical tube types, for reducing hum in the audio stages of ac/dc equipment.

621.375.23 1684
Design of Feedback Amplifiers for Rescribed Closed-Loop Characteristics—J. L. Stewart. (IRE Trans. on Circuit Theory, vol. CT-3, pp. 145–151; June, 1956. Abstract, Proc. IRE, vol. 44, p. 1492; October, 1956.)

621.375.23:621.396.621.55 1685
Modified Rice Neutralization—B. C. Das. (*J. Inst. Telecommun. Eng., India.* vol. 4, pp. 46–48; December, 1957.) The theory of Rice and modified Rice neutralization are discussed and formulas are derived for maximum stability with no feedback voltage on the grid. The conditions for positive and negative feedback are also derived.

621.375.3:621.318.435 1686
Subminiature Magnetic Amplifiers—A. H. Argabrite. (*Radio TV News*, vol. 58, pp. 70–71, 175; December, 1957.) A description of circuits using a new "ferristor" fast saturable reactor which may be used as a magnetic amplifier or as a bistable ferroresonant element.

621.375.4 1687
Transistor Bias Circuits—R. P. Murray. (*Electronic Indus. and Tele-Tech*, vol. 16, pp. 75–77, 148; November, 1957.) A detailed comparison of four bias circuits with reference to the performance and the operating-point stability. A practical stability factor is derived together with general design formulas for bias components.

621.375.4.001.2 1688
The Use of Universal Curves in the Design of Transistor Amplifier Stages—E. De Castro. (*Note Recensioni Notiz.*, vol. 6, suppl. to pp. 1–24; May/June, 1957.) Design curves are derived from the principal transistor parameters for linear operation at low frequencies.

621.375.4.024 1689
D.C. Transistor Amplifier for High-Impedance Input—D. Schuster. (*Electronics*, vol. 31, pp. 64–65; February 28, 1958.) A short discussion and circuit diagram of an amplifier using a double-emitter follower and grounded-emitter voltage amplifier. Temperature compensation gives short-term drift stability. The input impedance is 0.4 mΩ, and the current gain 1000.

621.375.9:538.221:538.569.4.029.6 1690
Theory of Parametric Amplification using Nonlinear Reactances—S. Bloom and K. K. N. Chang. (*RCA Rev.*, vol. 18, pp. 578–593; December, 1957.) "The parametric amplifier is analyzed phenomenologically in terms of an equivalent-circuit model. The model consists of a signal circuit resonant at ω_1, an idling circuit at ω_2, and a pumping circuit at $\omega_3=\omega_1+\omega_2$, these three circuits being coupled across a nonlinear inductance. The analysis is general enough to delineate the conditions on the signal level and circuit parameters which lead to distortionless amplification. Expressions are derived for power gain, bandwidth, and noise factor for the case in which the signal and idling frequencies are well-separated and for the degenerate case in which these two frequencies are equal."

621.375.9:538.569.4.029.6 1691
Solid-State Maser Amplifier—A. L. McWhorter and J. W. Meyer. (*Phys. Rev.*, vol. 109, pp. 312–318; January 15, 1958.) The operation of a solid-state maser amplifier at 2800 mc is described. A dual-frequency cavity containing paramagnetic potassium chromicyanide in an isomorphous cobalt diluent is used at 1.25°K. The upper three of the four energy levels of the Cr^{+++} ion are used. Spin state populations are inverted by saturating the resonance absorption at 9400 mc. The experimental observations of the maser, both as an amplifier and as an oscillator are compared with theory.

621.375.9:538.569.4.029.63/.64 1692
New Approaches to the Amplification of Microwaves—J. P. Wittke. (*RCA Rev.*, vol. 18, pp. 441–457; December, 1957.) The basic principles governing the operation of two new types of "molecular" microwave amplifier—the maser and the parametric amplifier—are described. Both types of amplifier have relatively narrow bandwidths, but excellent noise properties.

621.376.239:621.318.134 1693
Ferrite Microwave Detector—D. Jaffe, J. C. Cacheris, and N. Karayianis. (Proc. IRE, vol. 46, pp. 594–601; March, 1958.) It is shown theoretically that second-order terms in one component of the magnetization of a ferrite under the action of a RF field may be used to produce magnetostriction in the ferrite and so to detect an AM microwave signal. An experimental technique is described in which the detector consists of a long thin ferrite rod in a waveguide. Magnetostriction vibrations are observed by means of a polarized $BaTiO_3$ ceramic rod bonded to the ferrite. The qualitative results agree with theory, and factors which are expected to improve performance are discussed.

621.376.332:621.396.822 1694
Noise Output of Balanced Frequency Discriminator—D. Slepian. (Proc. IRE, vol. 46, p. 614; March, 1958.) A mathematical analysis for Gaussian noise input, assuming no limiter action.

621.376.54:621.314.7 1695
A Conductivity-Storage Transistor Pulse-Width Modulator—J. C. Price. (*Electronic Eng.*, vol. 30, pp. 88–90; February, 1958.) "Transistors of both point-contact and junction types exhibit in certain pulse applications, prolonged conduction generally ascribed to 'hole storage.' This can be controlled in a circuit to provide a simple means of pulse-width modulation for time-division multiplex. The technique is described for use with selected point-contact transistors."

GENERAL PHYSICS

537.32 1696
Thermoelectric Effects—F. E. Jaumot, Jr. (Proc. IRE, vol. 46, pp. 538–554; March, 1958.) The basic principles of thermoelectricity are reviewed, recent achievements are outlined in terms of specific practical applications, and the present status of the more detailed theoretical treatments is discussed in a nonmathematical fashion. Useful equations describing important parameters are tabulated. Over one hundred references.

537.533 1697
Optical Theory of Thermal Velocity Effects in Cylindrical Electron Beams—G. Herrmann. (*J. Appl. Phys.*, vol. 29, pp. 127–136; February, 1958.) "The present theory is based on a nonlaminar optical model which treats thermal

velocities as an integral part of the motion. A Maxwellian distribution of initial transverse velocities is assumed at the cathode, and a first-order focusing theory is applied in order to calculate trajectories at any point in the beam. It is shown that whenever a long beam is confined by a focusing field, images of the cathode are formed repeatedly along the axis. When applied to uniform magnetic focusing fields, the theory predicts the periodic formation along the axis of cathode images, and cross-overs, and a relative rotation of successive images. Such effects have been reported."

537.533 1698
Effect of Variation of D.C. Current in a Modulated Electron Beam—I. P. Shkarofsky. (*J. Appl. Phys.*, vol. 29, pp. 222–223; February, 1958.) Experiments indicate that existing theory needs correction. An empirical formula satisfying all experimental observations is difficult to obtain.

537.56:538.56 1699
Oscillations in Plasma: Part 1—S. Kojima, K. Kato, and S. Hagiwara. (*J. Phys. Soc. Japan*, vol. 12, pp. 1276–1281; November, 1957.) A sensitive super-regenerative detector was used to study oscillations in a Looney-Brown tube without auxiliary electron beams. Oscillations were detected by a small external antenna.

537.56:538.56 1700
Nonlinear Effects in Electron Plasmas—P. A. Sturrock. (*Proc. Roy. Soc. A*, vol. 242, pp. 277–299; November 5, 1957.) A mathematical study of three groups of effects, *viz.*, the excitation of harmonics, coherent interaction, and incoherent interaction. Complications of finite boundaries, external fields, nonzero temperature, multistream flow, and collisions are ignored. The main interest is in the incoherent interaction which results in spectral decay, and damping effects are compared with experimental data.

537.56:538.56:538.6 1701
Waves in a Plasma in a Magnetic Field—I. B. Bernstein. (*Phys. Rev.*, vol. 109, pp. 10–21; January 1, 1958.) An analysis of the small-amplitude oscillations of a fully ionized, quasi-neutral plasma in a uniform, externally produced magnetic field. No self-excitation of waves around thermal equilibrium is predicted, in contrast to the results of Gordeyev. For longitudinal electron oscillations propagated perpendicularly to the constant magnetic field, there are gaps in the spectrum of allowed frequencies at multiples of the electron-gyration frequency, but zero-Landau damping. When the ion dynamics are included, two classes of low-frequency oscillations are found and the results for the propagation of em waves in an ionized atmosphere are also derived.

537.56:538.566 1702
Conductivity of Plasmas to Microwaves—H. Margenau. (*Phys. Rev.*, vol. 109, pp. 6–9; January 1, 1958.) The complex conductivity is calculated for a neutral plasma with electrons having a distribution in space and velocity which does not change over a time interval long compared with the period of the microwave field. The conductivity is derived for velocity distributions given by the Dirac δ function, a step function, and a Maxwellian distribution.

537.56:538.6 1703
Plasma Diffusion in a Magnetic Field—M. N. Rosenbluth and A. N. Kaufman. (*Phys. Rev.*, vol. 109, pp. 1–5; January 1, 1958.) "The equations governing the diffusion of a fully-ionized plasma across a magnetic field are derived. It is assumed that macroscopic quantities vary slowly across an ion radius of gyration, and that the interparticle collision frequency is much less than the gyration frequency. The relevant transport coefficients—electrical resistivity, thermal conductivity, and thermoelectric coefficient—are derived. Some similarity solutions of the equations are found."

538.3 1704
Nonlinear Electromagnetism and Photons in the Functional Theory of Particles—F. Aeschlimenn and J. L. Destouches. (*J. Phys. Radium*, vol. 18, pp. 632–637; November, 1957.)

538.566:535.43 1705
New Tables of Total Mie Scattering Coefficients for Spherical Particles of Real Refractive Indexes ($1.33 \leq n \leq 1.50$—R. B. Penndorf. (*J. Opt. Soc. Amer.*, vol. 47, pp. 1010–1015; November, 1957.) K, the total Mie scattering coefficient, is defined as the total flux scattered by the particle divided by the flux incident on its cross section πr^2; the size parameter $a = 2\pi r/\lambda$. The theory applies only to a very dilute aerosol of randomly arranged spheres and does not allow for coherence in the field or for multiple scattering. K has been calculated on an electronic computer for $0.1 \leq a \leq 30$ in steps of 0.1 and for $n = 1.33$, 1.40, 1.44, 1.486 and 1.50.

538.566:535.43 1706
Scattering of Electromagnetic Waves by Long Cylinders—A. W. Adey. (*Electronic Radio Eng.*, vol. 35, pp. 149–158; April, 1958.) The field scattered by a metal or dielectric cylinder, when excited by a wave propagated in a direction normal to the cylinder axis, is discussed theoretically for plane and cylindrical waves. The radius of the cylinder is comparable with the wavelength. The dielectric cylinder is a resonant structure.

538.569.3 1707
Propagation through a Dielectric Slab—T. B. A. Senior. (*Electronic Radio Eng.*, vol. 35, pp. 135–137; April, 1958.) Propagation from a point source through an infinite slab is considered theoretically, with particular reference to the apparent source and its modified polar diagram. An appreciable change in polar diagram can be produced by even a thin sheet of dielectric.

538.569.4:535.34 1708
The Microwave Spectrum and Structure of Trichloracetonitrile—J. G. Baker, D. R. Jenkins, C. N. Kenney, and T. M. Sugden. (*Trans. Faraday Soc.*, vol. 53, pp. 1397–1401; November, 1957.) The microwave spectrum of $CCl^{35}{}_3CN$ has been studied in the range 16–27 kmc using a Stark modulation microwave spectrometer.

538.569.4:539.14 1709
Nuclear Magnetic Resonance—M. Lipsicas. (*Brit. Commun. Electronics*, vol. 4, pp. 686–690; November, 1957.) The phenomenon is briefly discussed and the Pound system for its detection is described. For high-resolution work the Bloch spectrometer is particularly suitable.

538.569.4:539.4 1710
Audio-Frequency Nuclear-Resonance Echoes—J. G. Powles and D. Cutler. (*Nature, London*, vol. 180, pp. 1344–1345; December 14, 1957.) A spin-echo technique for determining nuclear-magnetic resonance by experiments in the earth's magnetic field is described. It is possible to derive the true spin-spin relaxation time even if the field is not homogeneous.

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.16:621.396.677.833 1711
The 45-ft Radio Telescope at the Royal Radar Establishment, Malvern—(See 1636.)

523.164.3+551.594.6 1712
Radio Noise from Planets—F. Horner. (*Nature, London*, vol. 180, p. 1253; December 7, 1957.) A comparison is made of HF radio noise from Jupiter and Venus and from terrestrial lightning. The hypothesis that radio noise from the two planets is due to electrical discharges analogous to terrestrial lightning requires modification. See also 3357 of 1956 (Kraus).

523.164.32 1713
The Distribution of Radio Brightness over the Solar Disk at a Wavelength of 21 Centimetres: Part 4—The Slowly Varying Component—W. N. Christiansen, J. A. Warburton, and R. D. Davies. (*Aust. J. Phys.*, vol. 10, pp. 491–514; December, 1957.) The emitting regions were studied individually using a 32-element interferometer producing fringes 3′ of arc in width. During 1952–1953 the radio sources were found to lie about 22,000 km above and to have the same size as "plages faculaires." The angular distribution of radio flux follows approximately a cosine law suggesting that the source is a thin shell parallel to the sun's surface. The correlation between radio flux and sunspot areas is discussed. See Part 3 in 1706 of 1956 (Christiansen and Warburton).

523.53:621.396.96 1714
Meteor Radiant Determination from High-Echo-Rate Observations—C. S. L. Keay. (*Aust. J. Phys.*, vol. 10, pp. 471–482; December, 1957.) "A simplified analysis is given of the Clegg method for delineating meteor radiants from radar observations [see 1031 of 1949]. A further analysis reveals a new and faster method of interpreting the data contained in meteor-echo records. This method is applicable when sensitive equipment is employed and the resulting echo rate is very high."

523.75:523.164.32 1715
The Association of Solar Radio Bursts of Spectral Type III with Chromospheric Flares—R. E. Loughhead, J. A. Roberts, and M. K. McCabe. (*Aust. J. Phys.*, vol. 10, pp. 483–490; December, 1957.) Simultaneous optical and radio observations were made for over 300 flares 85 per cent of which were of Class 1, 20 per cent of which are associated with Type-III events. Sixty per cent of the bursts were recorded during the life of the flare, usually near the beginning. The probability of a burst accompanying a flare is greater for large flares and is the same for flares on the east limb as for those in the center of the disk. This implies a wide cone of escape for Type-III radiation.

523.75:621.396.812.5.029.51 1716
A New Effect of Chromospheric Eruptions—Waldmeier. (See 1865.)

550.389.2 1717
Bureau of Standards Role in I.G.Y—(*Radio TV News*, vol. 58, p. 41; December, 1957.) A short summary of the work undertaken.

550.389.2:621.396.11 1718
Radio Research and the I.G.Y—C. M. Minnis. (*Brit. Commun. Electronics*, vol. 4, pp. 691–693; November, 1957.) The objectives and organization of the IGY are outlined. The programs of observations which are of particular interest to radio engineers and the users of rockets and satellites are described.

550.389.2:629.19 1719
Artificial Earth Satellites—V. Vakhnin. (*QST*, vol. 41, pp. 22–24, 188; November, 1957.) English version of 3860 of 1957.

550.389.2:629.19 1720
Radio Observations on the Russian Satel-

lites—(*Proc. IEE*, vol. 105, pt. B, pp. 81–115; March, 1958.) The following short contributions were presented at a meeting of the Radio and Telecommunication Section of the IEE, London, November 22, 1957.

Observations at Cambridge—J. R. Shakeshaft (pp. 83–84).

Apparatus used at the Royal Aircraft Establishment—A. N. Beresford (pp. 85–88).

Some Direction-Finding Observations on the 20-Mc/s Signal—F. A. Kitchen, E. R. Billam, N. R. R. Joy, R. F. Cleaver, D. L. Cooper-Jones, and J. M. Beukers (pp. 89–91).

Observations of Bearing and Angle of Elevation of Satellite I—W. C. Bain and R. W. Meadows (pp. 91–93).

Estimating the Height of the First Satellite from Radio Interferometer Records—G. B. Longden (pp. 93–95).

Precise Frequency Measurements on First Russian Satellite—H. Stanesby (pp. 96–99).

Analysis of Doppler Data from Earth Satellites—D. E. Hampton (pp. 99–100).

Radio Observations of the Signal Characteristics of Satellite I—P. J. Brice and P. N. Parker (pp. 101–104).

Radar Observations of the Russian Earth Satellites and Carrier Rocket—J. Davis, J. V. Evans, S. Evans, J. S. Greenhow, and J. E. Hall (pp. 105–107).

Observations at the Royal Radar Establishment—J. S. Hey (pp. 107–108).

Discussion (pp. 95–96, 108–115).

550.389.2:629.19 1721

Ranging the Satellite by Doppler-Shift Observation—J. M. Osborne. (*Short Wave Mag.*, vol. 15, pp. 459–462; November, 1957.) An experimental method using simple apparatus.

550.389.2:629.19 1722

Unusual Propagation at 40 Mc/s from the U.S.S.R. Satellite—H. W. Wells. (PROC. IRE, vol. 46, p. 610; March, 1958.) Interferometry recordings were obtained in Washington on a few occasions during October, 1957, when the satellite was on the opposite side of the earth, near an antinodal point.

550.389.2:629.19 1723

A Note on Some Signal Characteristics of Sputnik I—J. D. Kraus and J. S. Albus. (PROC. IRE, vol. 46, pp. 610–611; March, 1958.)

550.389.2:629.19 1724

Detection of Sputniks I and II by C.W. Reflection—J. D. Kraus. (PROC. IRE, vol. 46, pp. 611–612; March, 1958.) The method described is based on the reception of the 20-mc transmission of WWV at a distance of about 330 miles.

550.389.2:621.396.11:629.19 1725

The Last Days of Sputnik I—J. D. Kraus. (PROC. IRE, vol. 46, pp. 612–614; March, 1958.) Deductions are based on radio-reflection records using WWV transmissions on 20 mc. See also 1724 above.

551.510.535 1726

Proceedings of the Polar Atmosphere Symposium Held at Oslo, 2–8 July 1956: Part II—Ionospheric Section—(*J. Atmos. Terr. Phys.*, special suppl., pt. II, p. 212; 1957.) The text is given, with ensuing discussions, of 21 papers presented at the symposium. Abstracts of some of these are given individually. Titles of others are as follows.

Results of Ionospheric Drift Measurements in the United States—V. Agy (pp. 23–25).

Results of Ionospheric Drift Measurements in Norway—L. Harang (pp. 26–32).

Movements of Ionospheric Irregularities Observed Simultaneously by Different Methods—I. L. Jones, B. Landmark, and C. S. G. K. Setty (pp. 41–43). See 2750 of 1957.

Turbulence in the Ionosphere with Applications to Meteor Trails, Radio-Star Scintillations, Auroral Radar Echoes, and Other Phenomena—H. G. Booker (pp. 52–81). See 1441 of 1957.

Geographic Distribution of Geophysical Stations on the Polar Cap—A. H. Shapley (p. 108).

A Theory of Long-Duration Meteor Echoes based on Atmospheric Turbulence with Experimental Confirmation—H. G. Booker and R. Cohen (pp. 171–194). See 1417 of 1957.

551.510.535 1727

Theoretical Views on Drift Measurements—I. L. Jones. (*J. Atmos. Terr. Phys.*, special suppl., pt. II, pp. 3–11; 1957.) The conversion of the amplitude-pattern drift at the ground, as sampled by three closely-spaced receivers, to the true drift in the ionosphere requires the determination of auto- and cross-correlation functions. Problems in relating ground-pattern drift to ionospheric drift are stated.

551.510.535 1728

The Drift of an Ionized Layer in the Presence of the Geomagnetic Field—K. Weekes. (*J. Atmos. Terr. Phys.*, special suppl., pt. II, pp. 12–19; 1957.) The efficiency of air winds in causing ionization-drift decreases with atmospheric pressure. Thus, in the *F* region, electric fields may be the main cause of drift; in the *E* region electric fields may contribute equally with air winds; in the *D* region air winds would be the main cause. The effect of winds and fields in causing drifting of cylindrical irregularities in each region is given.

551.510.535 1729

The Height Variation of Horizontal Drift Velocities in the E Region—I. L. Jones. (*J. Atmos. Terr. Phys.*, pt. II, pp. 20–22; 1957.) The drift was measured on two adjacent frequencies corresponding to heights of reflection differing by about 5 km. The diurnal change in the N-S and E-W velocity components differs in phase at the two heights.

551.510.535 1730

Large-Scale Movements of the Layers—H. W. Wells. (*J. Atmos. Terr. Phys.*, special suppl., pt. II, pp. 33–40; 1957.) Moving wave-like disturbances, with $\lambda \simeq 200$–400 km, appear to travel with inclined wavefronts—having both horizontal and vertical motions which are often of similar magnitudes—and with varying direction. The effects are independent of magnetic activity, and are probably not caused by atmospheric winds. A traveling compressional wave is suggested as an alternative to motion caused by electric fields.

551.510.535 1731

Electron Distribution in a New Model of the Ionosphere—H. K. Kallmann. (*J. Atmos. Terr. Phys.*, special suppl., pt. II, pp. 82–87; 1957.) Rocket measurements between 90 and 200 km for pressure, density, and temperature are used to derive a new empirical model for temperature and electron density in the ionosphere. This model agrees well with the theory of temperature variation and radio measurements of electron density. See also 436 of 1957 (Kallmann *et al.*).

551.510.535 1732

Some Implications of Slant E_s—E. K. Smith and R. W. Knecht. (*J. Atmos. Terr. Phys.*, special suppl., pt. II, pp. 195–204; 1957.) Slant E_s is common in polar regions, the virtual height of traces rising from 100 up to 500 km. A linear characteristic passing through the origin relates virtual height and frequency. It is suggested that slant E_s is due to back scatter from E_s. Four models of propagation are possible: 1) direct back scatter, 2) reflected back scatter, 3) single reflected scatter, and 4) double scatter. Experiments are suggested which would distinguish between them.

551.510.535 1733

An Easily Applied Method for the Reduction of *h-f* Records to *N-h* Profiles including the Effects of the Earth's Magnetic Field—E. R. Schmerling. (*J. Atmos. Terr. Phys.*, vol. 12, pp. 8–16; 1958.) The method depends on sampling h' at fixed submultiples of the frequencies f_n at which true heights are required. The latter are then obtained by averaging the values of h'. A complete computation is presented for Washington, D. C., and the results checked against an analysis of $h'(f)$ curves for known profiles.

551.510.535 1734

The Electron Distribution in the Ionosphere over Slough: Part 1—Quiet Days—J. O. Thomas, J. Haselgrove, and A. Robbins. (*J. Atmos. Terr. Phys.*, vol. 12, pp. 46–56; 1958.) The distribution of electron density with height is calculated from $h'(f)$ records using an electronic computer. The method assumes that the $N(h)$ curve increases monotonically and allows for the effect of the earth's magnetic field. The height of maximum electron density in the F_2 layer is found to be considerably lower than previously supposed, particularly in the summer and equinox months.

551.510.535 1735

The Height Variation of Drift in the E Region—I. L. Jones. (*J. Atmos. Terr. Phys.*, vol. 12, pp. 68–76; 1958.) Simultaneous observations at 2.0 and 2.5 mc of drift velocities show significant differences and it is deduced that they refer to different heights. The velocities rotated through 360 degrees at a non-uniform rate during daylight hours; the non-uniformity is due to the variation of reflection height. In the winter months the rotation at the smaller height lagged with respect to that at the larger. Rapid changes in drift were observed during September and October. The results agree with those deduced by Greenhow and Neufeld (1415 of 1957) from meteor-trail observations, if allowance is made for the height differences.

551.510.535 1736

Solar Tidal Effects in the F_2 Region of Ionosphere over Delhi—C. S. R. Rao. (*Indian J. Phys.*, vol. 31, pp. 516–525; October, 1957.) Harmonic analysis of h_pF_2 and f_0F_2 shows the existence of semidiurnal and seasonal solar-tidal effects in the F_1 layer at Delhi. Vertical drifts of 20 km/h in summer, 18 km/h in winter, and 33 km/h at the equinoxes are calculated from ionization density variations. Attachment coefficients, including these tidal effects, worked out for different seasons are in agreement with those obtained by Ratcliffe *et al.* (2724 of 1956).

551.510.535:523.164 1737

A Study of the Ionospheric Irregularities which Cause Spread-F Echoes and Scintillations of Radio Stars—B. H. Briggs. (*J. Atmos. Terr. Phys.*, vol. 12, pp. 34–45; 1958.) A discussion of the correlation between the occurrence of spread-*F* echoes at Slough, Inverness, and Oslo. The irregularities responsible for the spreading occur in bands which lie along parallels of latitude, and have a width of the order of 450 km. It is suggested that the irregularities occur at heights near 300 km.

551.510.535:523.78 1738

Ionospheric Records of Solar Eclipses—G. H. Munro and L. H. Heisler. (*J. Atmos. Terr. Phys.*, vol. 12, pp. 57–67; 1958.) The horizontal gradients of ionization produced during an eclipse introduce curvature into the isoionic contours so that the ionosonde soundings are effectively oblique. The resultant errors in the deduced ion distributions, assuming vertical soundings, give rise to many of the apparent abnormalities in eclipse records.

551.510.535:551.55 1739
Travelling Disturbances in the Ionosphere: Changes in Diurnal Variation—G. H. Munro. (*Nature, London*, vol. 180, pp. 1252–1253; December 7, 1957.) The mean diurnal variation in the direction of horizontal movement of traveling ionospheric disturbances is plotted for January, 1957, and for January in the years 1951–1954. The main feature of the former is an unusually large change of direction about midday possibly associated with high-sunspot activity.

551.510.535+551.510.52]:621.396.11 1740
Progress in the Field of Ionospheric Research and Tropospheric Wave Propagation—B. Beckmann. (*Nachr-Tech.*, vol. 10, pp. 369–376; August, 1957.) Report based on papers presented at a conference held at Kleinheubach, Germany, October 11–13, 1956, and organized by the German URSI Committee and the Nachrichtentechnische Gesellschaft.

551.510.535:621.396.11 1741
Ionospheric True Height and M.U.F. Calculations—J. O. Thomas and A. Robbins. (*J. Atmos. Terr. Phys.*, vol. 12, pp. 77–79; 1958.) MUF calculated from the more accurate determinations of the electron density distribution (see 1734 above) are consistently higher than the Slough Bulletin values.

551.510.535:621.396.11 1742
The Spectrum of the Electron Density Fluctuations in the Ionosphere—R. M. Gallet. (*J. Atmos. Terr. Phys.*, special suppl., pt. II, pp. 165–170; 1957.) The fluctuations are assumed to arise from the vertical transport of small pockets of air in the presence of 1) a non-adiabatic temperature gradient and 2) vertical gradients of mean electron density. A preliminary account of the theory of the spectrum of the fluctuations is given with references to the application of the results to ionospheric and tropospheric scattering of radio waves. See also 234 of 1956.

551.510.535+550.385](98) 1743
Polar Disturbances—J. H. Meek. (*J. Atmos. Terr. Phys.*, special suppl., pt. II, pp. 120–128; 1957.) Disturbances in the ionosphere and geomagnetic field, and also auroral behavior, are usually treated statistically. In this paper, an attempt is made to investigate what occurred in a few specific cases. There is some evidence for a spiral auroral zone.

551.510.535(98) 1744
Statistical Results and their Shortcomings concerning the Ionosphere within the Auroral Zone—R. W. Knecht. (*J. Atmos. Terr. Phys.*, Special suppl., pt. II, pp. 109–119; 1957.) The difficulties of obtaining significant data from high-latitude *h'(f)* curves are discussed together with the statistical treatment of such data. These difficulties could be minimized by the adoption of the recommendations of the URSI High Latitude Committee.

551.510.535(98) 1745
Measurements of Irregularities and Drifts in the Arctic Ionosphere using Airborne Techniques—G. J. Gassman. (*J. Atmos. Terr. Phys.*, special suppl., pt. II, pp. 44–51; 1957.) An *h'(f)* ionospheric recorder was installed in an aircraft and flights were made in North Polar regions. The interpretation of the experimental data in terms of ionospheric structure is discussed. Some drift measurements were made at the North Pole. See also 2382 of 1956.

551.510.535(98):621.396.11 1746
Quantitative Measurements of Absorption in the Auroral Zone—F. Lied. (*J. Atmos. Terr. Phys.*, special suppl., pt. II, pp. 135–146; 1957.) The various alternative methods of measuring ionospheric absorption are discussed and the results compared with particular reference to the North Polar region.

551.510.535(98):621.396.11 1747
Echoes from the Lower Ionosphere during Polar Blackouts—B. Landmark. (*J. Atmos. Terr. Phys.*, vol. 12, pp. 79–80; 1958.)

551.510.535(98):621.396.11 1748
Polar Blackout Occurrence Patterns—V. Agy. (*J. Atmos. Terr. Phys.*, special suppl., pt. II, pp. 129–134; 1957.) A brief survey of the geographical distribution of the probability of the occurrence of blackouts in North Polar regions. Difficulties in interpretation of the data are discussed. See also 1039 of 1955.

551.594.6 1749
Classification of Atmospheric Waveforms—F. Hepburn. (*J. Atmos. Terr. Phys.*, vol. 12, pp. 1–7; 1958.) The desirability and requirements of a systematic classification of atmospheric waveforms are discussed. An observational scheme is suggested and interpreted in terms of known properties of the discharge and propagation mechanisms. These data are reviewed to clarify application of the scheme to individual waveforms. The relation between the classification and previous inadequate groupings is indicated.

LOCATION AND AIDS TO NAVIGATION

621.396.663:550.372 1750
Phase Distortion due to Ground Inhomogeneities—K. Baur. (*Nachr-Tech.* vol. 10, pp. 385–389; August, 1957.) Formulas are derived for assessing the quality of the ground with regard to fluctuations of conductivity and dielectric constants, thereby assisting in the selection of a site suitable for DF.

621.396.933 1751
An Improved Medium-Range Navigation System for Aircraft—C. G. McMullen. (IRE TRANS. ON AERONAUTICAL AND NAVIGATIONAL ELECTRONICS, vol. ANE-3, pp. 103–107, September, 1956. Abstract, PROC. IRE, vol. 44, p. 1897; December, 1956.) A survey of existing systems leads to the conclusion that range-measurement equipment is more precise than bearing-measurement equipment. The use of a computer with existing equipment is suggested to give range-range measurements in terms of elliptical or hyperbolic coordinates.

621.396.933:621.396.676 1752
Azimuth Errors for the TACAN System—D. W. T. Latimer, Jr. (IRE TRANS. ON AERONAUTICAL AND NAVIGATIONAL ELECTRONICS, vol. ANE-3, pp. 150–156; December, 1956. Abstract, PROC. IRE, vol. 45, p. 570; April, 1957.)

621.396.96:621.396.677.832 1753
V-Reflex Aerial for an Information Radar Station— von Trentini and Kirkscether. (See 1635.)

621.396.96.001.362 1754
Radar Simulators—L. J. Kennard and C. H. Nicholson. (*J. Brit. Inst. Radio Eng.*, vol. 18, pp. 17–30; January, 1958. Discussion, pp. 30–31.) The characteristics required for an accurate presentation of radar signals for air-traffic control, surface-vessel movement and air and naval warfare, including various types of jamming are discussed. An accurate antenna-pattern function generator is necessary and two complete computing systems are described.

621.396.96.001.362 1755
The Use of Radar Simulators in the Royal Navy—P. Tenger. (*J. Brit. IRE*, vol. 18, pp. 33–47; January, 1958.) A detailed description of an instrument developed to meet specialized requirements.

MATERIALS AND SUBSIDIARY TECHNIQUES

535.215:546.482.41:539.23 1756
High-Voltage Photovoltaic Effect—L. Pensak. (*Phys. Rev.*, vol. 109, p. 601; January 15, 1958.) Vacuum-evaporated films of CdTe have been prepared that show unusually high photovoltages across their ends. The effect is independent of the electrode material and the voltage is proportional to the length of the film.

535.215:546.482.41:539.23 1757
Properties of Photovoltaic Films of CdTe—B. Goldstein. (*Phys. Rev.*, vol. 109, pp. 601–603; January 15, 1958.) The photoelectric properties of a CdTe film of the type described by Pensak (1756 above) are analyzed. Results are consistent with the film containing a series of *p-n* junctions having a distribution of barrier heights.

535.37 1758
Influence of Activator Environment on the Spectral Emission of Phosphors—G. R. Fonda. (*J. Opt. Soc. Amer.*, vol. 47, pp. 877–880; October, 1957.) For isomorphous basic compounds the spectral emission is governed by the field strength to which the activator ion is subjected by its environment.

535.37[546.321.31+546.472.21 1759
Nature of Luminescent Centres in Alkali Halide and Zinc Sulphide Phosphors—F. E. Williams. (*J. Opt. Soc. Amer.*, vol. 47, pp. 869–876; October, 1957.) "The theory of the excitation and emission spectra of Tl-activated KCl is reviewed and extended to the problem of oscillator strengths for luminescent transitions. Semiconductor theory is applied to ZnS phosphors and the acceptor and donor nature of activator and coactivator, respectively, is thereby revealed."

535.376 1760
Electroluminesence—S. T. Henderson. (*Brit. J. Appl. Phys.*, vol. 9, pp. 45–51; February, 1958.) The present state of research in field-controlled and carrier-injection luminesence is briefly reviewed. Intrinsic luminescence is considered in relation to the behavior of various phosphors, mainly ZnS with Cu as impurity activator, the voltage /brightness relation, temperature effects, and the dependence of the emission waveforms upon the waveform of the applied field. Differences in the theoretical explanations of the behavior are discussed and practical applications of the phenomenon are outlined. Sixty-nine references.

535.376:546.26–1 1761
A Surface Electroluminescence Effect in Diamonds—H. J. Logie and R. R. Urlau. (*Nature, London*, vol. 180, pp. 1254, 1271; December 7, 1957.) Diamonds coated with a thin layer of graphite have been found to luminesce with bright green spots of light when a potential difference is applied to them. See also 2468 of 1957 (Wolfe and Woods).

535.376:546.472.21 1762
Trapping Action in Electroluminescent Zinc Sulphide Phosphors—C. H. Haake. (*J. Opt. Soc. Amer.*, vol. 47, pp. 881–887; October, 1957.) Discussion of the results of brightness measurements showing that electron traps are more important in electroluminescent phosphors than in ordinary photoluminescent phosphors.

537.226/.227 1763
Optical and Dielectric Investigation of Boracite—Y. Le Corre. (*J. Phys. Radium*, vol. 18, pp. 629–631; November, 1957.) An abrupt change in the dielectric constant of $Mg_3B_7O_{13}Cl$ at 265 degrees and results of measurements support the hypothesis that the material is ferroelectric.

537.226/.227:
[546.431.824–31+546.42.824–31 1764
Phase Equilibria in the System $BaTiO_3$-$SrTiO_3$—J. A. Basmajian and R. C. DeVries. (*J. Amer. Ceram. Soc.*, vol. 40, pp. 373–376; November, 1957.) Report on investigations above 1200°C.

537.227/.228.1:546.32.882.5 1765
Method for Growing Single Crystals of Potassium Niobate—C. E. Miller. (*J. Appl. Phys.*, vol. 29, pp. 233–234; February, 1958.) Crystals approximately 1 inch on each side have been obtained.

537.311.33 1766
Problems of the Metallurgy and Physics of Semiconductors—(*Ak. Nauk S.S.S.R. Special Publication*, 152 pp.; 1957.) The texts are given of the following papers presented at the Second Conference on Semiconductors held in January, 1956, at the A. A. Baĭkova Institute of Metallurgy of the U.S.S.R. Academy of Sciences, Moscow.

Problems closely related to the Development of the Metallurgy of Semiconductors—D. A. Petrov (pp. 5–11). See also 2168 of 1957.

Preparation of High-Purity Silicon by an Iodine Method—I. A. Inozemtseva (pp. 12–17).

Preparation of Pure Silicon by the Method of Reduction of Silicon Chloride by Zinc—D. A. Petrov and L. K. Zhukova (pp. 18–23).

Preparation of Silicon Single Crystal by the Method of Drawing from the Melt—B. P. Mitrenin, Sh. S. Burdiashvili, N. A. Shamba, V. P. Volkov, V. K. Kovyrzin, and L. K. Solov'ev (pp. 24–34).

Use of Zone Melting for Obtaining Silicon Single Crystals—B. P. Mitrenin, S. P. Lalykin, Yu. P. Savrasov, and L. K. Radaĭkin (pp. 35–40).

Preparation of Silicon Single Crystals—D. A. Petrov, M. G. Kekua, V. D. Khvostikova, Yu. M. Shashkov, and A. D. Suchkova (pp. 41–46).

The Problem of Growing Single Crystals of Germanium from a Melt—A. P. Izergin (pp. 47–49).

Developments in the Purification of Germanium by Crystallization Methods, and in the Preparation of Single Crystals of Germanium with Uniform Longitudinal Properties—D. A. Petrov, M. G. Kekua, M. Ya. Dashevskiĭ, V. S. Zemskov, and P. L. Petrusevich (pp. 50–58).

Investigation of the Possibility of Obtaining a Homogeneous Alloy of Germanium with Silicon by means of Zone Melting—B. P. Mitrenin, N. E. Troshin, K. P. Tsomaya, V. A. Vlasenko, and Yu. D. Gubanov (pp. 59–69).

Preparation of Single Crystals of AlSb and Investigation of their Properties—D. A. Petrov, M. S. Mirgalovskaya, I. A. Strel'nikova, and E. M. Komova (pp. 70–79).

Synthesis of Aluminium Antimonide (AlSb) and Some of its Properties—G. N. Nikolaenko (pp. 80–90).

Investigation of the Systems Bi-Te—N. Kh. Abrikosov, V. F. Bankina, and G. A. Fedorova (pp. 91–96).

Investigation of Thermoelectric Properties of Cobalt Antimonide—L. D. Dudkin and N. Kh. Abrikosov (pp. 97–109).

Vitreous Semiconductors—N. A. Goryunova and B. T. Kolomiets (pp. 110–120).

Diffusion Coefficient of some Impurities in Germanium—B. I. Boltaks (pp. 121–129). See also 484 of 1957.

Diffusion of Antimony and Germanium in Silicon—D. A. Petrov, Yu. M. Shashkov, and I. P. Akimchenko (pp. 130–132).

Influence of Impurities on the Life-time of Excess Charge Carriers in Germanium—A. V. Rzhanov (pp. 133–137). See 2190 of 1957.

The Problem of Using the Photoelectric Method of Measuring the Diffusion Length of Minority Current Carriers in Silicon—I. D. Kirvalidze (pp. 138–141).

New Etchants for Silicon and Germanium—B. I. El'kin (pp. 142–151).

537.311.33 1767
Magnetic Field Effects on Electron Populations in Semiconductors—P. T. Landsberg. (*Proc. Phys. Soc.*, vol. 71, pp. 69–76; January 1, 1958.) The change in population of the states of the conduction band, when a magnetic field is applied, is calculated. It is assumed that the conduction-band states are shifted up or down by an energy d due to the interaction of their spins with the magnetic field and that the donor states are also shifted up or down in energy by the same amount d. The more important general properties of the model are discussed and a numerical example is worked out.

537.311.33 1768
The Influence of Interelectronic Collisions on Conduction and Breakdown in Covalent Semiconductors—R. Stratton. (*Proc. Roy. Soc. A*, vol. 242, pp. 355–373; November 5, 1957.) The breakdown field strength and variation of mobility with field strength are calculated for conditions of high, moderate, and low electron densities; results for all three cases are similar. The energy and momentum distributions of electrons (or holes) are used; at high electron densities, both distributions are largely determined by interelectronic collisions, but at lower densities only the energy distribution is affected. Acoustic and optical lattice-mode scattering are considered for various temperature ranges.

537.311.33 1769
On the Theory of Surface Recombination in Semiconductors for Large Potential Differences between Surface and Bulk—F. Berz. (*Proc. Phys. Soc.*, vol. 71, pp. 275–280; February 1, 1958.) When the potential variation over a carrier-mean free path is of the order of kT/e, the theoretical results show hole-electron capture cross-section ratios different from those to be expected on a simple Maxwell-Boltzmann distribution picture.

537.311.33:535.215 1770
Comparison of the Semiconductor Surface and Junction Photovoltages—E. O. Johnson. (*RCA Rev.*, vol. 18, pp. 556–577; December, 1957.) It is shown analytically that the surface and junction photovoltages are almost identical phenomena. The functional dependence of the two photovoltages on the light-injected carrier densities is exactly the same, except in the region of saturation. Charge changes in traps can have a marked effect on the surface photovoltage, however, no direct effect on the total junction photovoltage.

537.311.33:537.311.4 1771
Simplified Treatment of Electric Charge Relations at a Semiconductor Surface—E. O. Johnson. (*RCA Rev.*, vol. 18, pp. 525–555; December, 1957.) Simple, graphical representation is used to describe the electric charge and potential relations at a semiconductor surface. The balance between trapped and mobile charge at the surface is considered for both equilibrium and nonequilibrium conditions. The treatment is extended to cover metal/semiconductor, gas/semiconductor and p-n junction interfaces.

537.311.33:537.312.8 1772
Isotropic Approximation to the Magnetoresistance of a Multivalley Semiconductor—R. W. Keyes. (*Phys. Rev.*, vol. 109, pp. 43–46; January 1, 1958.) A multivalley model is suggested which describes approximately the magnetoresistance phenomena of a polycrystalline semiconductor. The results provide a means for determining the valley anisotropy of a multivalley semiconductor from magnetoresistance data without reference to a particular model of the band structure. See also 1480 of 1957.

537.311.33:537.312.9 1773
An Apparatus for Measuring the Piezoresistivity of Semiconductors—R. F. Potter and W. J. McKean. (*J. Res. Natl. Bur. Stand.*, vol. 59, RP 2814, pp. 427–430; December, 1957.) A detailed description is given of an apparatus and procedure designed to measure the piezoresistive effect in semiconductors over an extended temperature range. A tensile force up to 1 kg can be applied to the sample by means of a calibrated beam balance. The apparatus has been used for measurements on InSb over the range 78°K–300°K, and tensile stresses of the order of 5×10^7 dynes cm^2 can be applied to samples that are cut in a special manner.

537.311.33:538.63 1774
The Theory of the Nernst Effect in Semiconductors—J. E. Parrott. (*Proc. Phys. Soc.*, vol. 71, pp. 82–87; January 1, 1958.) The effects of phonon-electron drag on the Nernst effect are examined using general methods previously described (3511 of 1957). A quantitative agreement between theory and experiments on germanium is reported. It is shown that the sign of the Nernst coefficient can be altered by a phonon current.

537.311.33:[546.28+546.289 1775
Growth of Silicon and Germanium Disks—J. R. O'Connor and W. A. McLaughlin. (*J. Appl. Phys.*, vol. 29, p. 222; February, 1958.) A preliminary investigation has been made of the growth of large disks of semiconductor materials by slowly withdrawing a disk-shaped seed from a melt.

537.311.33:[546.28+546.289 1776
Electron Mobility in the Germanium-Silicon Alloys—B. Goldstein. (*RCA Rev*, vol. 18, pp. 458–465; December, 1957.) The method of measurement involves the determination of charge-carrier density from the voltage dependence of the depletion-layer capacitance of a p-n junction formed on the material under test. Similar qualitative behavior has been found for the conductivity and Hall mobilities as changes are made in alloy composition.

537.311.33:546.28 1777
Arrangements of Dislocations in Plastically Bent Silicon Crystals—J. R. Patel. (*J. Appl. Phys.*, vol. 29, pp. 170–176; February, 1958.) "Dislocations introduced into single crystals of Si by plastic bending at an elevated temperature have been studied quantitatively by the etch-pit technique. The average etch-pit density after deformation is approximately two to three times higher than the calculated dislocation density."

537.311.33:546.28 1778
Distorted Layers of Silicon Produced by Grinding and Polishing—W. C. Dash. (*J. Appl. Phys.*, vol. 29, pp. 228–229; February, 1958.)

537.311.33:546.28 1779
Experimental Study of Spin-Lattice Relaxation Times in Arsenic-Doped Silicon—J. W. Culvahouse and F. M. Pipkin. (*Phys. Rev.*, vol. 109, pp. 319–327; January 15, 1958.) Relaxation times for the stable As^{75} were measured

by using fast passage techniques to observe the relative amplitudes of the electron-resonance signals as a function of time. The relaxation times for the radioactive As^{76} were measured by observing the formation and decay of the nuclear alignment. The measurements were made at 8500 gauss and 1.3°K.

537.311.33:546.28 1780
Preparation of Pure Silicon by the Hydrogen Reduction of Silicon Tetraiodide—G. Szekely. (*J. Electrochem. Soc.*, vol. 104, pp. 663–667; November, 1957.) Investigation of this method shows that the reaction is heterogeneous, taking place on a hot surface. Dense Si layers as well as crystals can be deposited. The reaction of Si and I_2 to form SiI_4 and the fractional distillation of this compound are discussed.

537.311.33:546.28:621.314.7 1781
Transistor-Grade Silicon: Part 1—The Preparation of Ultra-pure Silicon Tetraiodide—B. Rubin, G. H. Moates, and J. R. Weiner. (*J. Electrochem. Soc.*, vol. 104, pp. 656–660; November, 1957.) "A stepwise method of preparing and purifying SiI_4 has been found involving the direct combination of the elements, recrystallization of the product, followed by sublimation and zone purification steps. The values of the segregation coefficients of several impurity elements have been determined."

537.311.33:546.289 1782
Relaxation-Time Anisotropy in *n*-Type Germanium—C. Goldberg. (*Phys. Rev.*, vol. 109, pp. 331–335; January 15, 1958.) The anisotropy parameter $K=K_m/K\tau$ is determined from magnetoconductance measurements in the temperature range 45°K to 300°K. Using the cyclotron resonance value for K_m, the measurements give $K_m=1.0$ for lattice scattering and $K\tau>1$ for moderate amounts of impurity scattering.

537.311.33:546.289 1783
Surface Properties of Semiconductors—W. H. Bratlain. (*Science*, vol. 126, pp. 151–153; July 26, 1957.) A *p-n* junction in a crystal of Ge and a Ge surface in an ambient gas are considered. The surface properties of the Ge in the latter case depend primarily on the surface treatment and on the nature of the gas, not on the type, *p* or *n*, of the body material.

537.311.33:546.289 1784
New Phenomenon in Narrow Germanium *p-n* Junctions—L. Esaki. (*Phys. Rev.*, vol. 109, pp. 603–604; January 15, 1958.) Dynatron-type current/voltage characteristics have been observed which are tentatively explained on the basis of field emission across the junction.

537.311.33:546.289 1785
Oxygen as a Donor Element in Germanium—G. Elliott. (*Nature, London*, vol. 180, pp. 1350–1351; December 14, 1957.) Single crystals of Ge grown in both pure N_2 or pure A showed sudden changes of resistivity when small quantities of air were added to the atmosphere.

537.311.33:546.289:537.534.9 1786
Etching of Germanium Crystals by Ion Bombardment—G. K. Wehner. (*J. Appl. Phys.*, vol. 29, pp. 217–221; February, 1958.) "A study is made of the etch effects produced by sputtering Ge crystals and bicrystals under normal incident low-energy (100 ev) Hg^+-ion bombardment in a low-pressure plasma (1μ gas pressure)."

537.311.33:546.289:538.63 1787
Galvanomagnetic Effects in Oriented Single Crystals of *n*-Type Germanium—W. M. Bullis. (*Phys. Rev.*, vol. 109, pp. 292–301; January 15, 1958.) Measurements of the magnetoresistance, Hall, and planar-Hall coefficients on oriented single crystals of *n*-type Ge at 77°K and 300°K are described. Effective values for the anisotropy factor and the mean free time τ are deduced from the 77°K data assuming τ anisotropic but energy-independent. The 300°K data are interpreted on the basis of the low-field approximation for the conductivity tensor and various simplifying approximations for the energy dependence of τ.

537.311.33:546.289:538.632 1788
Measurement of the Hall Mobility in *n*-Type Germanium at 9121 Mc/s—Y. Nishina and W. J. Spry. (*J. Appl. Phys.*, vol. 29, pp. 230–231; February, 1958.) A single crystal of 16-Ω cm *n*-type Ge at room temperature gave a microwave value of 2900 cm²/v sec compared with a measured dc value of 2670 cm²/v sec.

537.311.33:546.289:539.16 1789
Low-Temperature Irradiation of *N*-Type Germanium—J. W. Cleland and J. H. Crawford, Jr. (*J. Appl. Phys.*, vol. 29, pp. 149–151; February, 1958.) Studies of irradiation effects in Ge at temperatures well below that of liquid nitrogen have been conducted to examine the thermal stability of radiation-induced defects and the importance of minority-carrier trapping processes.

537.311.33:546.289:539.4 1790
Some Effects of Environment on Fracture Stress of Germanium—P. Breidt, Jr, J. N. Hobstetter, and W. C. Ellis. (*J. Appl. Phys.*, vol. 29, p. 226; February, 1958.)

537.311.33:546.289:621.396.822 1791
Generation Recombination Noise in Intrinsic and Near-Intrinsic Germanium Crystals—J. E. Hill and K. M. van Vliet. (*J. Appl. Phys.*, vol. 29, pp. 177–182; February, 1958.) Measurements are made on single crystals at temperatures between 300°K and 450°K. Results are compared with theory considering generation and recombination by means of direct transitions or via recombination centers located either in the bulk or at the surface. Reasonable agreement is found in most cases. In some the spectrum falls off rather weakly at higher frequencies indicating that the recombination centers do not lie at a single sharp energy in the forbidden gap but are distributed within a small range.

537.311.33:546.47.19 1792
Zn_3As_2, Semiconducting Intermetallic Compound—G. A. Silvey. (*J. Appl. Phys.*, vol. 29, pp. 226–227; February, 1958.) Preparation and properties are discussed.

537.311.33:546.682.18 1793
Decomposition Method for Producing *p-n* Junctions in InP—K. Weiser. (*J. Appl. Phys.*, vol. 29, pp. 229–230; February, 1958.) A simple method is described to produce *p-n* junctions in compound semiconductors which decompose before melting and contain a volatile constituent such as InP or GaAs.

537.311.33:546.817.221 1794
Intrinsic Optical Absorption and the Radiative Recombination Lifetime in PbS—W. W. Scanlon. (*Phys. Rev.*, vol. 109, pp. 47–50; January 1, 1958.) A description of measurements of the absorption coefficient in the region of intrinsic absorption in PbS. The coefficients range from about 10 cm^{-1} to 10^5 cm^{-1}, and the radiative recombination lifetime for PbS calculated from the data is 63 μsec at 300°K.

538.22:621.318.1 1795
Magnetism in Materials—D. H. Martin. (*Wireless World*, vol. 64, pp. 28–30; January, 1958, pp. 70–74; February, 1958, pp. 126–131; March, 1958, and pp. 178–180; April, 1958.)

Part 1—The Physical Basis of Dia-, Para-, Ferro- and Ferri-magnetism.

Part 2—Ferromagnetic Domains and their Influence on Magnetic Properties—Hysteresis, coercivity, and magnetostriction are explained physically in terms of domain-wall movement, rotation of the axis of magnetization within a domain and impurity content. Fine powder magnets in which each grain of powder is a single domain are discussed.

Part 3—Commercial Magnetic Materials and Domain Theory—Hysteresis and associated parameters are considered, and characteristic values for magnetically soft materials including ferrites are given, with details of their composition and preparation.

Part 4—Rectangular—Hysteresis—Loop Materials—Permanent Magnets—A note on the applications of these materials and a review of the development of permanent-magnet materials leading to Co and Ba ferrites and powdered alloys.

538.221 1796
Ferromagnetism of a Zirconium-Zinc Compound—B. T. Matthias and R. M. Bozorth. (*Phys. Rev.*, vol. 109, pp. 604–605; January 15, 1958.)

538.221 1797
Studies on the Magnetic Anisotropy Induced by Cold Rolling of Ferromagnetic Crystal: Part 1—Iron-Nickel Alloys—S. Chikazumi, K. Suzuki, and H. Iwata. (*J. Phys. Soc. Japan*, vol. 12, pp. 1259–1276; November, 1957.) Magnetic domain patterns and torque measurements were made with single crystals and polycrystals of Ni_3Fe, the direction of easy magnetization being found for different crystallographic orientations. The results are theoretically explained by assuming that slip deformation induces the directional order observed after rolling.

538.221:538.569.4 1798
Microwave Resonance in Nickel at 35 Gc/s—G. S. Barlow and K. J. Standley. (*Proc. Phys. Soc.*, vol. 71, pp. 45–48; January 1, 1958.) From measurements on a Ni single crystal, the anisotropy constants K_1 and K_2 have been determined from 20 to 150°C. At 20°C, $K_1=K_2=-6.06\times10^4$ ergs cm^{-3} gives the best fit to the experimental data. Measurements on Ni-Cu and Ni-Mn alloys are also reported.

538.221:539.215.1 1799
Loss of Exchange Coupling in the Surface Layers of Ferromagnetic Particles—F. E. Luborsky. (*Phys. Rev.*, vol. 109, pp. 40–42; January 1, 1958.) Experiments with spherical iron particles 28 Å to 265 Å in diameter show that the suggested nonferromagnetic surface layer on an air iron particle must be less than 1 Å thick.

538.221:539.23 1800
Thin Ferromagnetic Films—S. J. Glass and M. J. Klein. (*Phys. Rev.*, vol. 109, pp. 288–291; January 15, 1958.) "The spontaneous magnetization of thin films of ferromagnetic materials has been studied by means of spin-wave theory. Results have been obtained for the magnetization as a function of temperature and film thickness for body-centered and face-centered cubic materials, generalizing earlier calculations by Klein and Smith [1675 of 1951]. The approximations in the theory are critically discussed, and the relevant experimental material is briefly reviewed."

538.221:539.23:538.569.4 1801
Ferromagnetic Resonance at U.H.F. in Thin Films—R. H. Kingston and P. E. Tannenwald. (*J. Appl. Phys.*, vol. 29, pp. 232–233; February, 1958.) Experimental results are compared with theoretical values.

538.221:548.0 1802
The Crystal Structures of a New Group of

Ferromagnetic Compounds—P. B. Braun. (*Philips Res. Rep.*, vol. 12, pp. 491–548; December, 1957.) A description of four new compounds which are structurally related to magnetoplumbite. O and Ba atoms form a slightly expanded closely packed arrangement, with the Ba atoms in certain selected positions, and the smaller ions in certain of the holes between the large ones. "Plates," either four or six O layers thick, can be distinguished. The relation between the structures is discussed. An appendix describes a calculator for performing Fourier syntheses with indices up to 60.

538.221:621.318.2 1803
Extremely Small Permanent Magnets—(*Tech. Bull. Natl. Bur. Stand.*, vol. 41, pp. 179–180; November, 1957.) Details are given of the processing and magnetic properties of cold-drawn cunife wire 0.005 inch in diameter.

538.221:621.318.134:537.226 1804
The Dielectric Behaviour of Magnesium Manganese Ferrite—J. Peters and K. J. Standley. (*Proc. Phys. Soc.*, vol. 71, pp. 131–133; January 1, 1958.) Measurements on a ferrite having the approximate composition 0.9 MgO, 0.1 MnO, 0.8 Fe_2O_3 in the frequency range 30 cps–100 mc and in the temperature range 20–220°C are reported and discussed.

538.221:621.318.134:548.0 1805
Crystal Distortion in Ferrite-Manganites—G. I. Finch, A. P. B. Sinha, and K. P. Sinha. (*Proc. Roy. Soc. A*, vol. 242, pp. 28–35; October 8, 1957.) The origin of the distortion of spinels from cubic to tetragonal symmetry is examined using copper ferrite and a series of manganite ferrites. The degree of distortion depends on temperature and on the fraction of cations forming appropriately oriented dsp^2 bonds in octahedral sites. There is agreement with experiment.

528.221:621.318.134:548.73 1806
An Improved X-Ray Method for Determining Cation Distribution in Ferrites—L. P. Skolnick, S. Kondo, and L. R. Lavine. (*J. Appl. Phys.*, vol. 29, pp. 198–203; February, 1958.) The method is of general value in distinguishing between two elements distributed over non-equivalent positions in a crystal lattice when their X-ray scattering factors are almost equal.

538.221:621.318.134:[621.317.335.3 +621.317.41 1807
Measurement of Ferrite Loss Factors at 10 +Gc/s—Srivastava and Roberts. (See 1820.)

538.569.4:666.94 1808
Debye-Type R. F. Absorption in Cements—J. Le Bot. (*J. Phys. Radium*, vol. 18, pp. 638–639; November, 1957.) The values of ϵ^{I} and ϵ^{II} in Portland and non-normalized aluminous cement for temperatures from 4° to 350°K and frequencies λ 0.1, 1.0, 10 and 100 kc were determined in an investigation of the process of water fixation.

621.315.612+621.318.124+621.318.134 1809
Recent Developments in Ceramic Materials for the Electronic Industries—P. Popper. (*Brit. Commun. Electronics*, vol. 4, pp. 694–701; November, 1957.) A review of the properties and applications of ceramic materials with a list of insulators, resistors, ferrites, and dielectrics giving their main characteristics and the names of British manufacturers.

621.319.2:535.215 1810
Theory of Photoelectrets—V. M. Fridkin, N. T. Kashukeev, and I. S. Zheludev. (*Dokl. Ak. Nauk S.S.S.R.*, vol. 117, pp. 804–807; December, 1957.) An expression for the electron concentration in trapping levels in single-crystal sulphur is derived. Results show a direct ratio between the charge of an illuminated specimen and the intensity of the polarizing field. No saturation was observed even with fields of 20 kv/cm. See also 3627 of 1955 (Chatterjee and Bhadra).

MATHEMATICS

517.6:517.52 1811
On the Calculation of the Function j_0 (z, θ) for Large Values of "z"—H. E. Fettis. (*J. Math. Phys.*, vol. 36, pp. 279–283; October, 1957.) Asymptotic and integral expansions of the function $j_0\ (z,\ \theta)=\int_0^\theta e^{iz\cos\phi}d\phi$ are considered when z is large, *e.g.*, of the order of 1/λ in optical diffraction or radar scattering problems.

517.946.4:530.145.6 1812
The Reduced Wave Equation in a Medium with a Variable Index of Refraction—W. L. Miranker. (*Commun. Pure Appl. Math.*, vol. 10, pp. 491–502; November, 1957.)

517.946.4:530.145.6 1813
On Solutions of Nonlinear Wave Equations—J. B. Keller. (*Commun. Pure Appl. Math.*, vol. 10, pp. 523–530; November, 1957.)

517.949:681.142 1814
On the Solution of the Schroedinger and the Klein-Gordon Equations by Digital Computers—H. F. Harmuth. (*J. Math. Phys.*, vol. 36, pp. 269–278; October, 1957.)

MEASUREMENTS AND TEST GEAR

621.3.018.41(083.74):538.569.4 1815
Experimental Evaluation of the Oxygen Microwave Absorption as a Possible Atomic Frequency Standard—J. M. Richardson. (*J. Appl. Phys.*, vol. 29, pp. 137–145; February, 1958.) "Theoretical design, actual design, and results for an oxygen microwave spectrometer for use either in observing the line frequency or as a discriminator in a frequency-control loop synchronizing an oscillator are described. Essential characteristics are the rate of change of spectrometer-output signal with frequency and the output-noise level. General expressions for these quantities for a wide range of experimental arrangements are obtained, and may be used to predict the attainable frequency precision."

621.3.018.41(083.74):621.373.421.13 1816
A Frequency Standard Stable to 2 Parts in 10^{10}. (*Brit. Commun. Electronics*, vol. 4, p. 681; November, 1957.) A brief description of a quartz crystal oscillator using a servosystem of frequency control.

621.317.1:621.395.625.3 1817
Magnetic Tape Recorders in Measurement Techniques—H. Wehde. (*Elektrotech. Z., Ed. A*, vol. 78, pp. 792–796; November 1, 1957.) Advantages and some applications are discussed.

621.317.2:621.373.4.029.3 1818
Calibrated Audio Oscillator—G. C. Fox. (*Short Wave Mag.*, vol. 15, pp. 514–519; December, 1957.) Practical details of the design and construction of an instrument useful for Doppler-shift measurements and AF testing. Frequency is controlled by a nonlinear potentiometer.

621.317.2:621.373.421.13 1819
Wide-Range Crystal Marker Generator—H. Pollack. (*Radio TV News*, vol. 58, pp. 68–69, 179; December, 1957.) Design detail of a unit providing 100-kc and 1-mc check points up to 150 mc.

621.317.335.3+621.317.41]:538.221 :621.318.134 1820
Measurement of Ferrite Loss Factors at 10 Gc/s—C. M. Srivastava and J. Roberts. (*Proc. IEE, London*, vol. 105, pt. B, pp. 204–209; March, 1958.) "The analysis is presented of the losses arising in a rectangular cavity containing ferrite slabs which extend the full length of the cavity. The loss factors associated with the dielectric constant and the scalar, and tensor permeabilities are deduced from Q-factor measurements on the cavity. The methods are particularly suited to low-loss ferrites."

621.317.337:621.385.029.6 1821
"Cold" Methods of Measuring Magnetron Quality—W. Schmidt. (*Elektronische Rundschau*, vol. 11, pp. 235–241; August, 1957.) Three groups of methods are distinguished and compared and examples of each are given.

621.317.35.082.5:621.372.412 1822
Piezo-optic Frequency Analyser—T. Ogawa (*J. Acoust. Soc. Amer.*, vol. 30, pp. 46–47; January, 1958.) Note of a method of frequency analysis in which the birefringence induced in one of a set of ADP crystals at resonance is detected using a beam of polarized light passing through the crystal.

621.317.39.088.7 1823
Extending Transducer Transient Response by Electronic Compensation for High-Speed Physical Measurements—F. F. Liu and T. W. Berwin. (*Rev. Sci. Instr.*, vol. 29, pp. 14–22; January, 1958.) Electronic compensators are described which automatically and continuously correct for dynamic errors of electromechanical transducers during transient and steady-state measurements, even in regions beyond the transducer's natural frequency. Transient phenomena with rise time a fraction of a microsecond can be measured directly with a minimum of amplitude and phase distortion.

621.317.42:550.380.87 1824
An Electrical Recording Magnetometer—P. H. Serson. (*Can. J. Phys.*, vol. 35, pp. 1387–1394; December, 1957.) The equipment described, which is of the saturated-transformer type, is used for recording at a fixed station variations in three orthogonal components of the earth's magnetic field. See also 229 of 1957 (Serson and Hannaford).

621.317.44:621.375.2 1825
Integrator-Amplifier for Core Measurements—C. E. Goodell. (*Electronics*, vol. 31, pp. 110–113; February 14, 1958.) Instantaneous flux is measured as the time integral of voltage. Details of design and complete circuits are given.

621.317.619:621.316.825 1826
Measurement of some Characteristic Parameters of Thermistors with Low Time Constant based on their Harmonic and Transient Characteristics—V. Andresciani and A. Lepschy. (*Note Recensioni Notiz.*, vol. 6, suppl. to no. 3, pp. 25–48; May/June, 1957.) Three methods are described, two dealing with the determination of the impedance-locus curve and one with obtaining the time constant of a thermistor from an analysis of its transient response characteristic.

621.317.7:621.314.7 1827
A 1-kc/s Junction-Transistor *T*-Parameter Measurement Set—R. A. Hall. (*Electronic Eng.*, vol. 30, pp. 82–85; February, 1958.) A description of the set and experimental procedure is given. Frequency-dependent errors which occur in the case of low-frequency transistors can be avoided by reducing the measurement frequency to 200 cps.

621.317.7:621.397.62:621.373.444.1 1828
Television Timebase Measurements: Anode Dissipation of Line Output Valves—A.

dipole located over a flat surface with a specified surface impedance Z is derived from the formal integral solution by a modified saddle-point method." Twenty-seven references.

621.396.11.029.62:551.510.535 1853
Results of Scatter Measurements at 36 Mc/s over a 1200-km Path—T. Hagfors. (*J. Atmos. Terr. Phys.*, special suppl., pt. II, pp. 205–209; 1957.) The results refer to a north-south path in Norway and include data on the diurnal changes in signal strength, the correlation of field strength with ionospheric and magnetic data, and the angular dependence of the scattering cross section.

621.396.11.029.63 1854
Broad- and Narrow-Beam Investigations of S.H.F. Diffraction by Mountain Ridges—K. Nishikori, Y. Kurihara, M. Fukushima, and M. Ikeda. (*J. Radio Res. Labs., Japan*, vol. 4, pp. 407–422; October, 1957.) The results are given of measurements of the horizontal angle of arrival, signal strength, and spatial variation of 2980-mc radio waves transmitted over ridges and mountains. The received signals consisted of multiple components arriving from directions up to 7 degrees apart. Spatial variations was caused by interference between these multiple components. The increase of loss with diffraction angle was found to be greater than that predicted by the Fresnel-Kirchhoff theory.

621.396.11.029.64 1855
Microwave Propagation over the Sea beyond the Line of Sight—M. Onoue, K. Nishikori, M. Nenohi, A. Takahira, H. Irie, and R. Usui. (*J. Radio Res. Labs., Japan*, vol. 4, pp. 395–406; October, 1957.) The vertical angle of arrival of 3-cm waves over an 80-km path and the variation of field intensity with distance up to 120 km have been compared with the vertical distribution of refractive index. Four types of diurnal and seasonal variation were distinguished depending on the season. A qualitative correlation between meteorological factors and variation in field strength was found with ducting playing an important part. Leakage from the duct and variation in the profile with time have also been studied.

621.396.11.029.65 1856
Propagation of Millimetre Waves through the Atmosphere—A. B. Crawford and D. C. Hogg. (*Bell Labs. Rec.*, vol. 35, pp. 494–497; December, 1957.) A general discussion of atmospheric absorption at mm wavelengths. A two-way transmission method is described for measuring absorption in the range 0.5–0.6 cm which is more accurate than the one-way method.

621.396.81.029.63 1857
Microwave Field Strength and Fading in the Presence of Intervening Ridges—R. Vikramsingh, M. N. Rao, and S. Uda. (*J. Inst. Telecommun. Eng., India*, vol. 4, pp. 18–24; December, 1957.) Propagation at 2 kmc over mountain ridges has been studied for two paths of length 14 and 54 km. Fresnel's diffraction theory gives values of path loss lower than those measured. The fading in the shadow region is reduced which may be of advantage in some microwave-link applications. See also 1040 of 1958.

RECEPTION

621.396.621:621.314.7 1858
A Portable Transistor Receiver—L. E. Jansson, J. B. Ruming, and J. M. Tapley. (*Mullard Tech. Commun.*, vol. 3, pp. 198–208; December, 1957.) A design, based on six transistors, giving maximum output power of 200 mw and a sensitivity of 200 μv across the antenna tuned circuit for 50 mw output.

621.396.621:621.376.33 1859
Frequency-Modulation Negative Feedback in F.M. Receivers— L. Ya. Kantor. (*Radiotekhnika Moscow*, vol. 12, pp. 58–62; January, 1957.) The IF pass band required to ensure stability and to limit nonlinear distortion is determined.

621.396.621:621.376.33:621.373.421 1860
Choice of the Interstage Coupling Circuit in Frequency-Modulated Receivers—L. Ya. Kantor. (*Elektrosvyaz'*, pp. 29–32; April, 1957.) The use of band-pass filters is suggested for low-sensitivity receivers; for high-sensitivity receivers single-tuned circuits are preferred. Expressions are derived for the increase in the receiver selectivity due to FM feedback. See also 1427 of 1952 (Hacks).

621.396.621.029.62:621.376.332 1861
Pulse-Counter F.M. Receiver—M. G. Scroggie. (*Wireless World*, vol. 64, pp. 181–183; April, 1958.) Supplementary notes based on one year's operation of the prototype (2524 of 1956) are given, including particulars of conversion to crystal control.

621.396.621.029.64 1862
Designing Low-Noise Microwave Receivers—C. T. McCoy. (*Electronic Indus. and Tele-Tech*, vol. 16, pp. 54–57, 154; November, 1957, and pp. 64–65, 146; December, 1957.) The effects of local oscillator noise, mixer variations, and varying bandwidth are summarized. Experimental data on microwave-crystal mixers are included.

621.396.621.54:621.396.96:621.396.822:621.317.6 1863
Pencil and Paper Calculation of Noise Level in Superhetrodyne Radar Receivers—D. W. Haney. (IRE TRANS. ON AERONAUTICAL AND NAVIGATIONAL ELECTRONICS, vol. ANE-3, pp. 157–160; December, 1956. Abstract, PROC. IRE, vol. 45, p. 570; April, 1957.) See also 3828 of 1956.

621.396.662 1864
Miniature Ferrite Turner Covers Broadcast Band—E. A. Abbot and M. Lafer. (*Electronics*, vol. 31, pp. 72–73; February 28, 1958.) A "rotary-axial" RF tuning element using two pairs of ferrite cups is described; rotation of D-shaped center sections combined with an axial movement separating the cores gives linear frequency variation from 500 to 1600 kc for 270 degrees shaft rotation.

621.396.812.5.029.51:523.75 1865
A New Effect of Chromospheric Eruptions—M. Waldmeier. (*Naturwissenschaften*, vol. 44, p. 439; August, 1957.) Field-strength measurements made near Berne of a 56.35-kc transmission from London during the solar eruption of April 16, 1957, show an unexpected decrease of signal strength by up to 14 db, whereas on 101.65 kc an increase of up to 6 db was measured.

621.396.821 1866
Atmospheric Noise Interference to Short-Wave Broadcasting—S. V. C. Aiya. (PROC. IRE, vol. 46, pp. 580–589; March, 1958.) An idealized cloud discharge containing four strokes, each with a stepped leader, is considered. The parameters required by a receiving system for assessing the noise are derived, taking into account the characteristics of the human ear. Each discharge may be considered as a single acoustic impulse, and the estimation of the noise level in terms of a modulated CW signal, as used in the noise meter described in 257 of 1955, is discussed. See also 3263 of 1955.

621.396.822 1867
Freedom from Interference in Different Systems of Radiotelegraphy—Yu. S. Lezin. (*Elektrosvyaz'*, pp. 40–47; April, 1957.) A comparison of AM, FM, and PHM systems indicating the advantages of PHM.

621.396.823 1868
Radio Interference by Corona Discharges on High-Voltage Lines—W. Wechsung. (*Elektrotech. Z., Ed. B*, vol. 9, pp. 385–388; October 21, 1957.) A method is proposed for assessing the amount of interference to radio reception caused by neighboring high-voltage lines. Measurements are based on a frequency of 250 kc and a distance from the line of 20 m, and with a maximum permissible value of 1 mv/m for the interference field strength interference-free medium-wave reception should be possible at a distance of at least 100 m from the line where the useful signal strength is at least 1 mv/m.

STATIONS AND COMMUNICATION SYSTEMS

621.391 1869
On the Compressibility of the Spectrum of a Signal—A. A. Kharkevich. (*Elektrosvyaz'*, pp. 3–11; April, 1957.) General aspects of the problem of bandwidth compression are considered and some examples are given.

621.391 1870
Some Graphical Approaches to Coding Problems—J. Dutka. (*RCA Rev.*, vol. 18, pp. 466–474; December, 1957.) "The problem of constructing error-detecting and error-correcting codes for use in communicating information in binary coded form has received considerable attention in recent years. Some graphical methods for constructing such codes are presented, their geometrical interpretations are discussed, and some illustrative examples are worked out."

621.391:621.376:534.78 1871
On the Power Gained by Clipping Speech in the Audio Band—W. Wathen-Dunn and D. W. Lipke. (*J. Acoust. Soc. Amer.*, vol. 30, pp. 36–40; January, 1958.) Available data on speech amplitude distributions are briefly examined and the results of Davenport (3314 of 1952) are used to calculate the power increase obtainable by peak clipping and subsequent amplification.

621.391:621.376.56 1872
A Coder for Halving the Bandwidth of Signals—A. R. Billings. (*Proc. IEE*, vol. 105, pt. B, pp. 182–184; March, 1958.) A possible practical system is described in which a continuous message of finite bandwidth is coded into a continuous signal of smaller bandwidth.

621.396.2:621.394.3 1873
Communication Technique for Multipath Channels—R. Price and P. E. Green, Jr.—(PROC. IRE, vol. 46, pp. 555–570; March, 1958.) A new system known as "Rake" is described. The mark/space sequence of symbols is transmitted as a wide-band signal and those portions arriving at the receiver with different delays are isolated, using correlation-detection techniques. The separated signals are weighted and appropriate delays applied to bring them back into time coincidence. Communication theory applicable to the system is reviewed and examples are given of experimental tests of the system. Fifty-three references.

621.396.41 1874
Design Principles of Equipment for Simplified Systems of Multichannel Links in Cable and Radio Relay Systems—K. P. Egorov and M. U. Polyk. (*Elektrosvyaz'*, pp. 48–54; April, 1957.) A coaxial-cable system is described with 32 groups of 30 channels operating in the fre-

quency band 312–8500 kc; repeater spacing is 6–6.5 km.

621.396.712.3 1875
Two New Large Vehicles for Sound-Broadcast Transmissions—L. V. Türkheim. (*Rundfunktech. Mitt.*, vol. 1, pp. 145–150; August, 1957.) Description of mobile control rooms used by the Bayerische Rundfunk for outside-broadcast transmissions via Post Office lines.

621.396.74.029.62(43) 1876
List of V.H.F. Transmitters in the German Federal Republic—(*Rundfunktech. Mitt.*, vol. 1, pp. 165–167; August, 1957.) See also 1894 below.

SUBSIDIARY APPARATUS

621.311.6:621.314.7 1877
Heat Transfer in Power Transistors—I. G. Maloff. (*Electronic Indus. and Tele-Tech*, vol. 16, pp. 54–55; 157; December, 1957.) A general discussion of thermal problems in operating power transistors between 25°C and 85°C.

621.311.6:621.396.931 1878
Power Supply and Suppression in Portable /Mobile Working—D. T. Bradford. (*Short Wave Mag.*, vol. 15, pp. 465–469; November, 1957.) Practical details of the use of car batteries or petrol-electric sets for power supply.

621.311.6.027.3:621.385.032.22 1879
Stabilized E.H.T. Unit—D. J. Collins and J. E. Smith. (*Wireless World*, vol. 64, pp. 184–186; April, 1958.) Design of a compact equipment for anode supplies of 1350–1500 v.

621.316.722.078.3 1880
Improved Control Circuit for Regulated Power Supplies—G. W. Jones. (*QST*, vol. 41, pp. 30–33; November, 1957.) A cathode follower is inserted between the control tube and the regulator tube in an electronic voltage regulator to increase the current range over which regulation may be maintained.

TELEVISION AND PHOTOTELEGRAPHY

621.397.24 1881
Economic Considerations in Closed-Circuit Television System Design—D. Kirk, Jr. (*J. Soc. Mot. Pic. Telev. Eng.*, vol. 66, pp. 661–671; November, 1957.) During the last five years a number of systems for distribution of entertainment-type television programs via wire to homes of paying subscribers have been successfully installed and operated. The economics and design of each system are considered here, and possible improvements are outlined.

621.397.5:535.623 1882
Simulating Sharpness in Colour Television—M. W. Baldwin, Jr. (*Bell Labs. Rec.*, vol. 35, pp. 481–484; December, 1957.) A "defocusing" projector is used to simulate the blurring that results when a color television picture is transmitted over a circuit of limited bandwidth.

621.397.6.001.4 1883
Pulse-Cross Modification of TV Receivers—H. E. O'Kelley. (*Electronics*, vol. 31, pp. 54–55; February 28, 1958.) "Phantastron circuits delay horizontal and vertical sync pulses when added to monitor or TV receiver to provide pulse-cross display. System gives simple means of checking operation of station sync generator."

621.397.61:535.623:778.5 1884
Advanced Performance and Stability in Color TV Film Channel Amplifiers—M. H. Diehl. (*J. Soc. Mot. Pic. Telev. Eng.*, vol. 66, pp. 750–754; December, 1957. Discussion, pp. 754–755.) "The use of three-channel AGC, precision gamma circuits, and high-level black clipper yields long-time stability of the critical parameters affecting colour balance. With large amounts of negative feedback in the monitoring section, drastic reduction in the number of controls, and built-in calibration features, setup and adjustment can be rapidly accomplished."

621.397.61:778.5:621.396.665 1885
Automatic Gain Control in Television Automation—M. H. Diehl, W. J. Hoffman, and W. L. Shepard. (*J. Soc. Mot. Pic. Telev. Eng.*, vol. 66, pp. 755–757; December, 1957.) Describes a system providing a constant level output from a monochrome vidicon camera channel for light-level changes of 30:1. The application to color film systems is also discussed.

621.397.61.001.4 1886
Video Testing Techniques in Television Broadcasting—A. Ste-Marie. (*Elec. Eng., N. Y.*, vol. 76, pp. 968–973; November, 1957.) "A discussion is presented of the practical effects on signal degradation of the parameters in a video-transmission system. An attempt is made to establish their true significance and correlation. New video-testing techniques have been established for improved and simplified methods of specification and measurement."

621.397.611:535.8 1887
Resolution Chart aids TV Camera Focusing—G. Southworth. (*Electronics*, vol. 31, pp. 100–101; February 14, 1958.) The chart consists of a number of parallel lines of different thickness which are scanned and displayed on a waveform monitor.

621.397.611.2 1888
Test and Measurement Methods for Image Orthicon Camera Tubes—F. Pilz. (*Rundfunktech. Mitt.*, vol. 1, pp. 125–138; August, 1957.) Methods are outlined of measuring characteristics peculiar to the image orthicon, such as the secondary-emission factor, gain of signal multiplier, capacitance of target-mesh assembly, storage time, and modulation depth. Details of a specially designed test set for image orthicons are given.

621.397.62:621.314.7 1889
Transistor Television Circuits: Part 1—Synchronizing Separators and Timebase Oscillators—J. N. Barry and G. W. Secker. (*Wireless World*, vol. 64, pp. 154–158; April, 1958.) Practical details are given of a common-emitter sync separator, a line oscillator, and a frame oscillator, for a 17-inch television receiver.

621.397.62:621.373.444.1:621.317.7 1890
Television Timebase Measurements: Anode Dissipation of Line Output Valves—Ciuciura. (See 1828.)

621.397.62:621.385.832.001.4 1891
Colour and Monochrome Cathode-Ray-Tube Performance Tests—C. F. Otis. (*Elec. Eng. N. Y.*, vol. 76, pp. 990–995; November, 1957.) Acceptance tests for cathode-ray tubes should be simple and, if possible, quantitative. A description is given of a 6-position test rack for monochrome tubes, and the characteristics of 3-gun color tubes most troublesome in set design are discussed.

621.397.62:621.396.665 1892
A.G.C. Circuits for Positive-Modulation Television Receivers—P. L. Mothersole. (*Mullard Tech. Commun.*, vol. 3, pp. 214–227; December, 1957.) A number of representative AGC systems are examined and their main failings are discussed. The development of a simple gate circuit free from these faults and having other advantages is described.

621.397.621 1893
Investigation of Aperture Distortion by the Method of Split Image Reproduction—E. L. Orlovskii. (*Elektrosvyaz'*, pp. 55–66; April, 1957.)

621.397.7(43) 1894
The Television Network of the German Federal Republic—(*Rundfunktech. Mitt.*, vol. 1, pp. 159–162; August, 1957.) Tabulated data on television transmitters as at June 1, 1957, with maps showing their location and that of television links.

621.397.7(43) 1895
List of Television Transmitters in the German Federal Republic—(*Rundfunktech. Mitt.*, vol. 1, pp. 163–164; August, 1957.) See also 1894 above.

621.397.8 1896
Subjective Sharpness of Television Pictures—W. N. Sproson. (*Electronic Radio Eng.* vol. 35, pp. 124–132; April, 1958.) "The subjective sharpness of television pictures has been measured using a comparison technique and a multicriterion scale for assessment. Two types of degrading network were used and the subjective sensitivity to changes in equivalent rectangular bandwidth has been evaluted for both static and moving pictures."

621.397.8 1897
Influence of Periodic-Type Interference on the Quality of a Television Image—A. P. Efimov. (*Elektrosvyaz'*, pp. 22–28; April, 1957.) The effect of interference on the reproduction of static and moving images is examined for interference frequencies in the ranges 0.1–6.4 mc and 0.1–26 mc, respectively. The relation of interference level to image quality is determined experimentally.

621.397.8 1898
Band-V Signal Strength—A. Hale. (*Wireless World*, vol. 64, pp. 162–163; April, 1958.) Investigation of reception conditions along the A5 and A10 roads from London as far as Towcester and Cambridge.

621.397.822 1899
Measurement and Evaluation of Shot Noise in the Video Band—E. Sennhenn. (*Elektronische Rundschau*, vol. 11, pp. 271–274; September, 1957.) Curves are derived relating the theoretical and observable peak-noise voltages to the effective value as a function of frequency. Subjective tests were made with a noise signal 1 mc wide, variable in the range 0–7 mc, superimposed on a 625-line image. The peak noise voltage required to create a given impression of "graininess" is plotted against noise frequency for two different viewing distances. The sensitivity of the observer decreases with increasing frequency. Photographs of images with interference of constant level but differing frequency are reproduced.

621.397.9 1900
New Developments in the Field of Industrial Television—E. F. Spiegel. (*Elektronische Rundschau*, vol. 11, pp. 261–264; September, 1957.) Applications outlined include the testing of bore holes using a miniature camera with a vidicon-type tube of reduced size, temperature measurement by means of infrared-sensitive vidicons, and the telemetering of width, *e.g.*, of sheet material in rolling mills, using two television cameras.

621.396.61:621.376.2 1901
The Effect of Electron Inertia on the Shape of the Modulation Characteristic of A. M. Transmitters—L. N. Kolesov. (*Radiotekhnika, Moscow*, vol. 11, pp. 28–36; December, 1956.) Recommendations are made for ensuring the

linearity of the modulation characteristic, and the requisite design formulas are derived.

TUBES AND THERMIONICS

621.314.63+621.314.7]:539.169 1902

The Effects of Short-Duration Neutron Radiation on Semiconductor Devices—W. V. Behrens and J. M. Shaull. (PROC. IRE, vol. 46, pp. 601–605; March, 1958.) Transistors suffered a decrease in forward-current gain and an increase in backward-collector current, the effect being much greater with AF than with HF transistors, the former being virtually useless after irradiation at 10^{13} neutrons/cm.^{2} Diodes exhibited an increase in forward resistance and a decrease in back resistance. The results suggest that the integrated neutron dosage is of more importance to semiconductor devices than the rate of exposure.

621.314.63+621.314.7]:621.396.822 1903

Theory of Junction-Diode and Junction-Transistor Noise—A. van der Ziel and A. G. T. Becking. (PROC. IRE, vol. 46, pp. 589–594; March, 1958.) A rigorous yet general proof of the equations governing shot noise, in which the only restriction to the model is that individual holes may be considered independent. See also 600 of 1956.

621.314.7 1904

Transistor Technology—(*Nature, London*, vol. 180, pp. 1329–1330; December 14, 1957.) Summaries of papers read at a conference on transistors organized by the Institute of Physics and held at Acton, Middlesex, September 27–28, 1957.

621.314.7 1905

Transistors, Reliability and Surfaces—C. G. B. Garrett. (*Bell Labs. Rec.*, vol. 35, pp. 466–470; November, 1957.) A descriptive account of the physical effects of the surface-oxide film on semiconducting materials.

621.314.7 1906

Influence of Hydration-Dehydration of the Germanium Oxide Layer on the Characteristics of *P-N-P* Transistors—J. T. Wallmark and R. R. Johnson. (*RCA Rev.*, vol. 18, pp. 512–524; December, 1957.) When Ge *p-n-p* transistors are subjected to a change in temperature, the zero-frequency common-emitter current gain shows a corresponding change, approaching an asymptotic value in approximately 48 h. The effect is interpreted in terms of a hydrated oxide layer on the Ge surface.

621.314.7 1907

Variation of Junction-Transistor Current Amplification Factor with Emitter Current—A. W. Matz. (PROC. IRE, vol. 46, pp. 616–617; March, 1958.) A short mathematical note on the volume recombination and emitter-efficiency terms which helps to resolve the difference between analysis of Webster (2798 of 1954) and Rittner (3390 of 1954).

621.314.7 1908

Experimental Determination of the Base and Emitter Lead Resistances of Alloy-Junction Transistors by means of Low-Frequency Measurements—W. Guggenbühl and W. Wunderlin. (*Arch. elekt. Übertragung*, vol. 11, pp. 355–358; September, 1957.) The method described is based on the low-frequency *h* parameters; results obtained compare satisfactorily with those given by more elaborate methods thereby proving the validity of one-dimensional equations in determining the low-frequency characteristics of alloy-junction transistors.

621.314.7:621.317.7 1909

A 1-kc/s Junction-Transistor *T*-Parameter Measurement Set—Hall. (See 1827.)

621.314.7:621.376.54 1910

A Conductivity-Storage Transistor Pulse-Width Modulator—Price. (See 1695.)

621.314.7(083.57) 1911

Designing Stability into Transistor Circuits—S. Schenkerman. (*Electronics*, vol. 31, pp. 122, 124; February 14, 1958.) Chart and nomographs simplify calculation of circuit and cooling-facility parameters necessary for stable operation of Ge and Si transistors at elevated junction temperatures.

621.314.7.001.1(091) 1912

Research Leading to Point-Contact Transistor—J. Bardeen. (*Science*, vol. 126, pp. 105–112; July 19, 1957.)

621.383.2 1913

On the Phototubes Sensitive to the Wide Spectral Region—M. Sugawara. (*J. Phys. Soc. Japan*, vol. 12, pp. 1282–1290; November, 1957.) The light transmission and photoelectric yields of thin photocathode films were investigated. A combination of Sb-Cs and Ag-CsO surfaces gave a photocell suitable for spectral photometry from ultraviolet to infrared.

621.383.4 1914

Maximum Performance of High-Resistivity Photoconductors—R. W. Redington. (*J. Appl. Phys.*, vol. 29, pp. 189–193; February, 1958.) It is shown that the transit time in a material showing space-charge-limited current cannot be less than the charge-relaxation time. In consequence the photoconductor cannot simultaneously act as a detector, an amplifier, and a storage element, and still have a response time as short as the storage time. This puts a restriction on the performance of high-resistivity photoconductive devices.

621.383.4:535.371.07 1915

Solid-State Light Amplifiers—B. Kazan and F. H. Nicoll. (*J. Opt. Soc. Amer.*, vol. 47, pp. 887–894; October, 1957.) The characteristics of photoconductive and electroluminescent materials are summarized with particular emphasis on the problems of their optimum combination in the double-layer type of intensifier with or without optical feedback. The use of the over-all device for radar display and X-ray intensification is discussed. See also 1897 of 1956 (Diemer *et al.*).

621.383.42 1916

Internal Resistance and Capacitance of a Selenium Photocell at Low Temperatures—G. Blet. (*J. Phys. Radium*, vol. 18, pp. 572–578; October, 1957.) Observed variations of capacitance appear to be related to the resistance variations reported earlier (960 of 1958), and are such that the product *CR* tends in general to a constant value.

621.385.029.6 1917

Understanding the Travelling-Wave Amplifier—D. A. Dunn (*Electronic Indus. and Tele-Tech*, vol. 16, pp. 67–69, 142; November, 1957.) A fundamental discussion of the physical processes occurring in a helical slow-wave structure.

621.385.029.6 1918

Low-Noise Tunable Preamplifiers for Microwave Receivers—M. R. Currie and D. C. Forster. (PROC. IRE, vol. 46, pp. 570–579; March, 1958.) A description of a new gun design for *S*-band backward-wave amplifier tubes. The operation of the tube as a receiver component is discussed and detailed experimental performance data are given. Noise figures less than 6 db and 4.5 db for 25 per cent and 10 per cent of the tuning range respectively, have been measured. Still lower figures appear possible for backward-wave and other microwave tubes using the new gun design.

621.385.029.6:537.533 1919

On the Adiabatic Self-Constriction of an Accelerated Electron Beam Neutralized by Positive Ions—J. D. Lawson. (*J. Electronics Control*, vol. 3, pp. 587–594; December, 1957.) The build-up of the self-magnetic field causes the transverse oscillation of the electrons to be damped, but this damping is partly counteracted by an outward diffusion due to multiple scattering of the electrons on the ions. Inductive effects appear as an apparent increase in the mass of the electrons.

621.385.029.6:537.533:538.691 1920

Structure in Magnetically Confined Electron Beams—H. F. Webster. (*J. Appl. Phys.*, vol. 28, pp. 1388–1397; December, 1957.) "A number of observations have been made of structure changes that occur in hollow and solid electron beams which are confined by a magnetic field. These structure changes occur in both the density of the beam and the transverse velocity components of the beam electrons." See also 4060 of 1957 (Kyhl and Webster).

621.385.029.6:621.317.337 1921

"Cold" Methods of Measuring Magnetron Quality—Schmidt. (See 1821.)

621.385.029.65 1922

Travelling-Wave-Tube Experiments at Six Millimetres Wavelength: Part 1—Phase-Velocity Measurements—K. Kamiryo, H. Hozumi, Y. Shibata, and Y. Fukushima. (*Sci. Rep. Res. Inst. Tohoku Univ., Ser. B*, vol. 8, pp. 35–47; June, 1956.) A report of phase-velocity measurements carried out on first and second spatial harmonic waves both forward and backward in a traveling-wave tube of the type described by Millman (547 of 1952 and 1187 of 1953).

621.385.032.2:537.533 1923

Aperture Lens Formula Corrected for Space Charge in the Electron Stream—C. K. Birdsall. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 132–134; April, 1957. Abstract, PROC. IRE, vol. 45, p. 1163; August, 1957.)

621.385.032.21:537.533 1924

Valve Instability with Cathode Standing Waves of Cylindrical Symmetry—W. W. H. Clarke. (*Brit. J. Appl. Phys.*, vol. 8, pp. 486–490; December, 1957.) Experimental results obtained with a circular cathode of very small dimensions show a significant repeatability not attainable in previously reported experiments with a larger cathode. This confirms the existence of preferred standing-wave patterns, satisfying the boundary conditions, and associated preferred emission current characteristics in the cathodes of thermionic tubes. See also 1913 of 1956.

621.385.032.21 1925

The Physics of the Cathode—L. S. Nergaard. (*RCA Rev.*, vol. 18, pp. 486–511; December, 1957.) Recent work on thermionic emitters suggests some generalizations bearing on all electron emitters. Four propositions are advanced for consideration and discussion. The propositions are: 1) every cathode is a reducing agent; 2) every cathode lives in equilibrium with its environment; 3) every cathode is a dispenser cathode; and 4) monolayer-film emitters do not exist. Evidence to support these propositions is adduced. The evidence of the first three propositions is regarded as conclusive. Fifty-six references.

621.385.032.213.13 1926

On the Mechanism of Operation of the Barium Aluminate Impregnated Cathode—E. S. Rittner, W. C. Rutledge, and R. H. Ahlert. (*J. Appl. Phys.*, vol. 28, pp. 1468–1473;

December, 1957.) Emission and evaporation characteristics of a porous tungsten cathode impregnated with the composition $5BaO \cdot 2Al_2O_3$ are presented and are interpreted in terms of the cathode mechanism. Emission is less than that of an L cathode, presumably because of release of a poisoning agent accompanying the activator. See also 2978 and 2979 of 1957.

621.385.032.213.13 1927
Cavity-Type Barium-Tungsten Cathode—T. Hashimoto. (*Rep. Elec. Commun. Lab., Japan*, vol. 5, pp. 1–8; October, 1957.) A report on development of a procedure for manufacturing satisfactorily dispenser-type L cathodes.

621.385.032.213.13:537.311.33 1928
Analysis of the D.C. and Pulsed Thermionic Emission from BaO—G. A. Haas. (*J. Appl. Phys.*, vol. 28, pp. 1486–1492; December, 1957.) "The effects of field penetration and donor mobility on the chemical potential of BaO have been computed by using a non-degenerate single-donor-level semiconductor model. Calculations which neglect the effects of surface states and porosity predict that the pulsed emission starts lower, but increases with field more rapidly than given by simple Schottky theory, actually being capable of exceeding the theoretical Schottky emission. The dc emission level is always lower than the pulsed emission, the difference being more pronounced at higher fields and for less active cathodes."

621.385.032.269.1 1929
The Theory of the Pierce-Type Electron Gun—D. E. Radley. (*J. Electronics Control*, vol. 4, pp. 125–148; February, 1958.) "The problem of determining the Pierce electrodes in a gun reduces to a Cauchy problem on Laplace's equation. The questions of existence, uniqueness, and instability of solutions to general problems of this type are considered, together with their relevance to the design of electron guns. A general procedure for solving a Cauchy problem is developed, and simplified for two-dimensional cases. This method then is used to determine the electrodes which will maintain strip, wedge, cylindrical, and conical-shaped beams. The Cauchy conditions for these problems are given by the space-charge-limited potential from the appropriate complete diode solution."

621.385.1:621.376.32.029.3:621.3.011.3 1930
The Reactance Valve at Audio Frequencies—Alcock. (See 1646.)

621.385.2 1931
Transit Time and Space Charge for the Cylindrical Diode—L. Gold. (*J. Electronics Control*, vol. 3, pp. 567–572; December, 1957.) "Introduction of time-dependent Poisson equation admits a form of solution which leads to interesting relations for transit time and the current-voltage dependence for both zero and finite initial electron velocities. The analysis is expedited by employment of a reduced spatial variable and the development of inverse power series. The general correspondence with Langmuir's classic solution is demonstrated and, in particular, in the limit of vanishing cathode radius, a simple, nonseries description corresponds to the case $\beta = 1$."

621.385.2:537.525.92 1932
Parametric Solution for the Diode Space Charge at Relativistic Energies—L. Gold. (*J. Electronics Control*, vol. 3, pp. 564–566; December, 1957.) "Transformation of the basic equations that describe the behaviour of the diode space charge (including Poisson's relation) into a time-dependent forms allows straightforward solution in the relativistic domain. The parametric solution lends itself to securing various approximate explicit results and readily yields the extreme relativistic limit of a current linearly dependent upon anode voltage." See also 4076 of 1957 (Acton).

621.385.2:621.396.822 1933
Space Charge as a Source of Flicker Effect—C. S. Bull. (*Proc. IEE*, vol. 105, pt. B, pp. 190–194; March, 1958.) Three types of fluctuation are predicted by the analysis: 1) shot noise, 2) an enhanced shot noise, and 3) a flicker-effect dependent on the magnitude of the electronic capacitance. The results are discussed in relation to previous work (see 3080 of 1954 and 303 of 1955).

621.385.3.1 1934
Thermionic Emission from the Grid in Metal/Ceramic Valves—E. P. Korcehagine and G. M. Utkin. (*Elektrosvyaz'*, pp. 12–21; April, 1957.) Emission characteristics of Russian modulator tubes Types GI-6B, GI-7B and GS-9B are discussed.

621.385.5(083.57) 1935
Peak Anode Current Nomograms for Line Output Valves—A. Ciuciura. (*Mullard Tech. Commun.*, vol. 3, pp. 162–168; October, 1957.) The nomograms take into account production spread in tube characteristics, fall in emission with time, and feedback across the screen-grid resistor.

621.385.83 1936
Electronic Devices employing Cathode-Ray Beams—L. S. Allard. (*Brit. Commun. Electronics*, vol. 4, pp. 620–625; October, 1957.) The operating principles and applications of cathode-ray devices such as flying-spot scanners, image converters, storage, switching, and multiplier tubes, and function generators are outlined.

621.385.832 1937
Level Displacement Diagrams for the Description of Charging Processes in Storage Tubes—M. Knoll and W. Harth. (*Elektrotech. Z., Ed. A*, vol. 78, pp. 543–548; August 1, 1957.) Potential diagrams for a typical signal-storage tube (radechon) and a typical viewing storage tube are considered. Twenty-five references.

621.385.832.001.4:621.397.62 1938
Colour and Monochrome Cathode-Ray-Tube Performance Tests—Otis. (See 1891.)

MISCELLANEOUS

001.891:621.39:061.4 1939
The Post Office Research Station—(*Nature, London*, vol. 180, pp. 1240–1242; December 7, 1957.) A review of some of the research work of the station as reflected in exhibits at an open day at Dollis Hill, London, September 27, 1957. These included 4-kmc equipment for radiocommunication, an echo waveform corrector for long-distance television links, an automatic error counter and a fading simulator for tests on frequency-shift telegraph systems, an AF analyzer, and items relating to the technology of Ge components.

025.4 1940
A Statistical Approach to Mechanized Encoding and Searching of Literary Information—H. P. Luhn. (*IBM. J. Res. Dev.*, vol. 1, pp. 309–317; October, 1957.)

621.39(047.1) 1941
Communication Engineering and Radiolocation—(*VDI Z.*, vol. 100, pp. 193–205; February 11, 1958.) Progress report covering recent developments with references mainly to German literature. The following sections are surveyed:

Telecommunications—W. Althans (pp. 193–195).

Sound Broadcasting and Television—E. Schwartz (pp. 195–199). 76 references.

Electroacoustics—H. Harz (pp. 199–202). 60 references.

Radar and Radio Navigation—W. Stanner (pp. 202–203). 26 references.

High Frequency Measurements—H. Schneider (pp. 204–205).

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