PROCEEDINGS OF THE IRE®

Published Monthly by

The Institute of Radio Engineers, Inc.

VOLUME 45 *May, 1957* NUMBER 5, PART I

BOARD OF DIRECTORS, 1957
J. T. Henderson, *President*
Yasujiro Niwa, *Vice-President*
W. R. G. Baker, *Treasurer*
Haraden Pratt, *Secretary*
D. G. Fink, *Editor*
J. D. Ryder, *Senior Past President*
A. V. Loughren,
Junior Past President

1957
J. G. Brainerd (R3)
J. F. Byrne
J. J. Gershon (R5)
A. N. Goldsmith
A. W. Graf
W. R. Hewlett
R. L. McFarlan (R1)
Ernst Weber
C. F. Wolcott (R7)

1957–1958
H. R. Hegbar (R4)
E. W. Herold
K. V. Newton (R6)
A. B. Oxley (R8)
F. A. Polkinghorn (R2)
J. R. Whinnery

1957–1959
D. E. Noble
Samuel Seely

●

George W. Bailey,
Executive Secretary

●

John B. Buckley, *Chief Accountant*
Laurence G. Cumming,
Technical Secretary
Evelyn Benson, *Assistant to the Executive Secretary*
Emily Sirjane, *Office Manager*

EDITORIAL DEPARTMENT
Alfred N. Goldsmith,
Editor Emeritus
D. G. Fink, *Editor*
E. K. Gannett,
Managing Editor
Helene Frischauer,
Associate Editor

ADVERTISING DEPARTMENT
William C. Copp,
Advertising Manager
Lillian Petranek,
Assistant Advertising Manager

EDITORIAL BOARD
D. G. Fink, *Chairman*
E. W. Herold, *Vice-Chairman*
E. K. Gannett
Ferdinand Hamburger, Jr.
T. A. Hunter
A. V. Loughren
W. N. Tuttle

Responsibility for the contents of papers published in the PROCEEDINGS of the IRE rests upon the authors. Statements made in papers are not binding on the IRE or its members.

Change of address (with 15 days advance notice) and letters regarding subscriptions and payments should be mailed to the Secretary of the IRE, 1 East 79 Street, New York 21, N. Y.

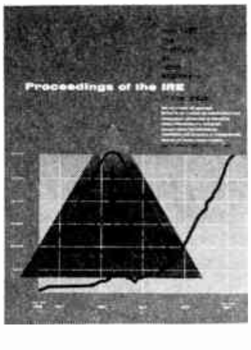
All rights of publication, including foreign language translations are reserved by the IRE. Abstracts of papers with mention of their source may be printed. Requests for republication should be addressed to The Institute of Radio Engineers.

CONTENTS

Correspondence:

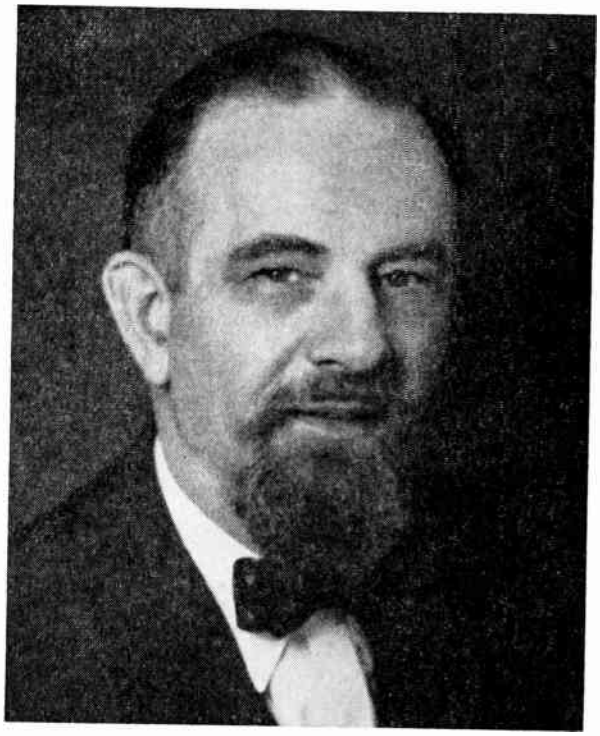
IRE News and Radio Notes:

ADVERTISING SECTION



THE COVER—May 13, 1957 marks the 45th anniversary of the formation of the IRE. Starting with 46 members in 1912, the IRE membership grew slowly but steadily during the first decade, accelerated as radio broadcasting came into its own in the late 20's declined during the depression years, and then rocketed upwards as wartime research opened up vast new fields for technical developments. Sometime this month the membership will pass the 59,000 mark, and by the end of this year will be well beyond 60,000. The interesting history of IRE's development over this period is described in the article starting on page 597.

Copyright: © *1957, by the Institute of Radio Engineers, Inc*



Alois W. Graf

Director, 1957

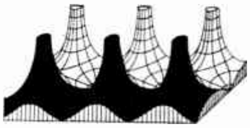
Alois W. Graf was born March 20, 1901, at Mankato, Minn. He obtained a bachelor's degree in electrical engineering from the University of Minnesota in 1926, and a bachelor of law degree from the National Law University in 1931.

Mr. Graf was first employed as an examiner in the U. S. Patent Office. He subsequently was employed by a patent lawyer to work on validity and infringement searches and resulting prosecutions. The next eight years, from 1930 to 1938, saw him associated with the patent department of the General Electric Company for which he standardized patent procedures and formulated manufacturing policies for vacuum tube devices. He became a patent lawyer for Productive Inventions, Inc., Gary, Ind. In 1940 he began his own private patent law practice, and subsequently became associated with a number of patent law firms, among which were Sheridan, Davis and Cargill; Davis, Lindsey, Smith and Shonts; and Loftus, Moore, Olson and Trexler. He again opened his own law practice in 1949, and in May, 1956, announced the formation of a new patent law firm with L. G. Nierman and M. A. Burmeister. This firm specializes in patent, trade-mark, and copyright law in the radio communications and electronics field.

Mr. Graf is a member of the bar in the District of Columbia, Indiana, and Illinois. He also holds membership in the American Bar Association, Illinois Society of Professional Engineers, and the National Society of Professional Engineers.

He became an IRE Associate in 1926, a Member in 1944, and a Senior Member in 1945. He was elevated to Fellow status in 1955. His IRE activities include membership on the Board of Editors from 1945–1953, Editorial Review Committee from 1954–1956, Education Committee from 1945–1955, and Policy Advisory Committee from 1954–1955 and 1956–1957. He was Chairman of the Sections Committee from 1948–1950, Vice-President of the Professional Groups Committee in 1954, and Chairman of the Constitution and Laws Committee from 1954–1955, 1956, and 1957. He held the office of Secretary from 1944–1945 in the Chicago Section; from 1946–1947 he was its Chairman. In addition, Mr. Graf served as IRE representative to the National Electronics Conference Board of Directors in 1952 and 1954.

Poles and Zeros



45 Years. In this issue we commemorate the 45th anniversary of the founding of the Institute of Radio Engineers by presenting a paper, "The IRE—45 Years of Service," prepared by Laurens E. Whittemore at the suggestion of the Committee on History. Mr. Whittemore, a member of the Institute since 1916, has spent months of painstaking research assembling the organizational record of IRE from 1912 to the present.

Anniversaries are times for reflection, occasions to discern the trends of the past and to plot a reasonable extrapolation to the future. We hope that this paper will inspire such reflection and we take the liberty of quoting some thoughts which occurred to G. C. Southworth (a comparative newcomer who joined IRE in 1926) when he read the paper in manuscript.

Wrote Dr. Southworth: "This is the 45-year life story of a remarkable organization, the IRE. Born within a few years of Marconi's early work, when considerable mystery surrounded the new field, it fell to this young organization to provide a healthy atmosphere in which young engineers might exchange ideas and a publication medium in which their conclusions could be recorded. That it has succeeded in its objectives is attested by the fact that during its 45-year life its membership on the average has more than doubled every five years and its publications have expanded at an even faster rate.

"The purpose of this paper is to record the more important organizational changes and events that led to the present status of the Institute; no attempt has been made to trace the corresponding development of radio itself. It is quite evident, however, that the two have been quite closely related. Without the phenomenal growth of radio technology, the Institute could not have reached its present proportions and without the Institute, radio technology could hardly have made its rapid progress.

"In reading this paper, it may appear that the Institute may have far outgrown the industry it has served, but reflection shows that this is not the case. One dimension by which the growth of an industry may be scaled is the dollars invested in it; the growth here need not be documented—it is enormous. Another dimension is the roster of services rendered by the industry. Starting with safety of life at sea at the turn of the century this has been expanded to so many services that "the electronic age" properly describes our epoch. A third dimension is the band of frequencies occupied by radio, analogous to the right-of-way of railway systems. In this dimension the expansion has been so rapid that the spectrum has doubled no less than twenty times during a period when the membership of the Institute has doubled only twice."

Little further need be said by way of introduction to Mr. Whittemore's thorough-going account of IRE's first 45 years. We express the thanks of all members to him for the hours of effort in collecting the material and for his skill in assembling it.

Dust. Dr. Southworth's reference to the spectrum reminds us of the great stretch of perspective needed in relating the frequency ranges occupied by various radio systems. Take the spectrum used in transmitting a video signal, extending uniformly from 30 cycles to about 4 megacycles. This range represents a mere modulating signal to the television engineer, not to be classed as "radio-frequency." But this signal covers a wide swath in the radio spectrum, from below the very low frequencies well into the high frequency range. This contrast is vividly illustrated in an experiment recently conducted by Ampex engineers with a tape recorder capable of recording television signals. It seems the boys hooked up an antenna to the recorder input and let her run. Then they played back the tape, feeding the output to a radio receiver. Sure enough, there were *all* the broadcast stations and their programs, among many others, frozen in magnetic dust.

Quarterly. Radio engineers don't have to be students in college to read, and enjoy thoroughly, the *IRE Student Quarterly*. Ted Hunter, who edits this remarkable journal, proceeds on the assumption that students are mature people (new graduates are paid on that basis, certainly) and he fills the *Quarterly* with papers that make excellent reading for many a forty-year-old "student." One such paper, explaining color television techniques in simple terms was reprinted in the PROCEEDINGS some months ago, and many other *Quarterly* articles deserve a wide audience. While it is not practical to reprint from every issue of the *Quarterly*, it is practical and rewarding to subscribe to it. The price to IRE members is $3.00.

Score. The total registered attendance at the March 1957 IRE National Convention was 54,074. This is an all-time record for our "annual classic" and represents by a large margin the largest gathering of engineers and technicians ever assembled anywhere.—D. G. F.

Scanning the Issue

The Institute of Radio Engineers, Forty-Five Years of Service (Whittemore, p. 597)—May 13 marks the forty-fifth anniversary of an historic meeting. On that date 46 members of the Society of Wireless Telegraph Engineers and The Wireless Institute, led by Alfred N. Goldsmith, John V. L. Hogan, and Robert H. Marriott, met at Fayerweather Hall, Columbia University, to form The Institute of Radio Engineers. From these humble beginnings has arisen one of the world's major professional societies which, by this May 13th, will be able to count 59,000 members in some 80 countries all over the globe. This article is far more than a statistical tracing of the growth of the IRE over the years. It is a penetrating and absorbing study of the management, administration and policy-making which has led the IRE to its present position of eminence. The preparation of this material, done at the request of the IRE History Committee, represents nearly a year's effort on the part of a Fellow and former Vice-President of the IRE, who himself has actively served the Institute for nearly four decades. He has brought to this monumental task not only his own intimate knowledge of IRE history but also the fruits of searching voluminous records and interviewing a score or more IRE leaders, past and present, resulting in an historical record of remarkable scope and authenticity.

The Effect of Fading on Communication Circuits Subject to Inteference (Bond and Meyer, p. 636)—Many types of communication systems are subject to fading, due to the signal arriving at the receiver via two or more paths of different lengths. In this paper the author analyzes what effects this has on the performance of communication circuits that operate in the presence of interference. He studies the fading of the signal alone, of the interference alone, and of both together and derives curves which indicate how much the signal-to-interference power ratio must be increased to maintain satisfactory operation a high percentage of the time. For example, the curves show that to obtain 99.9 per cent satisfactory operation will require 30 db more signal power in the presence of signal fading, regardless of whether the interference is also fading. The study also discloses the improvements offered by various diversity reception techniques. The formulas and curves presented will be especially useful to persons concerned with systems engineering and frequency allocation problems.

Microwave Frequency Doubling from 9 to 18 KMC in Ferrites (Melchor, *et al*, p. 643)—Although previous work has been reported on using ferrites as frequency doublers, the conversion efficiency obtained was very low, about −60 db. This paper reports results that are very much better. Using an input frequency of 9 kmc at a peak power level of 32 kw, the authors obtained an output of 8 kw at 18 kmc. This represents a doubling conversion efficiency of −6 db. These results demonstrate that ferrites are superior to crystal doublers, both as to efficiency and power-handling ability. Moreover, this work will serve notice on ferrite users that in addition to the more well-known applications (isolators, phase shifters, etc.), ferrites promise to become equally important as frequency doublers and mixers.

Effects of Zero Ferrite Permeability on Circularly Polarized Waves (Duncan and Swern, p. 647)—Theoretical predictions and experimental data are presented that describe the propagation characteristics of ferrites in circular and rectangular waveguides. It is shown that ferrites magnetized near zero permeability behave, under certain conditions, like a metal; *i.e.*, practically all the microwave energy is expelled from the interior and the ferrite exhibits skin effect and skin loss. This behavior is utilized to obtain large nonreciprocal attenuation at low applied magnetic fields over large bandwidths, that is, waves are passed in one direction with very little loss, and drastically attenuated in the other direction. The paper, while specialized, makes a contribution of fundamental significance to the development of ferrite isolators.

Binary Data Transmission Techniques for Linear Systems (Doelz, *et al*, p. 656)—A novel coding scheme has been combined with multiplexing and single-sideband techniques to maximize the amount of binary information that can be transmitted over a narrow-band communication link. The coding method is based on the idea of transmitting a "mark" and a "space" as signals of opposite phase and of comparing the phases of successive pulses as they are received to encode the message. The novelty of the method presented here is that the pulse is transmitted with not two, but four possible phases (0°, 90°, 180° or 270°), and thus can uniquely describe the "mark" and "space" information of two messages simultaneously. This method requires a transmission link of high linearity with precisely synchronized oscillators at either end—a situation ready-made for single-sideband equipment. By using frequency division multiplexing, it is possible to transmit 20 channels (40 messages) over a single SSB voice channel at a total rate of 3000 bits per second. This work will be particularly interesting to those engaged in information theory, radio teletype systems, and high frequency multipath transmission problems.

Temperature Dependence of Junction Transistor Parameters (Gärtner, p. 662)—This study provides a great deal of useful information, in the form of design equations, tables and graphs, on the effects of temperature variations on the electrical characteristics of four representative types of transistors. The extensive calculations made by the author represent a very considerable effort and will be a valuable reference for transistor designers and practicing circuit engineers, to whom the problems of temperature variations and compensation are important ones.

Design of Three-Resonator Dissipative Band-Pass Filters Having Minimum Insertion Loss (Taub and Bogner, p. 681)—Present-day design of narrow-band band-pass filters stems essentially from some general design equations developed eight years ago for various numbers of synchronously-tuned resonant circuits. As it turned out, each set of equations contained one more unknown than there were equations and, hence, their solution yielded many sets of circuit constants that would produce the desired amplitude-frequency response. In this paper the authors add one additional requirement, which permits them to find a single set of circuit constants. They specify that the insertion loss, that is, the ratio of generator power to load power, be a minimum, a stipulation that is frequently of practical interest. The calculations are carried through to produce universal design curves for three-resonator filters that will be especially useful to radio receiver, microwave, and filter engineers in general.

1956 Index to IRE Transactions (follows p. 734)—The tables of contents, a combined author index, and a combined subject index are presented covering the 69 issues of TRANSACTIONS issued by all IRE Professional Groups during the year 1956.

The Institute of Radio Engineers—Forty-Five Years of Service*

LAURENS E. WHITTEMORE†, FELLOW, IRE

FOREWORD

On October 6, 1955, the Executive Committee of the Institute approved a suggestion by Haraden Pratt, Chairman of the History Committee and Secretary of the Institute, that the May, 1957 issue of the PROCEEDINGS be planned as a special anniversary number in commemoration of the 45th anniversary of the founding of the Institute of Radio Engineers. It was proposed that a subcommittee of the History Committee be asked to prepare an historical article on IRE management, administration, and policy making. Pursuant to that action, this paper has been prepared.

FORMATION OF THE INSTITUTE OF RADIO ENGINEERS

Background

MEETINGS and publications have been the twin activities of the Institute of Radio Engineers from the beginning. The desire of members to improve communication among themselves, both through oral presentations and discussions and through writing and reading papers, was the basic reason for the formation of the Institute and this has continued to be the principal impelling force behind the growth of the Institute during its 45 years of existence. This same twofold reason for existence applied also to the two earlier associations—one in Boston and one in New York—that were merged in 1912 to form a new and stronger organization, which was named The Institute of Radio Engineers.

Some inkling of the limited field of activity of radio engineers in 1912 may be had from the fact that the principal, and almost the only, commercial use of radio was for marine radiotelegraph message transmission. In 1910 the Government had established a legal requirement that certain classes of ships leaving United States ports be equipped with radio transmitting and receiving apparatus. In that year also, a system of ship radio inspection was established by the Government.

This was an era of jealously guarded secrets and ruthless competition. The barriers of supersecrecy which existed between competing wireless companies were so great that men were dismissed for associating with engineers of rival firms. Competition was often devoid of ethics as we know them today. There was, however, a growing realization among a number of engineers that many of the technical problems encountered by one company were common to all and that these problems might be solved more readily if engineers from all companies could get together to discuss them.

Society of Wireless Telegraph Engineers

The Society of Wireless Telegraph Engineers (SWTE) had been formed in Boston, Mass., on February 25, 1907, by John Stone Stone as an outgrowth of seminars held by engineers on the staff of the Stone Wireless Telegraph Company. Membership was eventually opened to men from Fessenden's National Electric Signaling Company and some other organizations. Members of this society were familiarly known as "swatties." John Stone Stone was the first President of this society.

The Wireless Institute

Robert H. Marriott made what appears to have been the first specific attempt to form a radio engineering society composed of members from any and all companies. On May 14, 1908, he sent a circular letter to some two hundred persons interested in wireless asking their opinions regarding the formation of such a society. It is rather remarkable that after nearly 50 years the embryo of the IRE can still be clearly distinguished in Marriott's letter, the text of which was published in the PROCEEDINGS OF THE IRE for May, 1952, on page 516.

Marriott's letter bore fruit. He received about 60 replies, and with one or two exceptions they were favorable to forming an institute on the lines he indicated. On January 23, 1909, a temporary organization was formed to draw up a constitution, and on March 10 of that year the first meeting was held at the United Engineers Building (now the Engineering Societies Building) in New York City at which a constitution was adopted and officers were elected. The name of the new society was "The Wireless Institute."

Robert Marriott was elected first President of The Wireless Institute, and served in that capacity during the three years of its existence.

---

* Original manuscript received by the IRE, February 1, 1957; revised manuscript received, March 4, 1957.

† American Telephone and Telegraph Co., New York, N. Y.

ORIGINAL MEMBERS OF THE INSTITUTE OF RADIO ENGINEERS AND THEIR AFFILIATION WITH PARENT SOCIETIES

Society of Wireless Telegraph Engineers

J. C. Armor
Sewall Cabot
W. E. Chadbourne
G. H. Clark
T. E. Clark
E. R. Cram
G. S. Davis
*Lee DeForest
E. D. Forbes
V. F. Greaves
*J. V. L. Hogan, Jr.
W. S. Hogg
Guy Hill
F. A. Knowlton
W. S. Kroger
Fritz Lowenstein
Walter W. Massie
G. W. Pickard
Samuel Reber
Oscar C. Roos
J. S. Stone
*A. F. VanDyck

The Wireless Institute

William F. Bissing
A. B. Cole
*P. B. Collison
James N. Dages
*Lloyd Espenschied
Philip Farnsworth
Frank Fay
Edward G. Gage
*Alfred N. Goldsmith
Francis A. Hart
Robert L. Hatfield
Arthur A. Hebert
*Frank Hinners
James M. Hoffman
Robert H. Marriott
A. F. Parkhurst
G. W. Pickard
H. S. Price
A. Rau
Harry Shoemaker
*Emil J. Simon
A. Kellogg Sloan
C. H. Sphar
Floyd Vanderpoel
R. A. Weagent

* Member of the IRE as of January, 1957.

After about a year, it was decided to incorporate the society. A meeting to decide details of this move was held at Sweet's Restaurant on Fulton Street in downtown New York, on June 23, 1913. Those members with a more legal mind in the make-up of the Institute, drew up Articles of Incorporation and on August 23, 1913, the organization was incorporated under the laws of the State of New York.

In brief, the expressed aims of the new association were:

> "To advance the art and science of radio transmission, to publish works of literature, science and art for such purpose, to do all and every act necessary, suitable and proper for the accomplishment of any of the purposes or the attainment of any of the powers herein set forth, either alone or in association with other corporations, firms or individuals to do every act or acts, thing or things, incidental or appurtenant to or growing out of or connected with the aforesaid science or art, or power or any parts thereof, provided the same be not inconsistent with the laws under which this corporation is organized, or prohibited by the State of New York."

One of the most important functions of the Institute was to preserve its technical papers, and the remarks made regarding them, in published form. One of the early decisions of the Institute, therefore, was to publish a technical magazine which was named THE PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS. The first issue was dated January, 1913.

In his inaugural address as President of the IRE for 1928, Dr. Alfred N. Goldsmith made some remarks about the beginnings of the Institute which, he said, originated "among a little group of serious thinkers in the radio field who felt the urgent need for some means for self-expression and mutual cooperation among radio engineers. . . . It is composed of televisionaries—men who see far into the future and are yet realists."

By the end of 1912, the Institute's membership had risen to 109 and during the succeeding year more than doubled. The rapid increase in membership after consolidation, compared with the slow rate of growth of SWTE and TWI, bore out the wisdom of the founders who suggested the merger.

GROWTH OF MEMBERSHIP OF THE INSTITUTE OF RADIO ENGINEERS AND ITS PREDECESSORS, 1907–1914

	SWTE	TWI	IRE
February 25, 1907	11		
January 1, 1908	17		
January 1, 1909	27		
March 10, 1909		14	
January 1, 1910	36	81	
January 1, 1911	36	99	
January 1, 1912	43	27	
May 13, 1912	(22)	(25)	46
January 1, 1913			109
January 1, 1914			231

The original ledger book of the Institute, in which the names and dues payments of early members were recorded, constitutes a veritable *Who's Who* in the early history of radio. The names of many radio pioneers can be seen in the illustration on the next page of the first few pages of the list of those members who joined the Institute during the first year.

Name of the Institute

In considering a name for the new organization the founders felt that something should be preserved from the names of both of the two component societies. The word "Institute" was borrowed from The Wireless Institute, and "Engineers" from the Society of Wireless Telegraph Engineers. Because the word "radio" was gradually supplanting "wireless," the title "The Institute of Radio Engineers" suggested itself. There was considerable temptation to add "American," particularly since TWI and IRE were modeled after the American Institute of Electrical Engineers in certain other respects. However, the temptation was resisted because it was expected that the IRE, as the only radio engineering society in existence, would be international in scope, an expectation that was promptly realized.

Why a Separate Organization?

The question arises from time to time: "Why did it happen that the radio engineers started an organization of their own instead of joining with the American Institute of Electrical Engineers as a subdivision of some kind?" The answer is that radio men, even in those earlier days, felt that they had so many problems of mutual interest that they would need to have monthly meetings of their own. They were not satisfied with the idea of perhaps one or two radio meetings per year, sandwiched in between meetings devoted to what was sometimes called "heavy-current" electrical engineering. The matter was discussed with representatives of the American Institute of Electrical Engineers, but the original members of the IRE felt that they needed and that they could develop a society of their own. Events have confirmed their judgment.

The Emblem or Symbol of the IRE

Neither of the emblems of the predecessor societies seemed readily adaptable to the new IRE. The SWTE emblem pictured a simple form of spark oscillator. The membership badge of TWI showed a spark gap functioning in the center of a dipole surrounded by a circular resonator provided with a micrometer gap for reception.

The founders of IRE decided not to use a representation of any specific form of equipment or physical structure but to devise a more general and perhaps perpetual symbol. It was realized that the Institute would always deal with electromagnetic energy, guided by conductors or passing through space, and that the distinguishing character of the transmission process was the existence of electrical forces and of their correlative magnetic forces. A representation of these forces was adopted as part of the symbol; the electrical force being represented by a vertical arrow and the magnetic force by a circular arrow surrounding the electrical line and in the conventional relationship to it. The shape of the resulting drawing lent itself to a triangular placement of the letters I, R, and E. This, in turn, led to the selection of a triangular emblem. Incidentally, the letters I, R, and E also symbolize the fundamental quantities, current, resistance and electromotive force, as well as the name, Institute of Radio Engineers.

OFFICERS

The officers of the IRE have from the beginning been President, Vice-President, Secretary, Treasurer, Editor, and Directors with the infrequent addition of an Assistant Secretary or an Assistant Treasurer. The President and Vice-President have always been elected by the IRE membership as have part or all of the members of the Board of Directors except the Editor. Beginning in 1915 the elected members of the Board were authorized by the Constitution to choose several additional persons to complete the Board membership. The Secretary and Treasurer have always been elected by the Board.

Prior to the 1931 revision of the Constitution the elected Board was known as the "Board of Direction," and its members—other than the Officers—were called "Managers." For the sake of simplicity, however, the term "Directors" will be used throughout this review.

An accompanying table shows, for each year since the formation of the IRE, the names of the Officers who served during that year.

G. W. Pierce had been elected President of the IRE for 1918, but served two years, since it was impossible, in view of the then-existing conditions during World War I, to get together enough members to hold an election.

Beginning in 1930, it became the custom for the Vice-President of the IRE to be a member who resides in a country other than the United States. In 1957, neither the President nor the Vice-President is a resident of the United States.

Prior to the year 1939 members of the IRE of all grades other than Junior Member and Honorary Member were voting members. Beginning with that year there has been a distinction between voting Associate members and nonvoting Associate members. Those who have been elected as Associate members subsequent to 1939 are not eligible to vote until they have transferred to a higher grade of membership for which they have become eligible.

A proposal was made to the Board in 1930 that membership on the Board should be limited to one person from any one company or government department, the purpose presumably being to insure diversification of representation. After very thorough and careful consideration by the Board it was agreed that members of the Board of Directors should represent no particular organization or group of organizations but should represent only the membership of the Institute in a broad sense. It was decided, therefore, not to include any such limiting requirements among the constitutional amendments which were then being formulated for consideration by the Institute members.

In order to facilitate action on various matters relating to the business of the IRE, an Executive Committee was formally established by the Board of Directors at its meeting in April, 1941. Subsequently, for several years, certain members of the Executive Committee were assigned responsibility for certain aspects of the Institute's activities. These assignments during the year 1944, for example, were such that one member of the Executive Committee took special cognizance of the activities of the Committees on Admissions, Membership, and Public Relations. Another member of the Executive Committee gave special attention to the work of the technical committees of the Institute. A third member of the Executive Committee concerned himself with activities covering sections, conventions, meetings, and advertising.

As the IRE membership increased in numbers and geographical distribution there developed an apprecia-

IRE Officers, 1912–1957

Year	President	Vice President	Secretary	Treasurer	Editor	Hdqs. Manager
1912	R. H. Marriott	Fritz Lowenstein	E. J. Simon	E. D. Forbes	A. N. Goldsmith	
1913	G. W. Pickard	R. H. Marriott	"	J. H. Hammond, Jr.	"	
1914	L. W. Austin	J. S. Stone	"	"	"	
1915	J. S. Stone	G. W. Pierce	David Sarnoff	W. F. Hubley	"	
1916	A. E. Kennelly	J. V. L. Hogan	"	"	"	
1917	M. I. Pupin	"	"	L. R. Krumm	"	
1918	G. W. Pierce	"	A. N. Goldsmith	Warren F. Hubley	"	
1919	"	"	"	"	"	
1920	J. V. L. Hogan	E. F. W. Alexanderson	"	"	"	
1921	E. F. W. Alexanderson	Fulton Cutting	"	"	"	
1922	Fulton Cutting	E. L. Chaffee	"	"	"	
1923	Irving Langmuir	J. H. Morecroft	"	"	"	
1924	J. H. Morecroft	J. H. Dellinger	"	"	"	
1925	J. H. Dellinger	Donald McNicol	"	"	"	
1926	Donald McNicol	Ralph Bown	"	"	"	
1927	Ralph Bown	Frank Conrad	"	"	"	J. M. Clayton
1928	A. N. Goldsmith	L. E. Whittemore	J. M. Clayton	Melville Eastham	"	"
1929	A. H. Taylor	Alexander Meissner	"	"	W. G. Cady	"
1930	Lee de Forest	A. G. Lee	H. P. Westman	"	A. N. Goldsmith	H. P. Westman
1931	R. H. Manson	C. P. Edwards	"	"	"	"
1932	W. G. Cady	E. V. Appleton	"	"	"	"
1933	L. M. Hull	Jonathan Zenneck	"	"	"	"
1934	C. M. Jansky, Jr.	B. van der Pol, Jr.	"	"	"	"
1935	Stuart Ballantine	G. H. Barkhausen	"	"	"	"
1936	L. A. Hazeltine	Valdemar Poulsen	"	"	"	"
1937	H. H. Beverage	P. P. Eckersley	"	"	"	"
1938	Haraden Pratt	E. T. Fisk	"	"	"	"
1939	R. A. Heising	P. O. Pederson	"	"	"	"
1940	L. C. F. Horle	F. E. Terman	"	"	"	"
1941	F. E. Terman	A. T. Cosentino	"	Haraden Pratt	"	" (Jan.–Oct.) J. D. Crawford (Nov.–Dec.)
1942	A. F. Van Dyck	W. A. Rush	"	"	"	J. D. Crawford (Jan.–Mar.) L. B. Keim (Apr.–May) W. B. Cowilich (Oct.–Dec.)
1943	L. P. Wheeler	F. S. Barton	Haraden Pratt	R. A. Heising	"	W. B. Cowilich
1944	H. M. Turner	R. A. Hackbusch	"	"	"	"
1945	W. L. Everitt	H. F. van der Bijl	"	"	"	G. W. Bailey
1946	F. B. Llewellyn	E. M. Deloraine	"	W. C. White	"	"
1947	W. R. G. Baker	Noel Ashbridge	"	R. F. Guy	"	"
1948	B. E. Shackelford	R. L. Smith-Rose	"	S. L. Bailey	"	"
1949	S. L. Bailey	A. S. McDonald	"	D. B. Sinclair	"	"
1950	R. F. Guy	R. A. Watson-Watt	"	"	"	"
1951	I. S. Coggeshall	Jorgen Rybner	"	W. R. G. Baker	"	"
1952	D. B. Sinclair	H. L. Kirke	"	"	"	"
1953	J. W. McRae	S. R. Kantebet	"	"	"	"
1954	W. R. Hewlett	M. J. H. Ponte	"	"	J. R. Pierce	"
1955	J. D. Ryder	Franz Tank	"	"	"	"
1956	A. V. Loughren	Herre Rinia	"	"	D. G. Fink	"
1957	J. T. Henderson	Yasujiro Niwa	"	"	"	"

tion by the members of the Board that some specific measures should be adopted, possibly of an organizational nature, to make it more certain that the contacts between the Board and the IRE membership would always be close and continuous and that the Board would comprise a truly democratic representation of the IRE membership. After several years of consideration of this problem the Board of Directors recommended an amendment to the Constitution which was adopted by the Institute membership in 1947, establishing Regional Directors, selected specifically to represent designated regions of the United States and Canada from which they came and whose memberships had elected them. Effective in January, 1955, a new regional boundary plan provided for a more even distribution of membership and Sections among the eight regions.

MEMBERSHIP

Growth in Numbers

It is fitting to consider as the "Charter Members" of the IRE those members of the two parent societies who became the first members of the IRE when it was organized on May 13, 1912. The formal charter of the Institute of Radio Engineers, however, was granted on October 24, 1913. The list of members of the IRE which appears in the 1914 YEAR BOOK does not identify "charter members" as such. That YEAR BOOK gives an analysis of the geographical distribution of the 271 Members and Associate Members of the IRE as of March 1, 1914 as follows:

GEOGRAPHICAL DISTRIBUTION OF IRE MEMBERSHIP, MARCH 1, 1914

	Members	Associates	Total
United States	52	197	249
Canada	3	2	5
Porto Rico	—	1	1
Philippine Islands	1	—	1
Honduras	—	1	1
British Guiana	1	1	2
Japan	1	1	2
Great Britain	3	4	7
Germany	3	—	3
Total	64	207	271

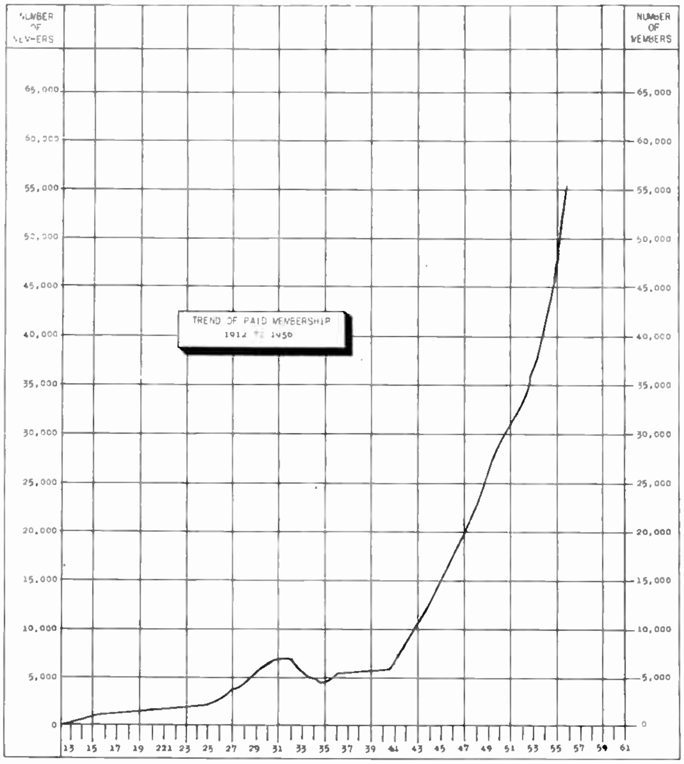
In 1914 a "Special Committee on Increase of Membership" was appointed, under the chairmanship of John Hays Hammond, Jr., Treasurer of the Institute.

The 1916 YEAR BOOK shows that the membership of the Institute immediately began to increase and by January 1, 1916, was only slightly under 1000. The membership figures shown are:

	Membership
January 1, 1914	231
January 1, 1915	633
January 1, 1916	984

The Constitution, as adopted in May, 1912, provided that the names of applicants for membership in the IRE should be sent out to each member of the Institute, prior to their acceptance as members. The members who were elected were required to subscribe personally to the Constitution of the IRE.

From the beginning, membership was open not only to radio engineers (Member grade) but also to those who had a real interest in radio engineering even though they were not professionally engaged in this field (Associate Member grade). Recognition of "Honorary Members" was provided for.



In 1916 the grade of Junior Member was established for persons under 21 years of age. The scale of annual dues for the several grades of membership was also slightly increased and transfer fees were established.

The entry of the United States into the World War in 1917 began a difficult period for the IRE. Many, if not most, of its members were engaged in some type of communication work directly or indirectly connected with wartime activities. The membership which had been about 1300 in 1917 fell to something like 800 the following year. Except for that period the membership, stimulated by the development of radio broadcasting during the 1920's, grew steadily until 1931 when a peak of 6700 was reached.

During the depression of the early 1930's, there was again a drop in membership to 4250 in 1934. In order to hold its members and to attract additional members the Board of Directors considered ways of publicizing the IRE. It was recognized that a closer insight into the activities of the IRE might give the existing membership a greater appreciation of the value to them of the various services of the Institute. This led to the expansion of "Institute Notes" section of the PROCEEDINGS.

In contrast to the experience during World War I, the IRE suffered very little diminution in membership during World War II. There was a drop in the number of members in European countries and in Japan in 1940 and 1941. Compensating for this, however, was the fact that the field of activities associated with radio engineering was becoming much broader and the applications of radio and allied engineering techniques related to wartime activities became much greater. Technicians were trained to handle radio equipment in the field and found that their interest became a continuing one calling for participation in IRE activities and resulting in their desire to obtain the benefit of IRE publications.

One of the outstanding aspects of IRE membership is the substantial number and generally increasing proportion of its membership living in countries outside of the United States. The IRE has taken special steps from time to time to recognize outstanding members living in other countries and to stimulate membership in such areas. In 1931 the IRE appointed a special committee to investigate the possibility of increasing its membership outside of the United States and establishing sections of the Institute in other countries. On a number of occasions, special dinners or meetings have been held in honor of Fellows from other countries who visited the United States.

MEMBERSHIP GROWTH IN U.S.A., CANADA AND ABROAD

Year	U.S. and Possessions	Canada	Abroad	Total
May 13, 1912	46			46
1927	3,550	184	476	4,210
1936	3,975	178	1,042	5,195
1946	15,898	978	1,278	18,154
1956	51,551	2,085	1,858	55,494

In 1948 the Board of Directors announced the resumption of formal membership in the IRE for German and Japanese nationals following the interruption of relations during World War II, even though dues could not then be paid by such members because of restrictions on foreign exchange. Meanwhile, however, the Board ordered that technical magazines published by the Institute be sent to the members residing in those countries.

During the year 1956, the increase in members living in the United States and its territories was 17 per cent and the increase in membership in other countries was 15.5 per cent. As of December 31, 1956 the dues-paying membership of the IRE was 55,494. Their geographical distribution included 80 countries outside of the United States.

Significance of Membership Grades

In the IRE, as is customary in professional societies, the several grades of membership are intended as a basis for giving recognition to the experience and achievements of the members in radio engineering and the related technical fields.

From the beginning the Fellow grade has been intended to represent high attainment. In 1914 Professor Jonathan Zenneck became the first person to be elected to this grade. In January, 1915, the Board elected A. N. Goldsmith, J. V. L. Hogan, Jr., R. H. Marriott, and E. J. Simon to the grade of Fellow. During the first 25 years of the Institute's existence, the attainment of Fellow grade was possible upon application subject to approval by the Board of Directors, or upon the initiative of the Board. Elections to Fellow grade were not numerous in any one year. Usually there were fewer than 10.

Beginning with the year 1940, all entries to the Fellow grade have been by invitation rather than upon application. The custom has been established of presenting the Fellow awards at meetings of the local Sections of which the recipients are members, and 75 persons were being honored in this way in the early part of 1957.

The Senior Member grade was established in 1943 as a means of providing a higher grade than the Member grade into which members of the IRE might advance on the basis of their experience and training. This enabled the Institute to keep the Fellow grade as a special recognition.

In 1955 there was an increase of 118 per cent in those of the Member grade resulting largely from the upgrading of qualified Associate members.

The Board felt that such upgrading was called for in order to give appropriate recognition to the professional attainments of many Associates, and it brought the per cent of professional grade members up to 42.1 per cent as compared with 29.1 per cent at the beginning of the year 1955.

Recognizing the desirability of encouraging engineering students to become affiliated with the Institute of Radio Engineers, a Student Grade of membership in the IRE was established by constitutional amendment effective in 1932. The previously existing grade of Junior member was dropped in 1943.

It was a natural development for the Student Members at a given college to meet together to discuss radio engineering questions among themselves or to hear ad-

MEMBERSHIP GROWTH BY GRADES

Year	Junior	Student	Associate Non-Voting	Associate Voting	Member	Senior Member	Fellow	Total
May 13, 1912				46				46
1936	34	299		4,092	637		133	5,195
1946		2,252	9,890	1,701	2,330	1,763	218	18,154
1956		10,384	18,491	388	19,110	6,486	635	55,494

dresses by visiting engineers, and a number of informal Student groups or "chapters" came into existence.

The Board consequently authorized the establishment of Student Branches in schools of recognized standing in order that the important segment of Student Members might be given official and direct support of the IRE. The first Student Branches which were formally recognized by the IRE were those at the College of the City of New York and at New York University, which were formed in February, 1947.

In order to promote affiliation of engineering students with the IRE Student Branches recognition was given to "100 Per Cent Clubs" in colleges where 100 per cent of the membership of the senior electrical engineering class had become affiliated with the IRE or the IRE-AIEE Student Branches through membership in one or the other of these engineering societies. In May, 1956, it was announced that 11 Student Branches were "100 Per Cent Clubs."

Interest in Student membership was stimulated during 1956 through visits made by the President of the IRE who traveled several thousand miles on his visits to Student Branches in the middle west and elsewhere. By the latter part of that year there were 135 Student Branches in as many colleges. Of these 107 operated as joint IRE-AIEE branches. In each of these schools a faculty representative who is a member of the Institute has been designated as IRE representative for that school. In addition there were 47 colleges having IRE faculty representatives where there was no organized Student Branch. Thus the IRE has a designated representative in each of 182 colleges in the United States and Canada.

The IRE Bylaws provide that every member who has attained the age of 65 years and who has been a member of the IRE for 35 years or more, is eligible for Life Membership with waiver of payment of further dues. As of December 31, 1956, there were 101 Life Members of the IRE.

Problems of the Depression

In November, 1931, in recognition of the difficult financial situation into which many members of the IRE had been forced because of the business depression, the Board of Directors voted to allow members who had paid their dues for the years 1929 and 1930 to have until December 31, 1932, in which to pay dues for 1931 and 1932, while still retaining full active membership in the IRE.

In January, 1932, the Board of Directors considered what steps the IRE might take to assist unemployed radio engineers and established a committee to survey the situation. This committee was to take appropriate steps to circularize IRE members for contributions, ascertain those radio engineers in need, determine what activities of interest to IRE members were not normally being carried out and employ needy engineers in such activities in so far as circumstances and finances would permit. The complete story of the relationships of the IRE to its membership during this trying time has never been fully disclosed publicly, but the relationships were of such a nature as to be thoroughly beneficial to its loyal and substantial members.

The offer by the IRE to extend the time for the payment of dues during the depression was accepted with great appreciation by several hundred members, the maximum number being about 730 at the end of 1933. The date for the acceptance of deferred payments without break in membership was extended but this practice was brought to a close at the end of 1935.

Early in 1932 an Emergency Employment Committee was established by the Board of Directors under the chairmanship of the first President of the Institute. Later in the year the membership of this committee was expanded to include the chairmen of all Sections of the Institute. Job surveys were conducted in 34 states by 105 IRE members. As a result of the committee's activities jobs were found for about 120 IRE members. Most of the expenses of the Emergency Employment Committee other than the maintenance of its office were paid by means of voluntary contributions rather than from IRE funds.

In May, 1933, the work of the Emergency Employment Committee was superseded by the "Emergency Employment Service" operated under the Secretary of the IRE. 185 registrants were placed in jobs during 1933 and 212 additional persons received jobs partly through the Institute's effort. It was estimated that the cost of this activity to the Institute was not more than $1000 per year.

STANDARDIZATION

From the beginning of its existence, the officers of the IRE have recognized that standardization is necessary for the orderly exchange of information and for effective progress in a technological field. A Committee on Standardization was one of the committees of the Institute during its first calendar year, 1913. In his inaugural address in April, 1913, the President of the Institute, Greenleaf W. Pickard, said "the work of our Committee on Standardization is admittedly of first importance. Our art has grown so rapidly that so many of us have, perforce, made our own and sadly variant technical vocabularies. To progress, we must standardize; we must all speak and understand the same language. . . . Standardization in such a branch of the electrical art as ours, may never be complete. Rather, it must be a living, growing structure, added to and revised to keep pace with the changes and development of the art."

The Standardization Committee in 1913 published a report dealing with definitions of terms, letter and mathematical symbols, and methods of testing and rating equipment. The Committee held fifty meetings before the completion of its report, which was then submitted to the membership of the Institute as a whole for adoption. This Standardization Committee was the forerunner of more than a score of technical committees and many more subcommittees whose activities have contributed appreciably to the advancement of the electronic and communication art bringing conformity and clarity to all fields of this endeavor.

The Standards publication program of the IRE has been modified from time to time to meet the needs of a rapidly growing field. The initial Standards report of 1913 was succeeded by revised reports by the Standardization Committee appearing in 1915, 1922, 1926, 1928, 1931 and 1933. Each of these reports contained, in a single document, data on many branches of the art. Due to the rapid strides made in certain fields, the Committee on Standardization, during 1924 and 1925 was supplemented by a number of subcommittees, each one concerning itself with one specialized branch. As a result of this change in committee structure, the 1926 Standards report and subsequent reports were separated into several sections. Eventually it was found desirable to give these subcommittees full standing-committee status. Accordingly there was initiated in 1938 a new series of Standards in which each Standard dealt with a separate field. More recently, this subdivision has been carried further by the publication of separate Standards within each field, on definition of terms, on symbols, and on measuring and testing methods.

With the advent of radio broadcasting and the rapid growth of the radio manufacturing industry during the 1920–1930 decade, the IRE undertook to coordinate its Standardization activities with those of the trade associations of radio manufacturers—The National Electrical Manufacturers' Association and The Radio Manufacturers' Association. Reciprocal committee memberships were arranged and steps were taken to avoid duplication or possible conflict of proposed standards. Copies of preliminary editions of several of the reports of the Standardization Committee of the IRE were distributed to members of NEMA and RMA as well as AIEE for comment prior to final adoption.

In connection with the publication, in the 1929 YEAR BOOK, of the Standardization report for 1928 this statement was made:

"The following plan has been evolved under which the field of radio standardization has been divided between the Institute of Radio Engineers on the one hand and the manufacturers' organization on the other. It is recognized, of course, that in this new field, it is impossible at the present time to determine upon any hard and fast dividing line.

"*Institute of Radio Engineers.* 1) Terms, definitions and symbols, and 2) methods of testing materials and apparatus in order to determine their important characteristics. This work may consist of purely advisory discussion as to convenient forms of tests, precautions to be taken, etc., or it may include standardization of definite test procedures to serve as a common basis of comparison of the properties or performance of material or apparatus.

"*Manufacturers' Groups.* 1) Standardization of size and characteristics of apparatus, to promote interchangeability of parts, either mechanical or electrical, and 2) setting of standard ratings for the properties or performance of material or apparatus."

In the YEAR BOOK published in 1929, and distributed to all IRE members, there was included for the first time the text of the report of the Standardization Committee. This 1928 Standardization report contained nine sections of definitions classified as follows: 1) General, 2) Waves and wave propagation, 3) Transmission, 4) Reception, 5) Vacuum tubes, 6) Circuit Elements and Properties, 7) Antennas, 8) Direction Finding and 9) Electroacoustic Devices. Additional sections of this Standardization report dealt with the Transmission Unit, graphical symbols, abbreviations, letter symbols (vacuum-tube notation), and standard tests of radio broadcast receivers.

During the period of the development of radio broadcasting which involved the formulation of a nationwide pattern for the assignment of frequencies to broadcast transmitting stations, it came to be recognized by radio engineers both in the government and in industry that the intervals between assigned channels should be measured in terms of differences between the frequencies of the carrier waves rather than in terms of differences between wavelengths. The "wavelength" concept had been predominant in radio terminology but it became clear that the "frequency" concept would in the long run be much more significant and convenient if it could be brought into the current discussions of this problem and into the literature. This recognition and a consequent change in terminology were slow in developing. In 1929 the Board of Directors of the Institute appointed a committee to consider publicizing the desirability of using the term "kilocycles" in place of "meters" in radio terminology wherever practicable. Largely as a result of the activities of Institute members and of the cooperation given by government officials a substantially complete conversion from the wavelength to the frequency concept was accomplished.

Recognizing that the promotion of standardization in the engineering field required continuing cooperation among the various agencies which are active in industry and in government, the Board of Directors of IRE in 1927 undertook the joint sponsorship with the American Institute of Electrical Engineers of the Sectional Committee on Radio of the American Standards Association. The field of radio standardization undertaken at that time on a broad cooperative basis with other related engineering groups consisted of the following: 1) nomenclature, symbols, definitions; 2) methods of testing; 3) acceptable limits for performance, ratings, capacities, operation, etc.; 4) sizes and dimensions, to provide interchangeability and economy; 5) quality of materials, and 6) safety.

This cooperative effort with other engineering groups, with the radio manufacturing industry, and with government has continued to be active and many standards adopted as a result of this procedure have been published and given wide distribution. In October, 1930, the IRE became a formal Member of the American Standards Association. The YEAR BOOK which was published in 1930 included a number of standards closely related to radio engineering, which had been prepared by other organizations, in order to encourage the use of these standards by IRE members and others. These standards were: mathematical symbols, letters symbols, preferred numbers, electrical measuring instruments, definitions—telephony and telegraphy, definitions—storage batteries and provisions that were particularly applicable to radio installations, selected from the National Electrical Code and the National Electrical Safety Code.

The standards report issued early in 1931 reflected the increasing interest in a new field of communication by including material prepared by a Technical Committee on Electro-Visual Devices. Later in that year the Board of Directors created a technical committee of the IRE on Television to operate under the Standardization Committee and to work jointly so far as possible, with the Television Committee of the Radio Manufacturers' Association.

In 1939 the American Standards Association listed four standards as having been sponsored by the IRE. They related to vacuum tubes, loudspeakers, radio receivers, and audio volume measurements. As of the end of 1956, thirteen current IRE standards have been adopted by the ASA as American Standards.

With the broadening of the field of activity of the Standards Committee it became increasingly important to provide close coordination between the recommendations of various technical committees in order to avoid unnecessary duplication in their activities as well as to avoid inconsistencies between their recommendations. To this end in 1947, one of the members of the Executive Committee of the Board of Directors was designated to serve as Standards Coordinator for the Institute. In 1948 a Definitions Coordinating Committee for the Standards Committee was established and at IRE Headquarters during the years 1948 and 1949 there was prepared a master index of all terms covered by standard definitions of the IRE and of other organizations in the electronics field.

A major innovation in IRE policy regarding the publication of standards was the appearance of four such standards in the PROCEEDINGS OF THE IRE for December, 1949. It was felt by the Board that this form of publication of each standard upon its adoption would serve to emphasize with all members of the IRE the existence and importance of the standards. It was believed also that availability in this form and also in separate reprints would make reference to this material more convenient and practicable. The standards that were published in the December, 1949 PROCEEDINGS were: standards of radio aids to navigation, definitions of terms; standards on railroad and vehicular communications, methods of testing; standards on piezoelectric crystals; and standards on radio receivers—tests for effects of mistuning and for downward modulation. There was recognized, here, the increasing use of radio in the mobile field.

The IRE technical committees (sometimes in collaboration with technical committees of other engineering societies) publish standards of definitions of terms and methods of measurement of physical quantities used in radio engineering practice that are widely accepted throughout the technical world.

The current IRE standards are 63 in number. Of these 37 standards deal with terminology, symbols, and definitions of terms, and 26 standards deal with testing or measurement methods. Most of these standards have appeared in the PROCEEDINGS and all of them are available in reprint form. A list of the current standards is published from time to time in the PROCEEDINGS.

SECTIONS

Formation

The activities of the IRE, originally confined to the New York area, quickly spread to other cities as the membership increased. Small groups of members in various localities began to hold their own local meetings and elected their own officers for organizing and running these meetings. These groups of members were called Sections.

The first local Section of the IRE was organized at Washington, D. C. in January, 1914. Section meetings were held each month for the benefit of the group of perhaps a score of engineers, then described as "a large number of members residing in the vicinity of the capitol." At that time it was expected that other Sections would be formed, as appropriate, with the increase in membership of the IRE in various cities. This did not take long, for a Section was established in Boston, Mass. in November, 1914, another in Seattle, Wash. in February, 1915, and one in San Francisco in 1917.

It is interesting to note how the development of IRE Sections reflected the growth of the radio field. The first four IRE Sections were formed in large coastal cities due to the predominance of maritime radio just prior to World War I. In 1925 other Sections were formed in Philadelphia, Chicago, and Toronto as the broader aspects of radio engineering began to materialize and as the influence of IRE was felt in other areas.

The Chairman of the Sections Committee of the IRE in 1925 (Donald McNicol, who became President of the Institute in 1926), realizing that the membership of the Institute had grown to the point where there were a number of additional localities which were potential centers of Section activity, made trips to a number of such cities to stimulate interest in the establishment of Sections and to help in their organization.

An approved form of a Constitution for Sections was made mandatory in 1930, by action of the Board of Directors. In 1940 a Manual for Sections was prepared to facilitate passing on to new Section officers the experience of earlier officers and to put in one place all rules and regulations relating to the management and operation of Sections. This manual was the forerunner of other manuals for other activities of the IRE.

The IRE headquarters staff has made special efforts, from time to time, to arrange tours by speakers of national reputation who would present papers on technical subjects to meetings of members of IRE Sections. In 1935, Harold P. Westman, the Secretary of the Institute, visited the Sections in Buffalo, Cleveland, Detroit, Emporium, Rochester, and Washington for the purpose of assisting the officers of these Sections in the further development of their local IRE activities.

In 1939 the President of the Institute, Raymond A. Heising, visited nineteen of the twenty-three IRE Sections. At their meetings he spoke of Institute affairs, outlining the significance of changes recently made in the Constitution, discussing the desirability of membership of the highest grade for which an individual is qualified, emphasizing the advantages of active participation in Institute affairs, and ascertaining first-hand their problems and their desires. Before several of these Sections he also presented technical papers of timely interest. Upon his return from these visits the President presented to the Board a number of questions to be resolved, if the Institute was to be of greatest value to the Sections and continue their active relationship with the IRE. These included the importance of emphasizing the identity of the local group as an IRE Section and the problem of making financial grants or allowances to a Section organization in order to enable it to strengthen its local program.

These early presidential trips were the forerunners of many visits by succeeding Presidents to Sections of the IRE in various parts of the country. In the course of these trips it was apparent that there was a desire to add greater significance to the Member grade and to find ways in which the management people in the companies whose engineers held Institute membership could be given a fuller appreciation of the values both to the men and to the companies resulting from such membership. At the same time there was developing, especially in some localities, a desire to have the requirements for eligibility for IRE membership broadened to include people in the various allied fields. This was a consequence of the fact that high-frequency techniques were being developed for use in nonradio industries.

It was felt that the primary problem with which the Institute would be confronted if membership requirements were to be broadened would involve the scope of the Institute's publication field. It was thought that if the Institute were to publish more varied types of technical material, it might find itself publishing many papers in which radio engineers—the backbone of the Institute membership—might be not interested. The solution of this problem was not clear at the outset but later became crystallized in terms of the wider scope of membership, the recognition of Professional Groups and the publication of Professional Group TRANSACTIONS.

The increase in Section activity continued during the late 1930's and it was reported that in 1941 a new record was established for the number of Section meetings held in a year, the total in that year being 235.

From the time of the formation of the IRE until 1941 the meetings in New York were considered meetings of the Institute as a whole. In that year, however, consideration was given to the formal establishment of a New York Section. This action was completed in 1942. Since that time several other Sections and Subsections have been established in the New York-New Jersey metropolitan area.

Effective January 1, 1946, the Board made a change in the method of assigning territory to Sections. Instead of assigning a small territory around a city as the area of each Section it was decided that the entire area of the United States should be assigned to one Section or another. This meant that every member of the IRE in the United States would automatically be on the membership list of a Section and would receive notices of Section meetings. This was a prelude to the establishment of territorial Regions as a basis for the election of Regional Directors. The Section boundaries and the Regional boundaries were established by the Board in such a way as to recognize such factors as community of interest and travel habits of members as well as to equalize, to the extent practicable, the membership in the several regions.

Following the establishment of Professional Groups, referred to below, there have been organized many Professional Group Chapters which meet jointly with other members of IRE Sections in various cities.

Assistance given to Section activities by the headquarters organization in 1945 included a traveling lecture series on television and frequency modulation. In 1954 a program of "tapescripts" or tape recordings, accompanied by lantern slides, was prepared for shipment to IRE Sections, Subsections, Student Branches, and Professional Group chapters which are so located that speakers for their sessions are not always readily obtainable. These tapescripts are useful as short supplements or additions to other programs.

In March, 1955, the administrative work of the Boston Section (with about 3000 members) had grown to such magnitude that an IRE office, with a paid employee, was established by the Executive Committee. At this time the Boston Section had a larger membership than did the IRE as a whole when it established its first regular office with paid personnel. The first Boston Office was at 12 Norfolk Street, Central Square, Cambridge, Mass. On September 1, 1955, the office was moved to 73 Tremont Street, Boston, Mass.

IRE SECTIONS BY REGIONS AND FOREIGN COUNTRIES

Region 1
- Binghamton
- Boston
- Buffalo-Niagara
- Conn. Valley
- Elmira-Corning
- Ithaca
- Rochester
- Rome-Utica
- Schenectady
- Syracuse

Region 2
- Long Island
- New York
- Northern New Jersey
- Princeton

Region 3
- Atlanta
- Baltimore
- Central Florida
- Florida West Coast
- Huntsville
- Miami
- North Carolina-Va.
- Northwest Florida
- Philadelphia
- Washington

Region 4
- Akron
- Central Pennsylvania
- Cincinnati
- Cleveland
- Columbus
- Dayton
- Detroit
- Emporium
- Pittsburgh
- Toledo
- Williamsport

Region 5
- Cedar Rapids
- Chicago
- Evansville-Owensboro
- Fort Wayne
- Indianapolis
- Louisville
- Milwaukee
- Omaha-Lincoln
- South Bend-Mishawaka
- Twin Cities

Region 6
- Alamogordo-Holloman
- Beaumont-Pt. Arthur
- Dallas
- Denver
- El Paso
- Fort Worth
- Houston
- Kansas City
- Little Rock
- Lubbock
- New Orleans
- Oklahoma City
- St. Louis
- San Antonio
- Tulsa
- Wichita

Region 7
- Albuquerque-Los Alamos
- China Lake
- Fort Huachuca
- Hawaii
- Los Angeles
- Phoenix
- Portland
- Sacramento
- Salt Lake
- San Diego
- San Francisco
- Seattle
- Tucson

Region 8 (Canada)
- Bay of Quinte
- Hamilton
- London
- Montreal
- Newfoundland
- Northern Alberta
- Ottawa
- Regina
- Southern Alberta
- Toronto
- Vancouver
- Winnipeg

Argentina
- Buenos Aires

Brazil
- Rio de Janeiro

Egypt

Israel

Japan
- Tokyo

Section Finances

In 1926 the Board of Directors decided to send "rebate checks" to five Sections in addition to two Sections which had previously received them, in order to assist the Sections in obtaining suitable meeting quarters or more helpful technical programs. A total of slightly more than $12,000 of Headquarters funds was devoted to Section operation during 1927.

In 1931 a more uniform system of Section rebates was put into operation. As then ordered, each Section was to be allotted $10 for each meeting during the year and, in addition, fifty cents for each paid member residing in the Section territory.

Increases in Section membership rebates were made at various times over the years and are now $1.10 per member up to 700 members and $1.25 per member for those Sections in excess of 700.

Sections in Other Countries

On October 2, 1925, the first Canadian Section was formed in Toronto at a meeting attended by fifty-three IRE members and guests. Now, twenty-six years later the IRE has a membership in Canada of over 2000 members of all grades. Meanwhile in 1945 the Canadian Council of the IRE had been formed to coordinate the activities of various Canadian Sections on a national basis. This plan formed the basis of the organization that later became effective in the eight IRE Regions of North America.

Consideration was given in 1927 and again in 1932 to the possibility of forming Sections of the IRE in countries outside of North America but on both occasions it was decided that such action would be inadvisable because of their remoteness and the problems of coordination of their activities with those of the Institute as a whole. The first Section of the IRE formally established outside of the United States and Canada was the Buenos Aires, Argentina Section established in 1939. In January, 1956 the IRE Executive Committee approved the establishment of an IRE Section in Tokyo, Japan. This was the sixth Section to be formed outside of North America and the sixteenth outside of the continental United States. These sixteen Sections are Egypt, Israel, Buenos Aires, Hawaii, Rio de Janiero, Tokyo, and ten cities in Canada. Although there are no IRE Sections in Europe, there are members of the IRE in most of the European countries. The total IRE membership in 80 countries other than the United States is about 4000.

Growth Under Regional Plan

The Sections were tied in more closely with the administration of the IRE in 1946 when the Sections were grouped into eight Regions and each Region was given representation on the IRE Board of Directors, each Regional Director being elected on a biennial basis by the membership of the respective Region. Since then the Regional Plan has provided an effective channel of communication between the Board and the membership of the local Sections. The growth of this important "grass roots" activity has continued unabated so that there were at the end of the year 1956, 85 Sections and 26 Subsections in the United States, Canada, and Hawaii. As noted previously, there were then five Sections in other countries. A list of Sections and their officers appears bimonthly in the PROCEEDINGS OF THE IRE.

PROFESSIONAL GROUP SYSTEM

The most basic change in the structure of the IRE which occurred during its more than forty years of growth was the establishment in 1948 of the Professional Group System, providing for Groups within IRE along lines of technical specialization of the members. The successful development of the Professional Group System is proving to be an effective means of counteracting the centrifugal tendencies that otherwise might have accompanied the rapid expansion of the Institute.

For several years prior to 1948 a study was made of various means for developing ways within the IRE whereby members having interests in a given specialized field could give expression to those special interests and develop appropriate activities related thereto. In May of that year plans were announced for the inauguration of a Professional Group System within the broad structure of the IRE. Within less than a year the System had become substantially an accomplished fact. Necessary amendments to the Bylaws had been adopted, a permanent Professional Groups Committee had been established, a model Constitution and Bylaws for Professional Groups had been prepared, and a detailed manual for the guidance of would-be Professional Group organizers had been published.

Under these provisions, those members of the IRE who are interested in a specific technical field can organize and elect their Chairman, Vice-Chairman, and Administrative Committee and, after approval by the IRE Board of Directors, hold meetings either of a national scope or as Chapter meetings associated with an IRE Section. A petition for the establishment of a Professional Group must bear 25 signatures. A petition for a Group Chapter must bear 10 signatures. When approved, any number of members of any Section, however small, may hold local Group Chapter meetings. All meetings of all Groups must be open to all members of IRE.

A Professional Group may establish its own publication which becomes known as TRANSACTIONS of that Group, as discussed below, under "Publications." The members of a Group may establish special honors to promote local and general recognition of their leaders.

It was recognized at the outset that the success of the Professional Group movement would depend upon the interest and spontaneous activities of the groups of IRE members. The multiplication of the applications of radio and electronics led to a greater divergence of the fields of interest of the individual specialists. They were linked together by the use of the same phenomena—electronics or radiation or both. The underlying organizational tie is The Institute of Radio Engineers. The means of expression of individual technical interests is the Professional Group System.

The first two Professional Groups were authorized by the Board on September 9, 1948. These were Groups known as "Audio," and "Broadcast Engineers." In 1948, also, steps had been taken to form Professional Groups on "Nuclear Science" and "Antennas and Wave Propagation." The subsequent establishment of these and other Groups has brought the list to 24 at the end of 1956. A list of the Professional Groups appears bimonthly in PROCEEDINGS OF THE IRE.

TOTAL PAID MEMBERSHIP OF IRE PROFESSIONAL GROUPS

	No. of Groups	Total Paid Members
1948	2	
1949	8	
1950	10	8,500*
1951	16	13,000*
1952	17	12,482
1953	20	21,797
1954	21	28,158
1955	23	36,562
1956	24	53,015

* Estimated; includes both paid and unpaid members.

Accounts of Professional Group activities are published in PROCEEDINGS OF THE IRE and the various Sections are kept informed of Group activities by notices which appear in the Section news letters.

Practically all of the Professional Groups have appointed Sectional Activities Committees to stimulate interest in the establishment of Group Chapters in the various Sections.

The IRE has followed the course of limiting the extent to which the headquarters staff undertakes to stimulate and guide the Professional Groups in their development. The IRE has established general policy and procedure but has left the formation and activities of individual Groups to the initiative of interested IRE members.

The Groups have not been uniformly active nor are their problems identical. Financial assistance has been provided by the headquarters including provision for reimbursing the Sections for Chapter meetings which have been held.

The procurement of papers and management of national symposia are now entirely in the hands of the Professional Groups. Each of the Groups had sponsored one or more technical meetings in the past year in addition to technical sessions at the IRE National Convention, the Western Electronics Show and Convention (WESCON), the National Electronics Conference, and other joint meetings, for a total of 91 meetings of national import in 1955.

Professional Group Chapters

There were 191 Professional Group Chapters, organized by Group members in 44 IRE Sections, as of March, 1957. Chapter growth is continuing at a healthy rate. The Chapters are meeting regularly and sponsoring meetings in the fields of interest of their associated Groups.

PROFESSIONAL GROUP CHAPTERS

Name of Group	No. of Chapters	Section Location
Aero. and Navig. Electronics	10	Akron; Baltimore; Boston; Dallas-Ft. Worth; Dayton; Kansas City; Los Angeles; N. Y.; Phila.; St. Louis
Antennas and Propagation	11	Albuquerque; Chicago; Denver; Los Angeles; Orange Belt (L. A.); Phila.; San Diego; Wash. D. C.; Akron; Boston; Syracuse
Audio	18	Albuquerque; Baltimore; Boston; Chicago; Cincinnati; Cleveland; Dayton; Hawaii; Houston; Milwaukee; Phila.; Phoenix; San Antonio; San Diego; San Francisco; Seattle; Syracuse; Wash. D. C.
Automatic Control	6	Akron; Baltimore; Boston; Dallas-Ft. Worth; Los Angeles; Twin Cities
Broadcast and TV Receivers	2	Chicago; Los Angeles
Broadcast Transmission Systems	8	Boston; Chicago; Cleveland; Houston; Los Angeles; Pittsburgh; San Francisco; Twin Cities
Circuit Theory	11	Albuquerque; Chicago; Urbana; China Lake; Dallas-San Antonio-Ft. Worth; Los Angeles; Montreal; Phila.; Seattle; Syracuse
Communications Systems	5	Chicago; Phila.; Rome-Utica; Syracuse; Wash., D. C.
Component Parts	6	Buffalo-Niagara; Dayton; Los Angeles; Joint, N. Y., No. N. J. & L. I.; Phila.; Wash., D. C.
Electron Devices	9	Boston; Elmira-Corning; Emporium, Pa.; Los Angeles; Jt., N. Y., No. N. J. & L. I.; Phila.; San Francisco; Schenectady; Wash., D. C.
Electronic Computers	15	Akron; Baltimore; Boston; Chicago; Dallas-Ft. Worth; Dayton; Detroit; Houston; Los Angeles; Montreal; N. Y.; Phila.; Pittsburgh; San Francisco; Wash., D. C.
Engineering Management	10	Boston; Chicago; Dayton; Los Angeles; Jt. N. Y., No. N. J. & L. I.; Phila.; Rome-Utica; San Francisco; Syracuse; Wash., D. C.
Industrial Electronics	3	Chicago; Cleveland; Schenectady
Information Theory	4	Albuquerque; Los Angeles; Wash., D. C.; White Sands Proving Grounds, (El Paso)
Instrumentation	6	Atlanta; Chicago; Houston; L. I.; Los Angeles; Wash., D. C.
Medical Electronics	10	Boston; Buffalo; Chicago; Conn. Valley; Los Angeles; Montreal; Jt. N. Y., No. N. J., L. I. & Princeton; Phila.; San Francisco; Wash., D. C.
Microwave Theory and Techniques	14	Albuquerque; Baltimore; Boston; Buffalo; Chicago; L. I.; Los Angeles; No. N. J.; N. Y.; Phila.; San Diego; San Francisco; Schenectady; Syracuse
Military Electronics	10	Boston; Buffalo-Niagara; Chicago; Dayton; Ft. Wayne; L. I.; Los Angeles; Phila.; Syracuse; Wash., D. C.
Nuclear Science	9	Albuquerque; Boston; Chicago; Conn. Valley; Dayton; Los Alamos; Oak Ridge, Tenn. (Atlanta Sec.); Pittsburgh; Wash., D. C.
Production Techniques	4	Los Angeles; Jt. N. Y. No. N. J. & L. I.; San Francisco; Wash., D. C.
Reliability and Quality Control	3	Chicago; Los Angeles; Wash., D. C.
Telemetry and Remote Control	6	Albuquerque; Chicago; Dayton; Central Florida; Los Angeles; Phila.
Vehicular Communications	11	Baltimore; Boston; Chicago; Detroit; Houston; Los Angeles; Jt. N. Y., No. N. J. & L. I.; Phila.; Portland; Wash., D. C.; Dallas
23	191	44

As of the end of 1956, about half of the IRE members had, on the average, joined two Professional Groups, for a total Professional Group membership of 53,015. About one-third of the Student Members of the IRE, numbering nearly 3619, had by the end of 1956, joined one of the Groups covering their particular field of interest at the Student Member rate of $1.00 for each year.

A copy of the portion of the IRE NATIONAL CONVENTION RECORD which pertains to the field of interest of his Group is sent without charge to all paid members of Professional Groups.

The comment has been made by John V. L. Hogan, one of the Founders and past Presidents of IRE that "the Institute of Radio Engineers can well be considered to be the federal body which unites an increasing number of autonomous professional groups."

This decentralized activity, with centralized service and coordination, seems to explain the extraordinary vitality of the Professional Group System. There has been growth, not only in number of Groups, but in the size and professional attainment of each Group. More and more first-rate papers are finding their way into the Group TRANSACTIONS, papers which in an earlier day would certainly have been published in the PROCEEDINGS.

"Affiliate" Plan

In January, 1957, the Board took a step which may prove to be a notable one in IRE history. Based on a need which had developed especially in the case of the Professional Group on Medical Electronics, it adopted on an experimental basis a plan which enables non-IRE members whose main professional interests lie outside the sphere of IRE activities to become affiliated with certain of the IRE Professional Groups in whose activities they wish to share without having to join the IRE. To be such an "Affiliate" of a Group a person must belong to an accredited organization approved by that Group and by the IRE Executive Committee. Participation in the Affiliate Plan is at the option of each Professional Group. On payment of the regular assessment fee of his Group, plus $4.50, the Affiliate is entitled to receive the TRANSACTIONS of the Group and the part of the IRE NATIONAL CONVENTION RECORD which pertains to that Group. The Affiliate Plan is intended to recognize and provide for the rapidly spreading influence of electronics in every walk of scientific and technological life, and to enable the IRE to further fulfill its aim—that of advancing radio engineering and related fields of engineering and science.

PUBLICATIONS

PROCEEDINGS OF THE IRE

As an essential element in meeting its objective of promoting the exchange of radio engineering knowledge the IRE at the outset undertook the publication of a periodical, and its publication program is perhaps the most important single activity of the Institute.

The PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS was established originally as a quarterly publication, in 1913. An amendment to the IRE Constitution, effective in 1916, authorized the publication of six issues of the PROCEEDINGS per year instead of four. For the last thirty years, beginning in 1927, the PROCEEDINGS has been published monthly. In 1939, the name of the journal was shortened to PROCEEDINGS OF THE IRE.

The first Editor was Alfred N. Goldsmith, one of the three Founders of the IRE. It is under his inspired leadership that the IRE has, through the ensuing years, turned out a publication which has been generally recognized as the leading technical magazine in the radio field.

Prior to the inauguration of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS there had been the *Proceedings of the Wireless Institute*, mentioned above. The only other radio engineering periodical of significance was *Jahrbuch der Drahtlosen Telegraphie* edited by Dr. Jonathan Zenneck in Berlin.

As to the early years of the IRE, it has been said that "the Secretary got members and the Editor got papers;" there was always an editorial office of the IRE wherever Dr. Goldsmith, a blue pencil, and a submitted manuscript got together. Editorial facilities other than those that were provided by the Editor were meager for a number of years. The correspondence, proofreading, typographical, and related editorial matters that had to be taken care of must have made a pretty strenuous task for one man. The recognition that the PROCEEDINGS has received throughout the world is in no small measure due to the determination and ability which Dr. Goldsmith exhibited throughout a period of four decades.

The PROCEEDINGS for the years 1913 to 1927 inclusive were printed at various printing plants in New York. Beginning with the October, 1927 issue the printing of the PROCEEDINGS was transferred to the Banta Publishing Company of Menasha, Wisconsin, by which firm it has been printed throughout the ensuing years. The Institute is fortunate in having a printing house with which such a close and cooperative relationship has developed as to make it seem like a member of the IRE family.

At the outset, the contents of the PROCEEDINGS consisted of certain papers and discussions as presented at meetings in New York and other cities. During the year 1913, thirteen technical papers were published and a total of 268 pages were occupied, an average of 67 pages per issue, size $6\frac{1}{2}$ by 9 inches. The scope of the PROCEEDINGS was soon broadened to include other technical papers, and also lists of newly elected members, personal notes, reports of meetings and committees, and other information pertaining to the Institute. In addition, from April, 1921 to January, 1928, inclusive, there was published a monthly Digest of U. S. Patents Relating to Radio Telegraphy and Telephony.

In order to relieve the Editor of the PROCEEDINGS of some of the burden of the technical editorial work that must be done on papers submitted for publication, a Board of Editors was established in 1928 to assist in this work. This Board consisted of the Editor and 5 other members of the Institute who were experienced in the editorial or publication field.

Throughout the years the IRE has followed in its publishing activities a policy which spreads ideas throughout the world hoping that somewhere they may fall on fertile ground. Thus, the Institute has been instrumental in disseminating scientific and technical information that forms the foundation of radio enterprises as they are developing. It has been effective in providing a world-wide avenue of discussion and publication that has promoted the rapid development of radio for nearly half a century.

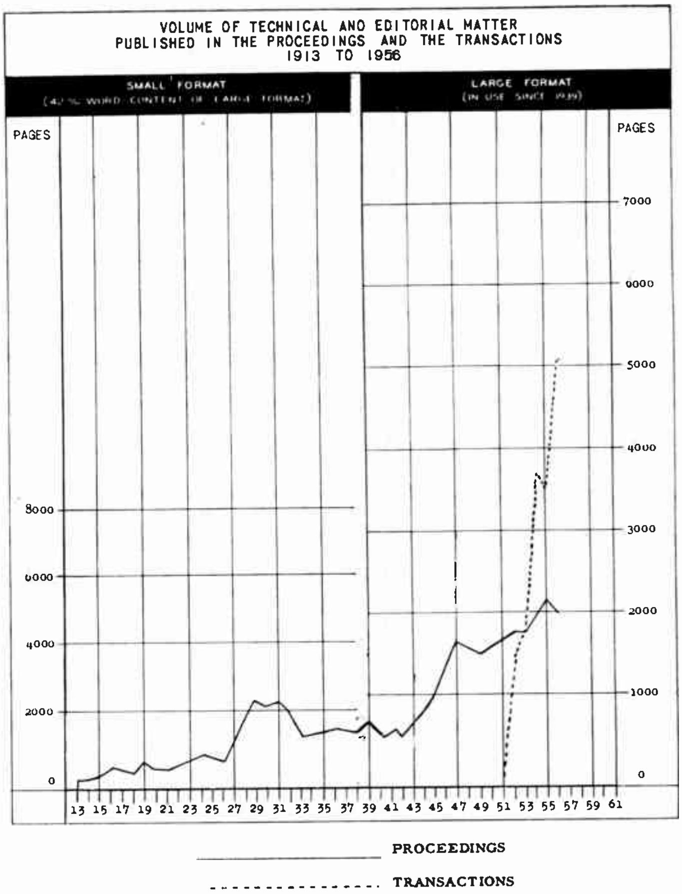
There was recognition, also, of the interest of European members of the IRE in the Final Protocol of the European Radio Conference signed at Prague, April 13, 1929, of which an English translation was published in the PROCEEDINGS in July of that year. That document related to radio broadcasting in Europe and dealt with frequency assignments, power limits, etc.

Beginning in January, 1939, each issue of the PROCEEDINGS has contained photographs of the authors of technical papers published in that issue, in addition to the biographical notes which had been printed previously.

In 1941 the practice of publishing an editorial in each issue of the PROCEEDINGS was begun. These started chiefly as "Guest Editorials" but have included from time to time editorial writings by the Editor of the PROCEEDINGS and by the President of the IRE or a Committee Chairman.

During World War II the volume of technical material published in the PROCEEDINGS was materially smaller than had been the case during the several prior years. While technical advances during that period were very extensive, censorship limitations applied to certain subjects. Furthermore, the preoccupation of IRE members with urgent military tasks precluded their devoting the necessary time to the writing of papers in form that would be most useful to PROCEEDINGS readers. The shortage of paper for printing necessitated the use of a minimum of paper and such paper as was available was of inferior quality. It was through the personal effort of the Editor that the supply of paper for the IRE PROCEEDINGS was not curtailed even further.

In 1946 the supply of paper suitable for magazine production was even shorter than during war time. On the other hand the number of meritorious technical papers submitted for publication increased substantially upon the termination of the war. It became necessary, therefore, to request authors to submit manuscripts in the briefest possible form, to materially shorten some papers which had already been accepted for publication, and to be patient with substantial delays in the publication schedule. The cooperation received from authors was gratifying and within a very few years the publication process was able substantially to keep pace with the supply of available papers.



During the years 1946 to 1949, inclusive, there was published along with the PROCEEDINGS and bound within the same covers a section known as "Waves and Electrons." This portion of the magazine was intended to meet the interest of readers of the PROCEEDINGS who wished to see more material published outside of the field of advanced research and technical developments. The "Waves and Electrons" section contained news, notes, book reviews, biographical notes, information regarding other technical organizations, and current information regarding radio apparatus developments, as well as some historical and tutorial papers. It was found, however, that this formal separation of material did not lend itself to the integrated arrangement of technical and editorial material which was desirable and the "Waves and Electrons" section, as such, was discontinued at the end of 1949.

Prior to 1949 there had existed from time to time a committee of the IRE known as the Papers Procurement Committee. The purpose of the committee was to canvass possible sources of technical papers, particularly to undertake to secure papers on specific subjects on which it was felt desirable to round out the material for the benefit of the readers of the PROCEEDINGS. Beginning in 1949 this activity was taken over by the Editorial Department of the Institute's staff, since it was in a position to know what papers were in process of publication.

For a period of 21 years from 1934 to 1954 inclusive, the IRE published an Annual Review of Radio Progress. The purposes of this review were: 1) to present to the specialist in one field a general picture of the important forward steps in the other specialist's fields which he can not follow day by day, and 2) to provide an historical record of the evolutionary progress in radio communication and allied fields in order that radio engineers might be better able to view current developments with a proper prospective.

It became increasingly difficult to cover adequately in a summary which could be published in March or April of each year all of the important technical developments that might be of interest to the members of the Institute. It was concluded, after the publication of the survey for the year 1954, to discontinue this Annual Review. Instead, it was decided to place more emphasis on the preparation by experts in various fields of a series of review papers, each of which would cover the developments in a given field during a recent period of years.

With the broadening of Professional Group activity and with the presentation of an increasing number of technical papers at Professional Group meetings and at the annual National Conventions of the IRE, it became desirable to crystallize on the terminology that would be useful in describing the growing variety of IRE publications. By 1951 it appeared that these publications might be primarily of the following four categories:

1) PROCEEDINGS OF THE IRE—the official monthly publication of the Institute,
2) TRANSACTIONS of each of the Professional Groups—publications sponsored by the groups, containing papers and discussions of a more specialized nature,
3) CONVENTION JOURNAL (hereafter to be known as the IRE NATIONAL CONVENTION RECORD)—a publication containing all papers presented at an IRE National Convention,
4) IRE YEAR BOOK AND DIRECTORY—an annual publication summarizing the categories of activities of the Institute and containing a list of IRE members together with listings of manufacturers and their products which might be found of interest to the members. The last three of these publications are discussed more fully below.

To accomplish a balanced publication program the IRE must supplement the contributed papers by invited papers, either to fill gaps in the coverage of new technical developments or to present a general review of a given field in a way which is helpful to a reader who is not a specialist in that field.

Beginning in 1951 there have been published, from time to time, nine unusually large issues of the PROCEEDINGS, each devoted exclusively to a single subject. The first of these was the October, 1951 issue devoted to color television. This issue consisted of 400 pages and was the largest single issue of the PROCEEDINGS ever published up to that time.

The Board of Editors, by 1949, had found that its work could be facilitated by the establishment of an Editorial Administrative Committee. This Committee made final decisions on papers under review for publication in the PROCEEDINGS, in addition to concerning itself with general editorial matters. In 1954, the Board of Editors and the Editorial Administrative Committee were replaced by the Editorial Board which concentrated its attention largely on policy questions and has left operational and papers review matters chiefly to the staff of the Institute.

The IRE has had the unique good fortune to benefit from the continuous service of the original Editor of the PROCEEDINGS who served in that capacity for all but one of the first 42 years of the existence of the Institute. As of January 1, 1954, Dr. Goldsmith was relieved of active editorial responsibilities and "in recognition of the invaluable service he has rendered the Institute and his monumental contributions to the growth and high standards of its publications" was appointed Editor Emeritus. Since that date two other persons, John R. Pierce and Donald G. Fink, have served as Editor. Previously, however, the Institute had established the position of Managing Editor which is filled by a full-time employee of the Institute.

Beginning in January, 1956, the section of the PROCEEDINGS known as "IRE News and Radio Notes" was expanded to include several pages of pictures as part of a new program of reporting more fully the activities of the Professional Groups and Sections. The news of IRE officers' visits, conferences, banquets, award ceremonies, and publications serve to keep the general IRE membership informed of current activities.

Beginning in February, 1956, there appeared in the PROCEEDINGS, under the caption "Poles and Zeros," a page of comment by the Editor on matters of concern to the IRE membership.

A regular editorial feature of the PROCEEDINGS written by the Managing Editor and which has also appeared since February, 1956, carries the caption, "Scanning the Issue." These "program notes" are intended to indicate to the general reader not only what is in the papers but what is behind them—what their significance is, to whom they will be of interest and, by implication, why they are being published.

A portion of the PROCEEDINGS is frequently devoted to correspondence with the Editor. During the past few years this feature has grown in significance. For example, in the August, 1956 issue 23 items appeared, includ-

Beginning in June, 1946, in place of these reference lists the Institute began the publication in the PROCEEDINGS of "Abstracts and References" which were made available by a special arrangement with Iliffe and Sons and the *Wireless Engineer* of London, England, as well as the Department of Scientific and Industrial Research of the British Government.

The Abstracts and References published in the PROCEEDINGS for December, 1956, number more than 300 references classified under 19 technical headings.

In 1955 it was felt that an index to these references would be useful to IRE members. An index covering the period June, 1946 to January, 1954 was published as Part II of the PROCEEDINGS for November, 1955. An index to references published from February, 1954 to January, 1955 inclusive had been published as Part II of the PROCEEDINGS for April, 1955. A third installment of this index covering the references published from February, 1955 to January, 1956 inclusive was published as Part II of the PROCEEDINGS for June, 1956. Accompanying the index is a selected list of journals scanned for abstracting together with publisher's addresses.

Indexes to IRE Publications

With the increasing quantity of material published by the Institute, and in view of the widening areas of subject matter dealt with, it became apparent that a general cumulative index should be prepared and made available to all subscribers to the PROCEEDINGS. Several such indexes have been compiled from time to time. The three indexes which now cover this material are:

Cumulative Index, 1913–1942 (Part II of PROCEEDINGS, June, 1943)
Cumulative Index, 1943–1947 (Part II of PROCEEDINGS, June, 1948)
Cumulative Index of IRE Publications, 1948–1953

This latter index, printed as a separate pamphlet, includes references to the PROCEEDINGS OF THE IRE, the IRE TRANSACTIONS, and the IRE CONVENTION RECORD.

Transactions of Professional Groups

The first major broadening of the IRE publication program was the appearance of the TRANSACTIONS issued by the Professional Groups. They immediately proved to serve a very useful purpose as a quick, practical method of providing Professional Group members with technical papers in their particular fields of interest. As early as in 1951, six issues of such TRANSACTIONS were issued by the Audio Group and two issues of TRANSACTIONS by the Airborne Electronics Group.

The material published in these IRE TRANSACTIONS consists in part of contributed papers, and in part of papers presented at meetings of the Professional Groups or at Symposia of which they undertake joint sponsorship. The growth of the Professional Group TRANSACTIONS is indicated by the fact that in 1951 eight issues of TRANSACTIONS appeared, each consisting of a single paper, whereas, in 1956 some 69 issues of TRANSACTIONS were published by 23 Professional Groups containing a total of over 500 papers. The total annual TRANSACTIONS output now exceeds that published in the PROCEEDINGS.

The principal Symposium publications that have not been included in TRANSACTIONS of Professional Groups, but of which copies are obtainable from the office of the IRE, are the following:

8 Electronic Computer Conferences (joint AIEE-IRE-AGM) 1951–1956 inclusive
3 National Telemetering Conferences, 1953–1955 inclusive
2 Electronic Components Symposia 1954–1955
2 National Symposia on Quality Control and Reliability in Electronics 1954 and 1956

Beginning with the issue for June, 1954, there were published in the PROCEEDINGS abstracts of all technical papers appearing in the TRANSACTIONS of the various Professional Groups. Further steps taken to avoid overlap of the PROCEEDINGS and the TRANSACTIONS were the establishment of restrictions on the reprinting of TRANSACTIONS papers in the PROCEEDINGS and the participation of Professional Group representatives in the review of papers submitted for publication in the PROCEEDINGS. The Professional Group TRANSACTIONS are proving to be such a substantial source of technical information that, by the end of 1956, 450 technical libraries, including those of many colleges and industrial organizations, had subscribed for all issues of all TRANSACTIONS of all Professional Groups.

CONVENTION RECORD

The papers that were presented at the National Conventions of the IRE in New York from 1953 to 1956, inclusive, have been published as Volumes I, II, III, and IV, respectively, of the IRE CONVENTION RECORD. This has grown to be a very sizable RECORD. An important feature of the publication is that each paid Professional Group member receives, free, a copy of the part pertaining to his Group.

About 6000 copies of each of the nine parts of the CONVENTION RECORD for 1956 were printed of which a total of 40,000 copies were sent free to Professional Group members. This publication is now known as the IRE NATIONAL CONVENTION RECORD.

Late in 1956 the Board decided that thereafter the papers presented at the Western Electronics Show and Convention should be published as the IRE WESCON CONVENTION RECORD

STUDENT QUARTERLY

In September, 1954, a new publication of the IRE was successfully launched. It was the IRE STUDENT QUARTERLY which is sent free to all Student Members of the

IRE as part of a program of increased service to students. It contains news of Student Branches, articles of technical value, and papers of significance to students who are interested in considering carefully whether to devote themselves to an engineering career.

YEAR BOOK AND DIRECTORY

The first published list of IRE members, dated January 1, 1913, was a 24-page pamphlet, size 3½ by 6 inches, listing 100 persons. The names of 15 of these persons still appear in the current list of IRE members —the 1956–1957 DIRECTORY.

The first YEAR BOOK was published in 1914, the second in 1916, and then they were published annually from 1926 to 1932, inclusive. The YEAR BOOK was published in 1937, 1942, and 1946. With the 1948 YEAR BOOK, annual publication was resumed. In 1950 its name was changed to DIRECTORY. The YEAR BOOK has customarily included the current list of members and basic information about the organization of the Institute. In some of the earlier issues, the report of the Committee on Standardization was included.

The 1946 YEAR BOOK was the first one that included as a separate feature the biographies of all who hold the Fellow grade of membership in the IRE.

The 1956 YEAR BOOK bearing the title IRE DIRECTORY—1956–57, contains a total of 1004 pages. Almost half of it consists of a list of members of the Institute (other than Student members) along with basic information regarding the Institute's organization, Officers, and Constitution. The second half of the YEAR BOOK is a section consisting of a directory of manufacturing firms and a product index. This latest YEAR BOOK weighs 5 lbs. The entire shipment of nearly 47,000 copies (copies are not sent to Student members) from the printing office at Menasha, Wisconsin in September, 1956, weighed more than 100 tons.

AWARDS

The Institute of Radio Engineers has, from the beginning, gone to some lengths to show honors to those among its membership who have made accomplishments of outstanding value to the development of the radio engineering field. Evidence of this attitude was the reference to "Honorary Membership" in the Constitution as originally adopted. In place of this membership grade, other honors of a formal nature were subsequently provided for, to be awarded by action of the Board of Directors. In addition, the granting of special honors for individual accomplishments, by the action of Sections, Professional Groups, and Student Branches has been authorized by the Board from time to time.

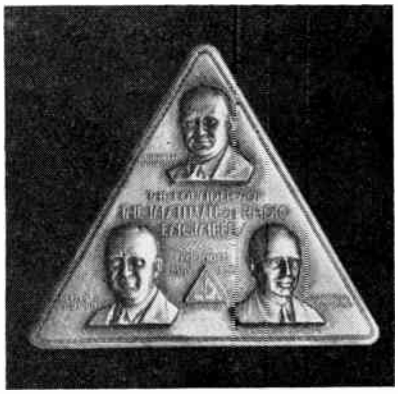
From the beginning the IRE has had a strong core of men who have given unstintingly of their time and effort for the promotion of the Institute's service to its members. The various IRE awards are the tangible expression of appreciation by the Institute and of encouragement to continue these individual professional contributions with renewed and greater effort, in order to serve better the IRE and the profession.

The IRE now bestows seven formal awards, of which six are awarded annually in recognition of outstanding technical and administrative achievements in the field of radio communication. The recipients of these awards are named by the Board of Directors upon the recommendation of the Awards Committee. The names of all of those who have received these formal awards are given in the 1956–1957 IRE DIRECTORY.

Medal of Honor

The Medal of Honor is given annually in recognition of outstanding scientific or engineering achievements in the field of activity of the IRE. This medal was first given in 1917 and has been given annually since that year, with the exception of the years 1918, 1925, and 1947 in which no award was made.

Medal of Honor.



Founders' Award.

Founders' Award

The Founders' Award is bestowed only on special occasions for outstanding leadership in planning and administration of important technical developments. The award commemorates the three radio pioneers who founded the Institute of Radio Engineers in 1912—Alfred N. Goldsmith, John V. L. Hogan, and Robert H. Marriott. This award has so far been made to three persons—David Sarnoff in 1953, Alfred N. Goldsmith in 1954, and Raymond A. Heising in 1957.

Vladimir K. Zworykin Television Prize

The Vladimir K. Zworykin Television Prize was first awarded in 1952 and is to be awarded annually for 20 times to the member of the IRE who makes the most important technical contribution to electronic television during the preceding three calendar years or the importance of whose contribution to electronic television shall have been realized during this period. The award consists of a citation and a check for $500 drawn from a fund of $10,000 donated to the Institute by Vladimir K. Zworykin to encourage outstanding technical developments in fully electronic television.

Morris N. Liebmann Memorial Prize

The Morris N. Liebmann Memorial Prize has been given annually beginning in 1919. This award was originally based on a fund made available to the Institute for this purpose by E. J. Simon to preserve the memory of Colonel Morris N. Liebmann, a member of the Institute who gave his life in the first World War. The award now consists of a certificate and a check for $1000 given to a member of the Institute who has made an important contribution to the radio art.

Browder J. Thompson Memorial Prize

The Browder J. Thompson Memorial Prize, established in 1945, is given annually to the author or joint authors under 30 years of age for a paper of sound merit recently published in one of the technical publications of the IRE, which has been selected as constituting the best combination of technical contribution to radio and electronics and presentation of the subject.

The award comprises the income from a fund established by voluntary contributions to preserve the memory of Browder J. Thompson, a Director of the Institute who was killed in action in World War II while on a special mission for the Secretary of War.

Harry Diamond Memorial Award

The Harry Diamond Memorial Award, established in 1949, is given annually to a person or persons in Government service for outstanding contributions in the field of radio or electronics, as evidenced by publication in professional society journals such as the PROCEEDINGS OF THE IRE or journals of similar standing. The award consists of a certificate provided for from proceeds of a fund established by friends who felt that the professional life of Harry Diamond, a Fellow of the Institute, exemplified the highest type of scientific effort in United States Government service.

W. R. G. Baker Award

The W. R. G. Baker Award, instituted in 1957, is to be given annually to the author of the best paper published in the TRANSACTIONS of the IRE Professional Groups. The award consists of a certificate together with a cash award comprising the income from a fund donated to the IRE by Dr. W. R. G. Baker, Chairman of the IRE Professional Groups Committee.

Other Awards

The Editor of the PROCEEDINGS, Alfred N. Goldsmith, was awarded in 1926 an embossed and framed "Memorial to the Secretary of the Institute" in recognition of his service to science and engineering in the upbuilding of the Institute of Radio Engineers. In expressing their appreciation to this Founder, who had been serving as Editor since the beginning of the IRE, the Board of Directors stated: "He has given unstintingly of his time, his substance, his ability and gracious good will to the Institute, has personally built into its structure much of the strength it now has, and has continuously borne the burden of its problems." He was also the recipient of the Medal of Honor in 1941 and the Founders' Award in 1954.

The other living Founder of the Institute, John V. L. Hogan, who had served as President of the IRE in 1920, was awarded the IRE Medal of Honor in 1956 "for his contributions to the electronic field as a founder and builder of the Institute of Radio Engineers, for the long sequence of his inventions, and for his continuing activity in the development of devices and systems useful in the communication art."

In 1950 the Board of Directors established a plan whereby students in the different Student Branches might be given awards by the local Sections. Seventy-eight Student Branch awards were announced for 1956.

A few of the local Sections of the IRE have taken steps to recognize and honor outstanding members of their Sections. One purpose of such an award is to give early recognition to accomplishments that have not previously received national attention. One such instance was the "Electronic Achievement Award of Pacific Region IRE" established in 1951 by the Pacific Region Committee. The recipient is to have made important contributions to the electronic arts and industry in one or more of the general categories of education, research and invention, system engineering, or contributions to the literature or to IRE activities.

Several of the Professional Groups have established the custom of making awards for outstanding papers or engineering accomplishments in their fields.

MEETINGS AND CONVENTIONS

National IRE Meetings

One of the principal purposes of the founders of the IRE and of the charter members was to hold meetings at which radio engineers could exchange information on questions of general interest. The first YEAR BOOK of the IRE, published in 1914, stated that "Institute meetings are held in New York monthly excepting in July and August of each year for the presentation and discussion of engineering papers. These papers are presented by members who have specialized in some division of the subject and who desire to lay their results before the profession." This same YEAR BOOK stated that the Annual Meeting, held during the first week in January, had up until then been held in New York City. It was stated that the Board of Directors intended to have it held in different sections of the country from year to year, according to the distribution of the membership, with special regard to conventions or congresses of the radio or allied professions which may from time to time convene.

It was not until 1925, however, that the Board made specific plans for an Annual Meeting outside of New York City. The January, 1926 Annual Meeting was held in Washington, D. C. with the active cooperation of members of the Washington Section of the IRE.

By 1928 the monthly meetings in New York were drawing an attendance sufficiently large to call for consideration of a regular meeting place of larger proportions than the college classrooms, members' private offices, committee rooms, etc., in which meetings had been held. Accordingly, it was decided to rent Room No. 1 on the fifth floor of the Engineering Societies Building, 29 West 39th Street, New York, for monthly meetings of the IRE, even though this meant an expenditure of $75 for each such meeting.

The interest of IRE members in holding meetings for technical discussions has never abated. It has, in fact, increased in an astounding manner. If one takes into account the annual meetings, the joint symposia, the meetings of Sections and Subsections, Professional Groups and their Chapters, IRE Student Branches, and not forgetting the many meetings of technical committees and subcommittees and of groups of IRE members who are planning and arranging for all of these meetings, it may be nearly literally the case that there is not a day on which there is not an IRE meeting somewhere.

What was apparently the first joint Convention of the IRE and the AIEE was the one held on the grounds of the Panama-Pacific Exposition at San Francisco in 1915. In recognition of this event, the IRE was awarded a bronze medal by the Exposition management. On this occasion two technical radio papers were presented. One of these entitled, "Radio Development in the United States," was given by R. H. Marriott, the first President of the IRE.

The annual IRE meetings in New York through the year 1925 were considered to be the meetings required by the provisions of the IRE Constitution. After that date the procedures for the election of officers were conducted by mailing ballots to the members as specified or permitted by successive amendments of the Constitution without the necessity of holding meetings for election purposes. Beginning in 1926, therefore, the annual meetings were much more in the nature of National Conventions and had emphasis on technical papers rather than on the conduct of the business affairs of the Institute.

The first Convention in 1926 had a banquet as one of its features, and appropriately enough, dinner music was received by radio. In 1928 in response to the appeal of the Convention Committee to the Board of Directors for funds to enable the Institute to have a more extended technical meeting of three days as well as the banquet on this occasion, the Board decided to appropriate "an undesirable maximum" of $900 for Convention expenses. In contrast, the expenses of the Convention held in New York in March, 1956, amounted to over $300,000.

In further appreciation of the desire of IRE members to hold more technical meetings and in recognition of the geographical distribution of members in areas somewhat distant from New York, the Institute has held or cooperated with other societies in holding many regional technical meetings, some of which have been carried out as symposia in specific technical fields.

Perhaps the first of these regional meetings was the one approved by the Board of Directors early in 1929. This was planned initially as a district convention of the Rochester, Buffalo-Niagara, Toronto, and Cleveland Sections. It was held in Rochester on November 18 and 19, 1929, and was later referred to as the Eastern Great Lakes District Convention. This Convention was a great success and was followed by a series of annual meetings, extending through 1948, known as the Rochester Fall Meeting of the IRE.

The first three Annual Conventions, however, were held in New York City (1926, 1927, 1928). The next eight Annual Conventions (1929–1936 inclusive) were held in other cities. Beginning in 1937 the Conventions were again held in New York, this having been necessitated by the large attendance and the availability of facilities for accommodating the many technical sessions. The only subsequent exception to this practice was the Convention held in Boston in 1940.

The interests of IRE members in the Pacific region who have found it inconvenient to attend the national meetings held annually in New York have been met by a series of Pacific Coast Conventions which have been held since 1937 at substantially annual intervals at principal cities on the West Coast.

Another regional conference is the New England Radio Engineering Meeting which has been held at Cambridge, Mass. each year beginning in 1947. The technical meetings have been supplemented by exhibits.

A series of regional Conferences in recognition of the interest of a substantial number of IRE members located at some distance from New York was the succession of Southwestern IRE Conferences held for several years beginning in 1948 at various cities in Texas.

History of IRE National Conventions

Date	City	Papers	Exhibits	Attendance
Jan. 18–19, 1926	N. Y. C.	6	0	**
Jan. 10–12, 1927	N. Y. C.	5	0	425*
Jan. 9–11, 1928	N. Y. C.	9	0	800
May 13–15, 1929	Washington	37	0	555
Aug. 18–21, 1930	Toronto	23	20*	575
June 4–6, 1931	Chicago	19	50	400
Apr. 7–9, 1932	Pittsburgh	23	25*	460
June 26–28, 1933	Chicago	24	35	487
May 28–30, 1934	Philadelphia	32	56	940
July 1–3, 1935	Detroit	21	34	586
May 11–13, 1936	Cleveland	19	40	360
May 10–12, 1937	N. Y. C.	30	37	1,189
May 15–17, 1938	N. Y. C.	49	29	1,866
Sept. 20–23, 1939	N. Y. C.	26	34	1,668
June 27–29, 1940	Boston	44	35*	1,071
Jan. 9–11, 1941	N. Y. C.	28	30*	1,310
Jan. 12–14, 1942	N. Y. C.	25	30*	1,790
Jan. 28, 1943	N. Y. C.	11	0	1,750
Jan. 28–29, 1944	N. Y. C.	22	0	1,704
Jan. 24–27, 1945	N. Y. C.	43	39	3,000
Jan. 23–26, 1946	N. Y. C.	88	135	7,200
Mar. 3–6, 1947	N. Y. C.	118	177	12,013
Mar. 22–25, 1948	N. Y. C.	130	180	14,459
Mar. 7–10, 1949	N. Y. C.	144	225	15,710
Mar. 6–9, 1950	N. Y. C.	163	253	17,689
Mar. 19–22, 1951	N. Y. C.	198	277	22,919
Mar. 3–6, 1952	N. Y. C.	211	365	28,673
Mar. 23–26, 1953	N. Y. C.	214	412	35,642
Mar. 22–25, 1954	N. Y. C.	242	605	39,302
Mar. 21–24, 1955	N. Y. C.	248	704	42,133
Mar. 19–22, 1956	N. Y. C.	277	716	41,017
Mar. 18–21, 1957	N. Y. C.	284	756	54,074

* Estimated.
** Information not available.

The Canadian IRE Convention held in October, 1956, gave special recognition to the 30th Anniversary of the IRE in Canada. The program at this Convention included more than 125 technical papers and more than 120 exhibits. Other features were a banquet and a program for ladies. Special arrangements were made to encourage attendance by university students.

An important feature of the recent National Conventions, and of some of the Regional Conventions, is the manufacturers' exhibit of equipment that is of interest to radio engineers. It is believed that through these exhibits of the products of radio engineering and electronic development, mutual benefits accrue to both engineer and manufacturer through first-hand acquaintance with the activities of one another. An accompanying table shows the date and meeting place of each of the IRE Annual Conventions as well as some additional information as to their size and, during the last ten years, of the extent of the Radio Engineering Show, held as a feature of the Convention.

Attendance at the 1956 National Convention in New York included persons from 36 countries outside of the United States.

Engineering Conferences and Symposia

For many years the IRE has cooperated with other scientific and engineering organizations, as a joint sponsor or in a similar capacity, in the conduct of engineering meetings or of extensive technical symposia.

In November, 1919, several technical papers were presented by IRE members at a joint meeting with the American Physical Society in Chicago.

Beginning in 1933 the American Section of the International Scientific Radio Union (URSI) enlisted the cooperation of The Institute of Radio Engineers in the conduct of a series of joint meetings usually held annually at Washington, D. C. The papers presented at these meetings have dealt largely with radio transmission questions, including studies of the propagation of radio waves and the characteristics of the electronic circuit elements employed in the transmission and reception of radio signals.

During the period 1937–1947 several Broadcast Engineering Conferences were held at which papers were presented and discussions took place with regard to technical aspects of radio broadcasting. This series of meetings was in some respects the forerunner of meetings of the Professional Group on Broadcasting and the organization of that Group made the continuation of separate Broadcast Engineering Conferences unnecessary.

During the Annual Convention in 1939, the presentation speech, awarding the IRE Medal of Honor to a British member of the Institute, was transmitted over the transatlantic radiotelephone service and the reply was heard by the group assembled at the Awards Luncheon in New York.

A special feature of the Annual IRE Convention held in January, 1946, was the conduct of a session which was in effect a joint meeting of the IRE and of the British Institution of Electrical Engineers. On this occasion, meetings that were held simultaneously in New York and London were joined by a radiotelephone circuit across the ocean, so that the participants at both locations could hear the addresses given by all of the speakers at both sessions.

The participation of the IRE in the newly developing field of nuclear physics is illustrated by a series of four Nuclear Conferences held during the years 1949–1952 inclusive. Papers presented at these conferences cover a field ranging from fundamental nuclear physics to nuclear-medical instrumentation.

A National Electronics Conference, in Chicago, in 1944 was attended by more than 2200 persons—more than had attended any IRE National Convention up to that time. This was the forerunner of an annual series of such Conferences sponsored jointly with other Societies and Universities.

The largest meeting under IRE joint auspices is the annual Western Electronics Show and Convention (WESCON), now held on alternate years in Los Angeles and in San Francisco. It is sponsored by the West Coast Electronic Manufacturers' Association and the Los Angeles and San Francisco IRE Sections. At the 1956 meeting in Los Angeles over 200 technical papers were presented in 48 technical sessions. There were 706 exhibits and five field trips. About thirty thousand engineers, scientists and business representatives of the electronics industry attended the convention.

The engineering conference or symposium has come to be one of the major activities of the IRE during the past few years and the "Calendar of Coming Events" has come to be a regular feature of the PROCEEDINGS. This Calendar referred to a total of 46 such meetings during the year 1956.

Radio Pioneers' Dinners

New York members of the IRE, numbering about 125, held an Old Timers' Meeting on May 6, 1942, to "call the roll of the past, and to view ancient scenes and personages of radio by means of lantern slides"—the television of 1912.

Another dinner meeting sponsored by the New York Section of the IRE—a much more elaborate event—was held on November 8, 1945, and was known as the Fourth Radio Pioneers' Dinner. This occasion was notable because of the large attendance—over 800 persons—and because of the enthusiastic and effective work of a number of pioneer radio engineers in the preparation of a souvenir booklet of 64 pages, edited by Harold P. Westman, a former Secretary of the IRE, presenting the history of "wireless" from its early beginnings through 1925, together with pictures of equipment and personalities associated with "the good old days." Attending this dinner as guests of the IRE were the presidents of the American Radio Relay League, Radio Club of America, and Veteran Wireless Operators Association.

COMMITTEES

One of the most effective means for collaboration among members of the IRE has been through the activities of the various IRE committees. In the YEAR BOOK for 1914, it was stated that a considerable portion of the important work of the Institute was accomplished by committees. The three Standing Committees of the IRE and their functions, as stated at that time, were:

Papers Committee—to secure papers of merit and interest

Standardization Committee—to prepare standard terms, symbols, units and methods of testing and rating radio apparatus

Publicity Committee—to keep the public and the technical press informed as to the work done by the Institute and its recommendations, thus ensuring that the public and the art shall benefit by the labors of the Institute

By 1915 another Standing Committee was added—the Finance Committee—and there were three special committees, one to consider possible representation of the IRE at the Panama-Pacific Exposition in San Francisco, one to consider the formation of a Seattle Section of the IRE, and a third to consider what amendments to the IRE Constitution should be recommended to the membership in order to make the Institute's work more effective.

The broadening scope of IRE interests over the years was accompanied by the establishment of additional committees dealing both with technical subjects and with operational matters. There has been repeated emphasis in the summaries of IRE activities published in the YEAR BOOK and in the PROCEEDINGS of the fact that the major activities of the Institute have been sponsored by and accomplished through the voluntary work of the many Institute committees.

The evolutionary development of IRE activities is indicated by some of the committees that have been established from time to time to deal with new problems or those which have assumed special significance.

In 1926 a Committee on Broadcast Engineering was established. In 1927 there was submitted to the IRE by the Federal Radio Commission of a series of questions on which it sought opinions. It was recognized by the Board of Directors that the field of activity of this committee could not be limited strictly to its technical aspects but that the very nature of radio broadcasting was such that the engineering conclusions would, if adopted, have an effect on some of the relationships between the public and the broadcasting industry. It was decided, therefore, that any publicity regarding the recommendations of this committee should be subject to approval by the Board of Directors.

The IRE Year Book—Directory for 1956–1957 lists as Standing Committee of the Institute 25 Technical Committees with a hundred Subcommittees, along with 13 other Committees dealing largely with management and operational aspects of the Institute. A complete list of all Committees of the Institute and of their members is published semiannually in the issues of the Proceedings for June and October.

The effectiveness of the IRE throughout these forty-five years of its existence has been due in no small measure to the enthusiastic collaboration of the many hundreds of Committee members and to their recognition that there could be no satisfactory substitute for the contributions which this activity could make to the more rapid and effective development of the field of radio engineering.

Cooperation with Governmental Bodies

Technical Aspects of Radio Regulation

The problems of radio regulation are such as to require, for their solution, a thorough consideration of the physical facts as to the behavior of radio waves, as to the external performance of radio transmitting equipment, and as to many of the operating characteristics of radio receiving apparatus.

At first, broadcasting, like Topsy, "just grew." Everyone wanted to operate on 360 meters, and it wasn't long before the interference was so great that almost all broadcast programs were meaningless, regardless of the care which had been put into their preparation. Herbert Hoover, Secretary of Commerce of the United States held a series of four National Radio Conferences in 1922, 1923, 1924, and 1925 in which representatives of the IRE took an active part. Government officials, senators, and congressmen began talking meters and kilocycles. A new radio law was passed in 1927, and the uses of radio began to be regulated by the Federal Radio Commission.

When the Federal Radio Commission was first organized it had no engineering staff, so it naturally looked to the engineers of industry for assistance on technical matters. This led to renewed activities of the IRE, those of studying and preparing reports on a series of problems put to it by the Commission and its Acting Chief Engineer.

At a special meeting of the Board of Directors the President of the IRE was authorized to appoint a Broadcasting Committee to assist the Federal Radio Commission and the general public in obtaining information on such subjects as service areas, interference areas, cross-talk interference between channels, harmonic and parasitic interference, the areas covered by network operation, frequency stability, and modulation as affecting service and interference areas.

The plan for the allocation of broadcast channels to zones and states which was put into effect by the Federal Radio Commission on November 11, 1928, was closely related in its main engineering aspects to that recommended by the IRE.

The IRE Committee on Broadcasting prepared a series of reports which, after approval by the Board, were forwarded to the Federal Radio Commission and published in the Proceedings during the years 1928–1930.

In order to make clear its position with respect to cooperation with the Government, the Board of Directors in February, 1931 adopted a resolution "that the records of the Institute be made available to all Governmental departments for their use in enforcing the laws and regulations of the United States and any other country."

The 1926 President of the IRE, Donald McNicol, in an editorial published in the Proceedings in February, 1948, sounded a renewed appeal to radio engineers to play their proper part in meeting the problems of the Government. He quoted the following from an address previously given by the President of the American Chemical Society: "Today scientists recognize that they have greater responsibilities than mere discovery and are determined to see that what they develop for the betterment of mankind shall not be used for its destruction."

Government agencies concerned with the regulation and use of radio facilities are faced with technical problems of ever increasing complexity; *e.g.*, propagation data are required over a spectrum spanning more than 25 octaves. Performance data on hundreds of different types of transmitters and receivers and antennas are required. As a supplement to the staffs of Government groups, impartial, skilled advisors are needed and are available through such groups as the Joint Technical Advisory Committee, the National Television System Committee, and the Radio Technical Planning Board which are referred to below.

An outstanding case of a call by the Government for wise technical-administrative assistance in the radio field was the designation by the President of the United States in 1951 of Haraden Pratt, the Secretary of the IRE, to serve as Telecommunications Advisor to the President.

Increasing reliance by Government agencies over the years on recommendations and reports of the Institute of Radio Engineers is exemplified by the reference to certain IRE Standards in rules promulgated by the Federal Communications Commission early in 1956. The IRE standard methods for measuring radiation and for measuring power line interference are relied upon for determining whether such incidental radiation exceeds the permissible limits specified by the Commission.

In a guest editorial in the Proceedings of the IRE for December, 1956 the Chairman of the Federal Communications Commission commended the IRE for its outstanding contributions toward advancement of the art of radio communication and for the whole-hearted cooperation it has always given all agencies of the government concerned with utilization and administration of the radio spectrum.

Joint Technical Advisory Committee (JTAC)

In response to a request from the Federal Communications Commission in 1948 for advice on a number of technical radio problems with which the Commission was concerned, a group of eight distinguished radio engineers was asked to form themselves into the Joint Technical Advisory Committee (JTAC). This joint action was taken in June, 1948, by the Boards of Directors of the IRE and the Radio and Television Manufacturers Association (RTMA). The purpose of JTAC was to consult with Government agencies and other professional and industrial groups, to determine what technical information was required to ensure the wise use and regulation of radio facilities, and to collect and disseminate such information.

JTAC has issued a series of technical reports on questions of public interest on which the FCC has sought information. JTAC has also presented technical testimony at meetings held under FCC auspices. The first request for advice from JTAC was for information on the utilization of ultra-high frequencies for television. A JTAC report entitled, "Utilization of Ultra-High Frequencies for Television" was issued September 20, 1948.

Subsequent reports issued by JTAC over the period of eight years since its formation have dealt with such subjects as fm broadcasting, interference problems in tv, standards of good engineering practice, principles for the allocation of frequencies in the land mobile and other radio communication services, interference from arc welders, etc.

Normally the reports of the Committee were issued in mimeographed form and distributed to several hundred interested individuals and agencies, including, of course, the Federal Communications Commission.

The eighth report in this series was believed to be of such general interest as to warrant the widest possible distribution and accordingly, the sponsoring organizations, IRE and RTMA, decided to underwrite its publication in book form. This report was a comprehensive analysis of the problems involved in the efficient use of the radio spectrum for the great and increasing variety of services for which radio waves are employed and was entitled, "Radio Spectrum Conservation—A Program of Conservation Based on Present Uses and Future Needs." Its purpose was to review the principles of radio transmission in language as simple as the subject allows, and to discern the course to be pursued in order to bring the benefits of radio in maximum measure to the largest number of the world's people. More than 2000 copies were mailed throughout the world as a public service to professional societies, industry groups, government officials, educational institutions, libraries, technical publications, research laboratories, etc.

Another outstanding report to the Federal Communications Commission by JTAC was on the subject of television. The IRE office staff also cooperated with RMA in the preparation of a report, which was made by that organization to the FCC in September, 1949, dealing with the technical aspects of manufacturing problems related to color television, which was included in part in the JTAC report.

COOPERATION WITH OTHER TECHNICAL ORGANIZATIONS

Early Activities

From the beginning the Board of Directors of the IRE has recognized the close relationships between the field of activity of the Institute and the activities of other scientific and engineering organizations. The IRE has, therefore, endeavored to keep closely in touch with such organizations and has appointed representatives to serve on many joint committees.

The development of radio broadcasting during the 1920's resulted in rapid expansion of the radio manufacturing field and in the organization of trade associations in that field. The IRE has contributed to the development of radio engineering and manufacturing through the expansion of its standardization activities and by the publication of technical and educational papers useful in training engineers for future employment by radio manufacturers.

The IRE YEAR BOOK for 1926 lists the following organizations on which the IRE had representation or with which it was engaged in active participation in joint projects:

Council of the American Association for the Advancement of Science
National Fire Protection Association
Fourth National Radio Conference called by the Secretary of Commerce
Radio Advisory Committee of the Bureau of Standards, Department of Commerce
Executive Committee of the Sectional Committee on Radio of the American Engineering Standards Committee.

In 1927 the IRE and AIEE undertook joint sponsorship of the Sectional Committee on Radio under the procedure of the American Engineering Standards Committee (later called the American Standards Association). The IRE at that time was also cooperating in the formulation of standards on five other subjects. Several years later the IRE accepted sole sponsorship of the Sectional Committee on Radio.

In 1928 the American Engineering Standards Committee invited the IRE to become formally affiliated as a member body of that organization.

Radio Technical Planning Board (RTPB)

In 1943, before the termination of World War II, a joint industry technical committee was formed to coordinate the advice and suggestions of various parts of the radio engineering, manufacturing, and operating agencies on questions which were believed to be helpful to the Government, particularly the Federal Communications Commission, in revising the regulations applicable to the operation of radio stations in such a way as to meet more adequately the needs of a rapidly developing postwar radio industry. The Chairman of the Radio Technical Planning Board (RTPB) was W. R. G. Baker, a Fellow of the IRE. The IRE sustained its status as a contributing sponsor by appropriating $500 toward the support of the RTPB in 1945.

The Radio Technical Planning Board went out of existence in 1948 when it appeared that its form of organization no longer served to meet the problems which had developed in the continuing postwar period. At about that time the IRE, in conjunction with the Radio Manufacturers Association and with the encouragement of the Federal Communications Commission, created in June, 1948, the Joint Technical Advisory Committee (JTAC), referred to above.

National Television System Committee (NTSC)

A notable example of the effectiveness of the IRE in its cooperation with other technical organizations has been in connection with the work of the National Television System Committee (NTSC). The first NTSC had been formed in 1940 by several industrial organizations which had a major interest in the sound development of television field and particularly in presenting to the Federal Communications Commission, in response to its request, a coordinated recommendation as to the technical standards that should be recognized as the basis for the licensing of television broadcasting stations for both monochrome and color television service. A report on this work was made in 1941. The monochrome standards then proposed were reviewed by the RTPB referred to above and became the basis for commercial monochrome television service authorized by the Commission in the United States.

The second NTSC became active in January, 1950, and was reorganized in June, 1951, in a renewed endeavor by representatives of various industrial organizations to obtain industry agreement on recommendations to the Federal Communications Commission on frequency allocation problems involved in television and on standards for color television. As an evidence of its desire to contribute actively to the attainment of a sound technical basis for the Committee's recommendations, the IRE put the facilities of its Headquarters Office at the disposal of the Committee. During the years 1952 and 1953, meetings of the NTSC or of its various panels were held at the IRE headquarters, there being on the average more than one meeting per week. In addition, the Technical Secretary of the IRE served as Secretary for the coordinating panel of the NTSC. The final report of the NTSC was filed with the FCC in the latter part of 1953.

In recognition of its distinguished contribution to the television industry and to the development of color television, the NTSC received the "Emmy" Award of the Academy of Television Arts and Sciences in 1954.

Other Activities

By 1956, in contrast to the situation in 1926 when the IRE was listed as cooperating with five societies, the IRE was carrying out formal active cooperative endeavors with 38 organizations. This included 30 Sectional Committees, boards, or other bodies organized under the procedures of the American Standards Association. Similar activities were also carried on jointly with the following organizations:

American Association for the Advancement of Science
Atomic Energy Commission
International Radio Consultative Committee (CCIR)
International Scientific Radio Union (URSI)
Joint IRE-AIEE Committee on High Frequency Measurements
Joint IRE-RETMA-SMPTE-NARTB Committee for Intersociety Coordination—Television (JCIC)
National Electronics Conference
National Research Council—Division of Engineering and Industrial Research
U. S. National Committee of the International Electro-technical Commission (IEC)

INTERNATIONAL COOPERATION

Radio engineers and scientists have unique opportunities to know and understand their fellow human beings in other countries. The very conduct of international radio transmission, both commercial and amateur, requires continual contacts. The problems of frequency allocation and the reduction of radio interference are continually compelling bases for collaboration and discussion of matters of mutual concern. International Communication Conferences—many of them under Governmental auspices—provide occasions not only for formal negotiation and agreement but furnish opportunities, sometimes even more valuable, for informal discussions, thus helping to avoid misinterpretation of the appellation "foreigner."

The founders of the IRE recognized that the nature of radio transmission is such that radio waves recognize no national boundaries. They realized, too, that the problems in the radio field and the accomplishments of radio engineers are bound to be of interest to technical radio men throughout the world. It has thus been traditional with the IRE to foster international cooperation in radio, to encourage interest in the IRE, and to promote its services and the spread of its publications as widely as possible in all countries of the world. As early as at the end of 1915 there were 83 members of the IRE living in eleven countries other than the United States; of these 20 were Canadian members.

In 1927, the International Radiotelegraph Conference, which was held in Washington, D. C., for the purpose of revising the International Radiotelegraph Convention and Regulations, brought to the United States several hundred representatives of other countries. This was the first world conference to deal with the allocation of radio frequencies to radio services which had expanded so rapidly since World War I. Accordingly, there were many radio engineers included in the delegations to this International Conference.

As a result of action taken at this International Conference there came into being the International Radio Consultative Committee (CCIR), an organization which, through the participation of representatives from all interested countries, has as its continuing task the preparation of advisory recommendations on technical questions that are involved in the allocation of frequencies to various radio services.

The first meeting of the CCIR was held at The Hague in 1929. One of the delegates to this meeting was designated by the Board of Directors to serve as the Institute's representative and to offer the facilities of the IRE and its committees to the CCIR in any manner in which it was thought that the Institute could be of assistance. Many members of the IRE and its technical committees have cooperated in the work of the CCIR and its Study Groups throughout the period of its existence.

As a contribution to the proceedings of the World Engineering Congress in Tokyo in October, 1929, the IRE Board of Directors asked a group of IRE members to prepare a symposium paper on "The Trend of Radio Broadcasting and Its Relation to National Solidarity."

In 1931 the United States National Committee, operating under the International Electrotechnical Commission, asked the IRE to cooperate with it in meeting some of the problems of international standardization of terminology. The IRE was very ready to lend its cooperation in this direction by contributing results of its own work on the standardization of terms and definitions.

Cooperation between the IRE and the International Union of Scientific Radio (URSI) has been active since 1926. By IRE representation on the USA National Committee of URSI there is a formal link. On repeated occasions, at International Assemblies and at meetings of the USA National Committee, members of the Institute have presented papers on radio transmission and other technical subjects. The IRE or one of its Professional Groups has also been joint sponsor of most of the meetings of the USA National Committee. Several members of the IRE participated in the Eleventh General Assembly of the URSI held at The Hague in 1954.

In 1946 the Board created an International Liaison Committee which continued until 1956. Its activities during the early part of this period formed the basis for the working arrangements for cooperation between the IRE and the Institution of Electrical Engineers in London.

Notices have been published in the PROCEEDINGS from time to time of radio developments of special interest in various countries. Notice was published in April, 1947, for example, of the Popov Gold Medal awarded annually by the Presidium of the Academy of Sciences of the U.S.S.R. to a scientist of any nationality for outstanding scientific research or invention in the field of radio on the basis of submission of manuscripts and other information.

By 1950 the variety of international contacts in the broadening field of interest of the Institute had become such that the Board of Directors appointed a member of the Institute to serve as chairman of an IRE Coordination Committee with international technical organizations. This involved cooperation with the CCIR, URSI, IEC, and other international bodies, as well as coordination with the interests of the United States Department of State in such matters. The chairman of this Coordinating Committee was to report directly to the Executive Committee of the IRE Board.

By the very nature of its worldwide effects, radio lends itself ideally to international collaboration and radio engineers feel that they are privileged to work in a field which promotes international understanding. It is the fact that radio services simply could not operate without world collaboration in the control of interference. The very fact that radio communications systems do operate smoothly on a worldwide basis proves that men of all nations can work out together the most complicated and difficult problems. This activity is in itself a real contribution to the development of good will and international friendliness.

CONSTITUTION

The Constitution adopted by the original members of the Institute at a meeting on May 13, 1912 was a fairly simple document. It stated the objectives of the Institute and recognized three grades of membership—Honorary Members, Members, and Associates. The dues for Members and Associates were set at $5 and $3, respectively. There was no entrance fee and Honorary Members were to pay no dues. The business affairs of the Institute were to be handled by a Board of Direction of nine persons, consisting of four Managers, President, Vice-President, Secretary, and Treasurer all of whom were to be elected by the Institute membership, and an Editor of Publications who was to be elected by the other members of the Board.

A few clarifying amendments of the Constitution became effective November 2, 1914, and December 5, 1915. Two new grades of membership were established—Fellow and Junior—and 5 additional members were added to the Board of Direction. Entrance fees ranging from $1 to $10, depending on the grade of membership, were established and dues for the several grades of membership were increased slightly. Honorary members and Junior members did not have voting privileges. The Board, comprising a total of fourteen persons, was to include six elected Managers and three Managers appointed by the elected members of the Board.

In January, 1921, the membership by letter vote approved a change in the Constitution to provide that the list of nominees should comprise at least one name and not more than three names, proposed by the Board or by petition, for each of the following offices: President, Vice-President, Secretary, Treasurer, and two Managers. The elected Managers held office for three years, and three Managers were elected by the Board, thus forming a total Board membership of fourteen.

The Constitution stood without further change until October 7, 1931. At this time the grade of Honorary Member was deleted. The name of the Board of Direction was changed to Board of Directors and all reference to Managers was deleted. The Board was again enlarged, this time to a total of 20 persons, consisting of the President, Vice-President, Secretary, Treasurer, nine elected Directors, five Directors appointed by the elected members of the Board, and the two most recent past Presidents. This revision of the Constitution brought in the first reference to Bylaws and gave the Board authority to adopt or amend Bylaws as might be appropriate within the terms of the Constitution itself. Specific recognition of local Sections of the Institute was included.

This revision also provided for nomination by the Board of Directors of only a single name for President so as to make the presidency more of an honor and less of a contest than had been previously the case.

A general revision of the Constitution was effective on March 1, 1939. The Chairman of the Board of Editors was added to the Board as an appointed member, making a total of 21 persons. At this time it was provided that Associates who joined after this date would have no voting privileges and that election to the Fellow grade would thereafter be by invitation by the Board of Directors. It was also provided that the ballots submitted to the membership should contain at least one candidate for each office.

In 1941 a proposed amendment to establish Regional Directors failed of adoption. Several amendments adopted in 1943, 1944, 1945, and 1946, made certain changes in the membership structure, in the entrance fees, transfer fees, and dues, and dealt with certain other details of committee appointments and other management matters.

The Executive Committee was established in 1941 to take over the administrative matters that had been handled by the Board of Directors since its early days so as to enable the Board to function more as a policy-making organization. The functioning of the Executive Committee has been discussed earlier in this paper.

Effective July 30, 1946, an amendment was adopted putting into effect a Regional Representation plan under which the Board having a total membership of 24, included six Directors elected-at-large (two elected each year for a three-year term), three appointed Directors, one Regional Director elected (for a two-year term in alternate years) by the members in each of eight Regions, and the two most recent past Presidents.

By 1946 the offices of Executive Secretary, Technical Secretary, and Technical Editor as full-time headquarters staff positions had been created by the Board and it was clear that some of the details of Institute procedures which had previously been dealt with in the Constitution should more properly be handled by the Board of Directors itself or by members of the staff to whom the Board would give authorization. Constitutional amendments in 1946 and 1947, recognized these principles and thus added other powers to the Board and to the administrative officers of the Institute, effective August 15, 1947. Regional Directors continued to be selected specifically to represent the Regions from which they come and whose memberships elect them. All details of membership requirements, dues, and fees were transferred from the Constitution to the Bylaws.

OFFICE LOCATIONS

The first meeting of members of the Institute of Radio Engineers was held in Fayerweather Hall at Columbia University, New York. For several years most of the meetings for the presentation of papers were held at that location. As has been already noted, some of the early meetings of the IRE or of the Board of Directors were also held at Sweet's Restaurant in the Fish Market area on Fulton Street in downtown New York. Sometimes meetings were held at Whyte's Restaurant, also on Fulton Street.

The initial arrangements for handling the Institute's office work were entirely dependent upon the personal cooperation of the various officers. The information pamphlet issued by the Institute under date of January 1, 1913, stated that correspondence relating to Institute matters in general should be sent to the Secretary and gave the address of his residence in Brooklyn, New York. It asked that all papers submitted to the Institute and all correspondence relating to such papers be addressed to the Editor of Publications at his office at the College of the City of New York.

The IRE had no headquarters staff office for a number of years. Some business was conducted at an office used by the 1913–1914 Treasurer, John Hays Hammond, Jr., located at 71 Broadway, New York. A year or two later the IRE moved "uptown" to 111 Broadway in the shadow of Trinity Church. Subsequently, for about six years beginning in 1918, the business affairs of the IRE were conducted from the office of Alfred N. Goldsmith, who served both as Secretary and Editor, located at the College of the City of New York.

In the spring of 1924 the Board of Directors felt that the IRE could afford to rent an office and employ a full-time clerk. A small suite of rooms was leased at 37 West 39th Street, closely adjacent to the Engineering Societies Building in which the monthly meetings for the presentation of technical papers were then being held.

Late in 1928, in order to obtain larger quarters, space was rented in the Engineering Societies Building at 33 West 39th Street. Committee rooms as well as larger rooms for the New York monthly meetings were available in this building.

The staff again was enlarged and included a full-time Secretary, Assistant Secretary, Assistant Editor, Circulation Manager, Advertising Manager, and Head Bookkeeper. The space in the Engineering Societies Building was adequate for a few years but in the spring of 1934 it was necessary to move again, this time to the McGraw-Hill Building at 330 West 42nd Street. In the winter of 1942, that suite proved to be too small and the Institute was moved, in the same building, to larger but soon inadequate quarters.

In order to relieve congestion at the IRE Headquarters in the McGraw-Hill Building and to permit expansion of the editorial staff of the PROCEEDINGS, the Editorial Department in April, 1945, was moved to the fourth floor of a loft building at 26 West 58th Street, New York. In July, 1946, the Editorial Department needed additional space and took occupancy of one half of the second floor in the same building.

The continued need for more space, which could be satisfied only by making frequent moves and by locating different parts of the Headquarters organization in separate buildings, was obviously not to be taken as a satisfactory answer to the Headquarters housing problem. Accordingly, in 1944 the Board of Directors appointed an Office Quarters Committee under the Chairmanship of Raymond A. Heising, the 1939 President of the Institute. As a result of a thorough study by this Committee and following a careful consideration of its report by the Board, it was decided to inaugurate a Building Fund Campaign with a goal of $500,000 for the purpose of providing the Institute with a permanent home which would permit the expansion of its facilities and service to its members and which would enable the IRE to create a closer union between engineers and their industries.

The $500,000 goal was arrived at on the basis that somewhat more than one half would be available for purchasing, altering, finishing, and equipping the land and building, and the remainder would be invested to give a return which would be applied to maintenance and carrying charges. The IRE had been paying $4000 annually for rental and it was estimated that the higher annual maintenance costs for a building could be met through the receipt of interest on the money invested without requiring any increase in the membership fees.

The Institute's Building Fund Campaign was publicly inaugurated under the chairmanship of B. E. Shackelford during the midwinter Technical Meeting in New York in January, 1945. The IRE asked for support from its members and from its friends in industry.

The members of the IRE and executives high in industry rallied with enthusiasm and vigor. Contributions to the fund were made by those in every grade of membership not excluding the Student grade. The bonds of common interest between the IRE Sections and the Headquarters organization were made evident through contributions received through Sections and from individual members amounting to well over $100,000.

By the end of 1945 the total subscriptions to the Building Fund were very close to $625,000 and this amount was exceeded within the first month or two of the following year. The overwhelming success of this campaign was recognized as an indication of the strength of the IRE membership and of the recognition by industry of its indebtedness to the engineering profession. The Board of Directors were in a position to move on to new tasks and plans for service to the membership with confidence and assurance.

With the money in hand the Board of Directors was in a position to proceed with the acquisition, for $200,000, of a building which had been sought out by the Office Headquarters Committee. The building so acquired was the former Brokaw Mansion located at 1 East 79th Street (corner of Fifth Avenue) in New York City. The Board felt that this building might serve the IRE for a period of 25–40 years, recognizing that their successors, alert to changing conditions, would in their time probably initiate more ambitious plans.

The building has four stories, attic, basement, and cellar. It is of chateau design and its facade is patterned on that of the Chateau de Chenonceaux in the Loire Valley in France. The building has rooms which are suitable for committee meetings, Board meetings, and activities of the Headquarters staff. No attempt was made to find a building that could serve as a meeting place for a large number of members. The cost of such a building would not be justified for meeting rooms which would be used by the IRE only once or twice a month. It was felt that meetings of the New York Section could continue to be held either in the Engineering Societies Building on 39th Street or in other auditoriums in the city. It was felt that the new Headquarters Building, with its exceptionally attractive appearance and efficient facilities for carrying out the work of the Institute's staff, would have a homelike and welcoming atmosphere and thus serve to encourage IRE members to plan and hold frequent conferences with the IRE staff and with their fellow members engaged in committee activities.

In November, 1946, the IRE staff moved into the new Headquarters Building. All departments except that concerned with advertising then came under one roof with over-all administration being directed by the Executive Secretary.

The tremendous growth in membership and related activities following World War II again made it clear that additional office space and meeting space were required. During 1953 the number of committee meetings of the IRE reached the unprecedented number of 369. Fortunately, there was available a six story building at 5 East 79th Street, New York, immediately adjoining the Headquarters Building. This annex building was purchased early in 1954 and has become the office quarters of the Editorial Department, Bookkeeping Department, and the Technical Secretary and their staffs. It thus serves as a base for the production of the publications of the IRE and for the cooperation of the IRE staff with Sections, Professional Groups, Student Branches, and other technical bodies with which so many joint meetings and symposia are arranged.

OFFICE MANAGEMENT

During the first few years of the existence of the IRE, the Secretary or the Editor made available for IRE work the part-time services of one of the members of his regular office staff. This, together with the use of individual services by the Secretary, the Editor, and others, kept the drain on the Institute's treasury at a minimum. The report of the Treasurer for the year 1915 shows expenditures for stenographic services and clerical help of $984. During that year, also, $200 was spent for office rent for a period of 8 months and $67.50 for typewriters.

By 1924 the volume of correspondence necessitated by the large increase in the membership and the additional work involved in preparing material for publication in the PROCEEDINGS had reached a point where the Board of Directors was beginning to realize that more adequate provisions needed to be made for office space, clerical assistance, and supervisory attention. In 1926 at a meeting of the Board authorization was given for the purchase of a "stencil making machine" for use in addressing publications. The purchase of two typewriters was also approved in order to replace machines which had been rented. Additional office equipment such as desks, chairs and filing cabinets were also purchased properly to furnish "the new and enlarged headquarters offices." During this period individual attention was given by various members of the Board to many details of the Institute's office management with a view to affecting savings wherever possible.

The President of the Institute, Donald McNicol, in 1926 undertook the preparation of a "Blue Book" as a guide to Board members and to Committee Chairmen in carrying on the routine duties of the Institute. The Board appreciated, however, that a more comprehensive look should be taken at the problems of organization of the Institute's management and upon recommendation of a special committee of the Board authorized the employment of John M. Clayton as a full-time Assistant Secretary of the Institute and its first headquarters manager, beginning January 1, 1927. The Board was fortunate in finding a person for this position who had experience in the radio field through his employment by the American Radio Relay League. A small clerical staff was provided to handle the increasing volume of correspondence.

Among the improvements in office management which were effected in 1927 was the adoption of a new system of bookkeeping that involved the expenditure of $400. Since 1918, the Treasurer's books, which had previously been kept at the Treasurer's own office, have been kept at the headquarters office of the Institute.

In 1928 the move of the Headquarters office to the Engineering Societies Building made available a 50 per cent increase in space. This was needed to provide facilities for the 9 new members added to the office force during a period of 2 years. By the end of 1929 the Headquarters staff numbered 15 persons. The increase from 5 to 15 staff members during a period of 3 years was necessitated by an increase during that period of 100 per cent in the membership of the Institute, 200 per cent in the pages published in the PROCEEDINGS, and 200 per cent in the number of standing committees in operation.

In 1927 John M. Clayton was elected Secretary of the IRE and thus became a member of the Board of Directors until 1930. His successor, Harold P. Westman, who also came to the Institute from the staff of the American Radio Relay League, held the position of Secretary and was a member of the Board of Directors from 1930 to 1942, inclusive.

The President of the IRE in 1941, F. E. Terman, devoted a great deal of personal attention to the operation of the Institute's office, even flying repeatedly across the country to attend the Board meetings. He spent many weeks examining the records of the IRE, observing the functioning of its processes, and considering the effectiveness of its facilities. Late in that year, on the recommendation of an outside management consultant, the Board of Directors employed an Office Manager to give more direct supervision to the Institute's clerical staff.

Late in the year 1944 in order to broaden the activities of the IRE, including the expansion of the publication program, the Board of Directors decided to establish three new staff positions—Executive Secretary, Technical Editor, and Technical Secretary. This was a major step in recognizing the fact that the supervision and operation of the administration of the activities of the IRE could no longer be a part-time job for individual members of the Board of Directors. The Executive Secretary, whose services the Institute was fortunate enough to obtain, was George W. Bailey, who had had some years of administrative experience as an officer of the American Radio Relay League and whose ability in administrative service with the Government during World War II had been well demonstrated.

The administrative activities of the IRE, by the end of 1956, required the services of about 130 people whose work was being directed by the Executive Secretary, Managing Editor, Technical Secretary, Chief Accountant, Assistant to the Executive Secretary, and the Office Manager. The Advertising Department, with its Advertising Manager and Assistant Advertising Manager is situated in another location in New York City.

ADVERTISING

The first volume of the PROCEEDINGS, published in 1913, did not contain any advertisements since in those days there was not much in the radio field to be advertised and there were not many people interested in buying radio apparatus. The principal interest in radio apparatus was in the radio amateur field and this field was being covered by one or two other publications of a somewhat less formal nature.

The first advertising appeared in the PROCEEDINGS in 1915. At that time the solicitation of advertising was in the hands of L. G. Pacent, a member of the IRE, who was mentioned in the 1916 YEAR BOOK as Advertising Manager. The 1916 YEAR BOOK noted that "the revenue derived from this source has been most helpful to the Institute." During the year 1917 there were 48 pages of advertising published in the PROCEEDINGS—an average of eight pages (size 6×9 inches) per month. Among the consistent advertisers were several who have continued to be well-known in the radio manufacturing field to the present day.

One of the Institute's regular office staff under the direction of the Assistant Secretary undertook to handle all advertising solicitation for the Institute beginning in 1928. The Board was apparently somewhat reluctant to include advertising in the 1928 YEAR BOOK but concluded that this should be done in an effort to obtain sufficient revenue from this source to cover the actual cost of printing. This YEAR BOOK contained 28 pages of advertising.

The arrangement whereby the Institute's office handled the advertising activities continued until 1941 when the Board of Directors felt that substantially increased revenue might be obtained if an experienced advertising manager were to handle this part of the Institute's business. Accordingly, a contract was entered into with an advertising manager who provided his own office assistance at an outside location for this task.

In order that the advertising rates of the IRE might be on a firm basis, the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS became a member of the Audit Bureau of Circulations in 1942.

The Institute's policy with respect to the textual content of advertising carried in its publications was once stated as follows: "Advertisements should present useful facts; engineers will thrive on them."

Today there are some 700 advertisers, representing over 80 per cent of the manufacturing volume of the radio-electronic industry, who use the Institute's publications to bring information about their products and services before the members of the IRE. This serves to stimulate a wide interest in the IRE on the part of industry management. It also makes it possible for the IRE to publish a far greater volume of editorial matter of scientific and technical value to its readers than would be possible without this recognition of the financial value of such readership on the part of the industry.

FINANCES

Throughout the life of the IRE the Board of Directors has planned and provided services to the membership with meticulous attention to the extent of the available funds. Accordingly, the publication program of the Institute at the outset was very modest—a small magazine published four times a year. The YEAR BOOK was small and was not published every year. Expenditures for meeting rooms and for Headquarters staff purposes were kept at a minimum.

The total receipts of the IRE for the year 1913 (including $150.97 carried over from the previous year) amounted to $850.93. This included $50.00 from the former Society of Wireless Telegraph Engineers and also $150.00 which was provided by or through the good offices of the Editor. The amount received in dues was $476.75. After payment of $647.25 for printing the PROCEEDINGS, $16.00 for janitor service in connection with meetings held at Fayerweather Hall at Columbia University, and other miscellaneous expenses, the balance at the end of the year 1913 was $24.43.

The report of the Treasurer contained in the 1916 YEAR BOOK referred to the fact that the Institute had "good friends and loyal members . . . who have donated money and fixtures more than enough to start the new year with a clean slate." These donations which included cash, a cancelled note, and furniture given to the IRE by the Editor out of his personal generosity, amounted in the year 1915 to over $1300.00 and this was specifically recognized in the Institute's Annual Report for that year which expressed deep gratitude to Professor Alfred N. Goldsmith "who has been so generous in providing the Institute home with complete furnishings which have added materially to the comfort and appearance of the Institute office."

By the year 1926, to meet the needs resulting from the growth in membership and the corresponding expansion of activities, the Institute's auditors recommended that a new system of bookkeeping be installed.

As the Institute's cash balance gradually increased, the Board of Directors gave repeated attention to the safe investment of its funds so as to insure to the utmost possible extent the continuing ability of the IRE to serve its members and especially to preserve the integrity of the specific funds which had been made available to the Institute for the granting of prizes and awards.

The importance of maintaining a financial reserve was emphasized by the experience of the IRE during the depression in the 1930's. The predepression peak of the Institute's balance in 1930 was $59,166. Even with a curtailment of the Institute's expenses there was so sharp a drop in membership dues collected during the next few years that the year-end unexpended balance dropped to a low of $31,141, in 1934. The process of recovery, however, was soon under way and by the end of 1940 the balance reached $60,905, which was the highest year-end balance in the history of the IRE up to that time. This amount was approximately the same as the operating expenses of the IRE during the year 1940.

The drain on the reserves of the IRE during the depression years in which there were annual deficits would have been serious if there had not been previously an accumulation of adequate surplus.

The upturn which enabled the IRE to operate in the black during 1935 after experiencing a deficit during the preceding 3 years enabled the Board of Directors to take steps immediately to relieve the back-log of papers awaiting publication and to materially enlarge the size of the PROCEEDINGS.

These early fiscal experiences of the IRE and the amounts of money involved in the financial storms which were major problems of the time stand in striking contrast to the amounts now involved in the Institute's operations.

During the year 1956 the total income of the IRE was slightly over $2,400,000, which exceeded expenses by a margin of only about 5 per cent. The total accumulated cash reserve at the end of the year, however, was somewhat less than the current operating expenses for one year.

IRE INCOME AND EXPENSES

	Income	Expenses
1913	$ 850.93	$ 826.50
1926	40,729.77	30,696.54
1936	62,591.44	57,096.65
1946	382,002.98	377,802.82
1956	2,451,237.67*	2,327,469.05*

* Subject to closing audit.

GENERAL CHARACTER OF ACTIVITIES AND POLICIES

Vigor and Enthusiasm

More important than the quantitative expansion of the IRE during the past 45 years is the aspect of its qualitative growth. The true measure of the success of the IRE is in the significance of its labors in serving humanity through the technology of the communications and electronics industry.

In taking stock, therefore, of the progress made by the IRE in fulfilling the vision of its founders, one should ask whether the quality, the aims, and the significance of the Institute's activities are always improving. From a look at the curves that portray the growth of the IRE from 1912 to the present and whether one considers membership, meetings, publications, or the many intangibles of engineering contribution to social welfare, one can only conclude that the IRE is still young and vigorous.

From the beginning of the IRE, its existence has been characterized by the enthusiasm that seems to be an attribute of individual radio engineers generally. The 1930 President, Lee De Forest, gave testimony to this and also reflected his own personality when he said that "A never tiring enthusiasm seems to distinguish the ever young in this game to a far more marked degree than in any other profession."

Cooperation and Good Citizenship

The new awareness of the indispensability of the technical man featuring the postwar era creates a serious challenge to the engineering profession to become acquainted with the reservoir of scientific knowledge, appraise it in the light of the needs of the life of the people, and then by judicious interpretation, develop useful applications. Engineers must themselves take the lead in enlarging the engineer's scope and educate themselves to fit it, thereby not only contributing to their own success, but also ensuring the better fulfillment of their proper function in the society of today and tomorrow.

Quality and Integrity

A clarion call for integrity among radio engineers was sounded by the first President, Robert H. Marriott, in an address delivered before the Institute of Radio Engineers on January 8, 1913, at Fayerweather Hall, Columbia University, in which he said:

"Misrepresentation concerning radio apparatus and radio companies has been, and unfortunately still is, a damper on the advancement of the radio science and art. One of the most commonly prevalent methods has been to provide an able press agent with a company owned or controlled publication, and with the privilege of inserting such statements as may suit his fancy in acquiescent newspapers. Many mysterious and hero-worshipping exaggerations have thus found their way into the press. Thus the public has been at times woefully misinformed. Such a misleading policy is directly opposed to the spirit of the Institute. What is wanted about radio apparatus and engineers is the simple truth."

An appeal for conformity with high standards in engineering relationships was made by the second president of the IRE, G. W. Pickard, in his inaugural address in 1913 on the subject "Engineering Ethics." The incoming President in 1927, Ralph Bown, emphasized further that the growing prestige and professional standing of the IRE must flow from recognized high standards and from the utility of the Institute's output. To command respect the IRE must maintain dignity.

Accepting the Challenge

The postwar expansion of the communication and electronics field resulted, on the one hand in a greater need for service to IRE members and the radio industry, and on the other hand, in the development of IRE activities and facilities for meeting this need. The 1947 Annual Convention, for example, included technical papers in larger numbers and variety as well as an engineering exhibit which was more comprehensive than any that had previously been held.

The IRE Constitution has been revised from time to time in ways which has made it possible for the Board of Directors to take various steps considered necessary for continued successful service to members. These new activities have included the provision of increased financial assistance to Sections, the enlargement of the PROCEEDINGS, the provision of a more adequate centralized staff in the new Headquarters Building in New York, and the payment of travel expenses to the Board meetings of the Board members elected to represent the several Regions of the country.

At a meeting of the Board of Directors early in 1947 the Institute's policy was confirmed as follows: "The Institute welcomes to its membership, in each case in an appropriate member grade, all persons professionally active in the communications and electronic engineering field or interested in that field. The meetings and publications of the Institute are exclusively of a professional engineering nature and will remain of that character. The Institute offers all its members the opportunity to mingle with its professional engineering members, to participate in the technical meetings of the Institute, and to study the scientific and engineering publications of the Institute."

The Executive Secretary of the IRE in 1947 called attention to the ways in which the IRE contributes directly to the opportunities and successes of its members and of the organizations with which they work. Through its Standards Reports and Technical Committee operations the IRE gathers and distributes to its members the most advanced and valuable engineering information, enabling the engineer to avoid "technical blind alleys and to create better products, and thus to provide larger quantities of communications and electronic equipment. The industry is developed, new jobs created, existing jobs become more important and have, it is hoped, greater recognition."

Even though the IRE had seemingly achieved significant stability as a technical society that uniquely served the field of radio communication, electronics, and allied activities throughout the world, the Board of Directors in 1947 established a Committee of the Board under the chairmanship of Raymond A. Heising to survey the Institute's activities in the light of greater possible service to its members and to plan a suitable course in future action.

In 1948 the Planning Committee reported to the Board that it had been developing the idea of Professional Groups in the Institute. The tremendous subsequent development of the Professional Group System described above is striking evidence of the soundness of that proposal.

Keeping Pace With an Expanding Field

The President of IRE for 1925, J. H. Dellinger, in his retiring address at the First National Convention in January, 1926 emphasized the rapidly broadening field of radio engineering by stating that, "A well-known radio engineer, in one of his moments of tribulation said that these days a radio engineer must be all of the following things: an electrician, a physicist, an expert in acoustics, a mechanical engineer, a musician and a diplomat." He stated his belief that the foundations of the services of radio to humanity had been laid, largely by empiricism. Now the task of the radio engineer was to apply the principles of science and technology to advance beyond these foundations and obtain, by both logical and laborious procedure, all of its possibilities for public good.

In considering applications for membership in the IRE, the Board of Directors in 1929 found that the broadening scope of activities in which radio engineers were becoming active was leading to a desire by people in associated fields to become affiliated with the IRE. After careful consideration of the question, the Board concluded that the words "closely allied work" contained in the Constitution of the IRE, as it then stood, should be held to include telephone, telegraph, and cable engineering. While it was planned to publish an increasing number of papers on those subjects, this was not to alter the fundamental interest of the IRE in radio and no change was to be made in the Institute's name.

The Board of Directors has endeavored to keep itself alert to every opportunity for meeting these widening interests of the IRE membership in the radio and electronic field. There was one proposal, however, considered in 1931, which the Board felt that it must reject. This was a proposal that a meeting of the Institute be held at which Dr. Charles P. Steinmetz , a notable radio and electrical engineer, then deceased, might address the audience through a suitably entranced medium. The Board felt that this would be beyond the scope of the Institute's proper function.

At the end of World War I, there had come radio broadcasting and a radio spectrum extending up to 3 megacycles. During the next two decades radio operations extended rapidly using frequencies up to 30 megacycles. At the end of World War II there existed many of the conditions necessary for an "explosive mixture." The spark of public demand for new forms of radio communication services and the allocation to various services of frequencies in the radio spectrum extending as high as 30,000 megacycles constituted one of the important milestones in radio history.

It seems significant that the scope of the field of the radio engineer has widened to the entire universe—as illustrated by the work on radio astronomy as well as other activities of the Professional Group on Antennas and Propagation; and has narrowed to the tiniest fragment of matter—as exemplified by the development of electron microscopy and by the activities of the Professional Group on Nuclear Sciences. Thus, the physicist, the geographer, even the astronomer, the medical investigator, the general scientist, and the industrialist find, in the issues of the PROCEEDINGS OF THE IRE, papers of substantial information and value.

One cannot help wondering what it is that 50,000 technical specialists in the field of radio, communication, and electronics have in common that would cause them to swarm in such numbers. It cannot be entirely the prestige of the membership or the practical utility of publications and meetings. While these are important, there appears to be real significance in the fact that the IRE has developed and put at the disposal of all of the members a technical language of unique value and significance—possibly to a degree unmatched among other professional people.

It may be that the work of the Technical Committees, particularly their Standardization Reports dealing with terms, definitions, and methods of measurement, have had a greater significance than has been appreciated at the time by the many hundreds of engineers who have been participating in this part of the Institute's activity.

One of the original members of the IRE gave an interesting description of the state of the art when the IRE was formed. In his presidential address in January, 1930, Lee De Forest, referring to the formation of the IRE in 1912, said that it was "at a time when our only source of wave energy was the open sparkgap, the only detectors the coherer and anti-coherer, when ten miles of sea were considered wide-open spaces, when all antennas were vertical and a wave-meter was unknown, it required more than a prophet to foresee just what radio communication was destined to become." He then referred by way of contrast to the "vivid example of the wonder which modern radio has achieved in the progress of communication . . . the reporting to the breathlessly awaiting world of the recent flight over the South Pole by Commander (now Admiral) Byrd." This brought a reality to the event and accomplishment which had not been possible twenty years earlier when Peary came out of the North to file his first dispatches five months after he had reached the Pole.

Radio was becoming an essential strand in the life line of communications on land, on the sea, and in the air.

POSTSCRIPT

In Washington, D. C. there is a large and imposing building erected to house the Government Archives. On its facade there appear in bold letters the words, "What is Past is Prologue." It is said that a Washington taxi driver told a visiting sight-seer that this really means, "You Ain't Seen Nothing Yet!" If radio engineers will continue to follow Marriott's injunction to cooperation, there appears to be every reason to believe that, for The Institute of Radio Engineers, also, as expressed in another inscription on the National Archives building, "The Heritage of the Past is the Seed that Brings Forth the Harvest of the Future."

ACKNOWLEDGMENT

In the preparation of this review of the activities of the Institute of Radio Engineers over the past 45 years, the author has consulted various records which are available in the IRE office. Material which has appeared in past issues of the PROCEEDINGS OF THE IRE has been drawn upon freely. This includes news items about IRE organization and Section activities, editorials by Institute officials and others, addresses which have been given at Annual Conventions and on other occasions, and several articles of a historical nature which have appeared from time to time. A list of the principal categories of IRE publications and records which are at the Office of the Institute is given in Appendix I. A list of outstanding historical summaries, including a few other papers that relate to special situations in the Institute's history, is given in Appendix II.

Acknowledgement is due also to a number of people, Founders, persons who have served as Secretary of the IRE, some of the past Presidents, and several others who were familiar with early activities of the IRE as well as the members of the IRE History Committee and members of the IRE staff, from whom helpful information and suggestions have been received. The author gives special thanks for the advice received from E. K. Gannett, Managing Editor, and for his cooperation in the endeavor to make this review as accurate as possible and in preparing the charts, tables and illustrations.

APPENDIX I

PREVIOUS PUBLICATIONS OF SIGNIFICANCE RELATING TO IRE HISTORY

"Silver Anniversary—The Institute of Radio Engineers," Beverly Dudley, *Electronics*, pp. 15–21; May, 1937.

"Institute of Radio Engineers to Act to Secure a Permanent Home," PROC. IRE, vol. 32, pp. 768–769; December, 1944.

"Symposium on the Occasion of the Completion of the

Building-Fund Campaign, Proc. IRE, vol. 33, pp. 620–630; September, 1945.

'Radio Pioneers, 1945." Pamphlet Commemorating the Radio Pioneers Dinner on November 8, 1945, under the auspices of the New York Section of the Institute of Radio Engineers. H. P. Westman, Editor-in-Chief.

'1 East 79 Street—A Pictorial Tour of the Home of the Institute of Radio Engineers," Proc. IRE, vol. 36, pp. 89–100; January, 1948.

'What's Behind IRE?" Proc. IRE, vol. 39, pp. 340–341; April, 1951.

Series of Papers on the occasion of the 40th Anniversary of the Institute of Radio Engineers, Proc. IRE, vol. 40, pp. 514–524; May, 1952

- "The Founders of the IRE"
- "Life Begins at Forty," The Editor
- "The Genesis of the IRE"
- "The IRE in Cohesion or Depression?" Donald B. Sinclair
- "A Look at the Past Helps to Guess at the Future in Electronics," William C. White

"The Institute of Radio Engineers," E. K. Gannett, *General Electric Rev.*, pp. 53–55; March, 1953.

Appendix II

Principal Categories of IRE Records at Office of Institute of Radio Engineers

Proceedings of the IRE, 1912 to 1956 inclusive, Bound Volumes

Annual Reports, 1927–1955, inclusive, Bound Volumes

Annual Reports of the Secretary, 1936–1955, inclusive, Bound Volumes

Year Books and Directories:

- 1914
- 1916
- 1926 to 1932, inclusive
- 1937
- 1946
- 1948 to 1956, inclusive
- 1956–1957

Minutes of Meetings of Board of Directors (originally called "Board of Direction"):

- 1926–1930 Bound Volume
- 1931 Bound Volume—includes Reports of Secretary and Auditor
- 1932–1955, inclusive—Bound Volumes, several years in each volume

Cumulative Indexes

- 1913–1942, inclusive
- 1943–1947, inclusive
- 1948–1953, inclusive

Standardization Reports

Master Index of IRE Definitions

Index to Testing Methods

Index to Abstracts and References

Professional Group Transactions

IRE Student Quarterly

1955 Proceedings of:

- National Symposium on Quality Control and Reliability in Electronics
- Western Joint Computer Conference
- WESCON Computer Sessions

Convention Record

JTAC Proceedings. Volumes, I to XIII, inclusive.

NTSC Final Report

Section Manual

Professional Group Manual (including PG Chapter Manual)

Note: There are in existence a number of complete sets of the Proceedings of the IRE, Volumes 1 to 44, inclusive, not only at the Office of the Institute and in the possession of several individual members of the Institute, but available for public reference at several libraries. Among such library reference sets are those at the Library of Congress, the New York City Public Library, and the Engineering Societies Library in New York City.

Correction

The editors wish to correct an error which appeared in the frontispiece article on page 2 of the January, 1957 issue of Proceedings. Following World War II, President John T. Henderson was the Canadian delegation's scientific advisor to the Atomic Energy Commission of the United Nations, not the United States.

The Effect of Fading on Communication Circuits Subject to Interference*

F. E. BOND†, SENIOR MEMBER, IRE AND H. F. MEYER†, SENIOR MEMBER, IRE

Summary—The statistical performance of radio communication circuits in the presence of interference is analyzed for the cases where either the desired or undesired signal or both are subject to Rayleigh fading over the propagation path. The significant parameter considered is the ratio of mean signal power to mean interference power needed at the receiver for satisfactory performance. When satisfactory performance is required a high percentage of the time the signal power must be greatly increased over the nonfading case, *e.g.*, 99.9 per cent satisfactory operation requires 30 db more signal power in the presence of signal fading whether or not the interference is fading.

The improvement which dual diversity reception offers is discussed for each case. For 99.9 per cent satisfactory operation a practical dual diversity system offers a 14 db improvement over nondiversity for fading signal and fading interference.

INTRODUCTION

ADVANCES in both the theory and the art of communications during the last decade have resulted in systems capable of giving satisfactory performance under many kinds of heavy interference. For every system, however, there will always be a definite amount of a given type of interference that can be tolerated when both signal intelligence and interference contain overlapping spectral components. It is the purpose of this paper to consider how fading modifies the amount of interference that can be tolerated.

For every type of communication system and every type of interference, a definite ratio of mean signal power to mean interference power, $\overline{S}^2/\overline{I}^2=K^2$, may be established which provides the minimum acceptable standard of performance. For example, tests of a particular start-stop frequency shift radio teletype system have shown that an average error rate of 1 error in 20 lines will not be exceeded when the signal to interference power ratio is 8 db, if the interference is caused by another radio teletype transmission with similar characteristics. Therefore, if an error rate not exceeding 1 in 20 lines is an *acceptable* standard for *satisfactory* operation, this standard can be met by establishing 10 log K^2 at 8 db and, provided this value of K^2 is maintained or exceeded, the acceptable standard or better will result. K^2, then, represents the minimum ratio needed for acceptable performance. Most communication systems can be designed to handle a large dynamic range of inputs; thus the absolute magnitudes of signal and interference are of little importance, but their ratio is the primary factor. The quality or standard of performance of the communication system will be some function of mean signal power $\overline{S}^2$ to mean interference power $\overline{I}^2$,[1] *i.e.*, K^2. The exact function depends upon the statistics of signal and interference and the characteristics of the communication system.

At the input to the receiver let the mean received signal power to mean received interference power be represented by R^2. If there were no other considerations, R^2 could be made equal to K^2. In the presence of fading, however, R^2 must be made greater than K^2 to obtain satisfactory performance for a large percentage of time. The larger R^2 is made, compared to K^2, the greater the percentage of time the standard of acceptable performance determined by K^2 will be achieved in the presence of fading. Returning to the previous example, under Rayleigh fading conditions, it may be found that by increasing the power ratio from 6.31 (8 db) to 100 (20 db), an error rate not exceeding 1 in 20 lines will be realized 99 per cent of the time. The ratio R^2/K^2 necessary to give the desired performance in the presence of fading will be designated as Q^2. In the example $Q^2=100/6.31$ (12 db). It should be noted that R^2, K^2, and hence Q^2 are determined from long-term averages.

FADING PHENOMENA

The most common type of fading is caused by propagation of the signal over more than one path followed by recombination of the components from the various paths by vector addition at the receiving antenna. The path lengths vary due to variations in the propagation medium and hence the phases of the individual paths at the receiver tend to vary at random with respect to one another. If the path length differences are small, an appreciable band of frequencies will tend to fade up and down in unison. The greater the path length differences, the narrower the band of frequencies that may be considered as fading together. In the extreme case the differences may be so great that frequencies within the channel carrying the intelligence will fade noncoherently giving rise to the effect known as selective fading. For the purpose of this paper the band of interest will be considered small with respect to the bandwidth of coherent fading, in other words, the nonselective or flat fading case.

From both theoretical considerations and experiment it has been determined that the amplitude of the envelope of this type of fading signal is generally Rayleigh distributed. The Rayleigh function may be de-

---

* Original manuscript received by the IRE, November 19, 1956; revised manuscript received, January 22, 1957.

† Signal Corps Eng. Labs., Fort Monmouth, N.J.

[1] The effect of local receiver noise is discussed later under "The Meaning of I^2."

rived by considering the distribution of the vector sum of a significant number of waves with independent, uniformly distributed varying phases. This well-known function may be expressed by the probability density

$$P(B) = \frac{2B}{b^2} e^{-B^2/b^2} \tag{1}$$

where $p(B)dB$ is the probability that the instantaneous length of the resultant vector lies between B and $B+dB$ when the constant b^2 represents the mean power of the sum of the waves. The instantaneous length of the resultant vector is equivalent to the instantaneous amplitude of the envelope. By integration and substitution of appropriate limits it may be shown that the probability that the instantaneous envelope amplitude will exceed B is given by

$$P(B) = e^{-B^2/b^2}. \tag{2}$$

The Rayleigh distribution will be used here for all fading phenomena.

Fading rates are ordinarily much slower than signal intelligence rates. Therefore, during a number of successive Nyquist intervals corresponding to the intelligence bandwidth the mean powers of signal and interference are quite constant. Under these conditions, fading varies the short-term mean power at the receiver but does not otherwise modify the short-term statistics of signal or interference.

Case I—Fading Signal in the Presence of Nonfading Interference

A fading signal received in the presence of nonfading interference is commonly encountered in practice when an ionosphere propagated signal is being received in the presence of ground-wave interference. The reception of scatter propagated signals under conditions of line-of-sight interference offers another example of this case of fading.

In the notation used here it is desired to find the probability that a signal subjected to Rayleigh fading in the presence of nonfading interference will exceed the desired K^2 as a function of Q^2. It is shown in Appendix I that this probability is given by

$$P(S^2/I^2 > K^2) = e^{-1/Q^2}. \tag{3}$$

The function is plotted as curve 3, Fig.1. It may be seen that at a value $Q^2=1$ (0 db), *i.e.*, with the same signal to interference power $\overline{S}^2/\overline{I}^2$ that would give acceptable operation 100 per cent of the time if there were no fading, acceptable operation can be expected only 37 per cent of the time. To obtain satisfactory operation 99.9 per cent of the time it is necessary to increase the received $\overline{S}^2/\overline{I}^2$ 1000 times (10 log $Q^2=30$ db).

Case II—Nonfading Signal in the Presence of Fading Interference

This is the opposite of Case I. The effect is found in practice when a ground-wave signal is being received in the presence of ionosphere propagated interference. In the case of scatter propagation this is the effect of interference from the scatter signal on reception of a line-of-sight signal.

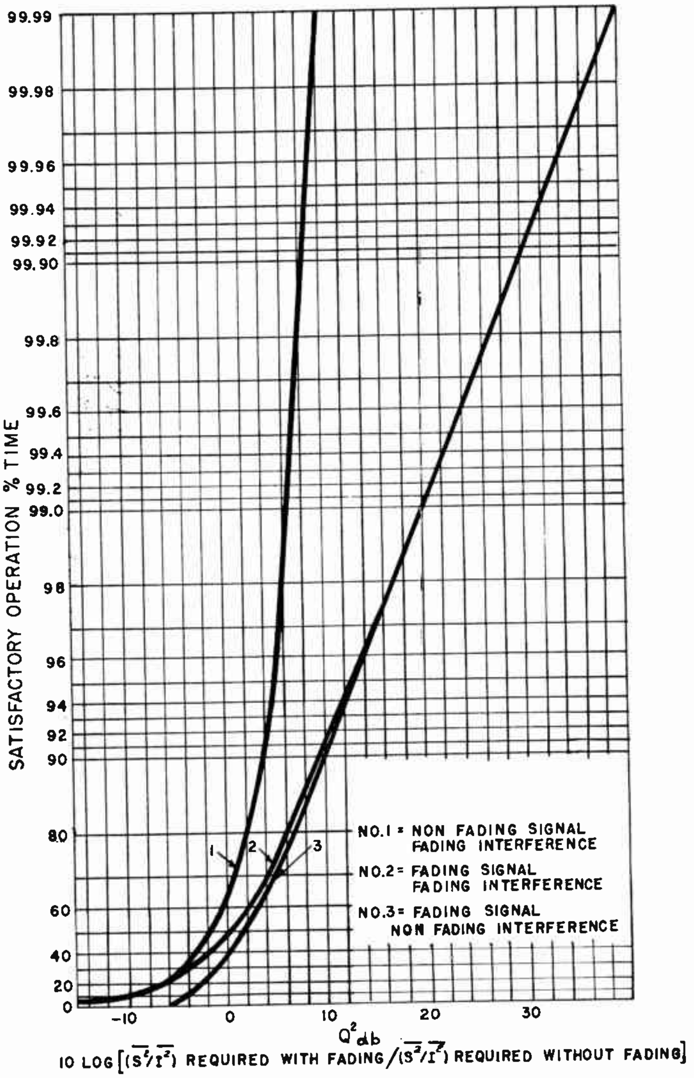


Fig. 1—Nondiversity.

The problem here is to determine the probability that a nonfading signal in the presence of fading interference will exceed the desired K^2 as a function of Q^2. Appendix II shows this probability is given by

$$P(S^2/I^2 > K^2) = 1 - e^{-Q^2}. \tag{4}$$

Curve 1, Fig. 1 is a plot of this case. It may be seen that the results are much more favorable to the desired signal compared to Case I. At a value of $Q^2=0$ db satisfactory operation can be expected 63 per cent of the time and to obtain satisfactory operation 99.9 per cent of the time it is only necessary to increase $\overline{S}^2/\overline{I}^2$ 8 db.

Case III—Fading Signal and Fading Interference

When both signal and interference are subject to Rayleigh fading it is shown by Appendix III that the probability of satisfactory operation is given by

$$P(S^2/I^2 > K^2) = \frac{Q^2}{1 + Q^2}. \tag{5}$$

Curve 2, Fig. 1 displays the results which are seen to be intermediate to the two previous cases. At low values of Q^2 the curve coincides with the curve for nonfading signal and fading interference. At high values of Q^2 (>12 db) the curve coincides with the curve of fading signal and nonfading interference. Therefore, for satisfactory operation greater than 94 per cent of the time it makes negligible difference whether the interference is fading or nonfading provided only that the signal is fading.

DIVERSITY RECEPTION

For many years the techniques of diversity reception have been applied to communication circuits to combat fading. The effects of interference on certain diversity systems will be considered.

A diversity system makes use of two or more independent channels containing the same intelligence and attempts to combine or select a resultant output that provides satisfactory operation a greater percentage of time than a nondiversity system. There are many different types of diversity, *e.g.*, space, time, frequency, polarization, and combinations thereof. Dual, triple, and even higher order diversity systems have found application. Dual diversity employing two independent channels is most common in practice on communication circuits today; this paper will be restricted to this type.

If possible, it would be desirable to choose parameters that would result in anticorrelation of signal fading on the two channels. The laws of nature do not generally allow this condition and an efficient diversity system depends upon independent fading in the two channels.

The method used to combine the outputs from the diversity channels has an effect on the performance of the system. Simple addition will not effect an improvement over nondiversity. One of the oldest types of combining and one that is in wide use today detects the output of each channel and makes a selection in favor of the channel with the highest output. Certain techniques, *e.g.*, common limiting, only partially suppresses the weaker output, while others act as a switch to select the stronger and eliminate the weaker. If interference was not a factor such a system would select the strongest signal. When interference is present the system selects the output with the strongest signal plus interference. The system is, therefore, designated herein as S^2+I^2 diversity. Since signal and interference are uncorrelated and are delivered to the same impedance they may be considered to add as the sum of the average powers. The success of S^2+I^2 diversity depends upon the premise that the channel having the highest signal plus interference has the best probability of simultaneously having the best signal to interference ratio, S^2/I^2. It is self-evident that this will be true when the mean signal power is greater than the mean interference power provided the signal is fading.

More recently, a technique has been devised to combine the outputs of the channels in order to obtain an instantaneous resultant signal to interference ratio greater than that of either channel by itself. Called ratio squared combining,[2] this system can give up to 3 db improvement compared to S^2+I^2 diversity when the outputs of the two channels approach equality and the interference is noncoherent in the two channels. When one output is much lower than the other there is no gain over S^2+I^2 diversity. This technique is not analyzed here, but experimental work on actual circuits has shown a long-term gain over S^2+I^2 diversity of the order of one to one and one-half db.

An idealized diversity system will be postulated here in which the output of the channel having the best S^2/I^2 is selected. Such a system is approached by existing techniques which are suitable for specific types of interference and signals. As will be shown later, under certain circumstances S^2+I^2 diversity becomes equivalent to S^2/I^2 diversity. As an example of a diversity combining system that approaches the S^2/I^2 criterion consider an FSK radio teletype system wherein the train of mark and space pulses can be passed through a diversity detector. In the absence of interference the output will be a slowly varying dc, corresponding to the varying amplitude of the signal as it fades. If the interference is nonperiodic such as noise or speech, the output will contain ac information with possible frequency components up to the bandwidth of the system. An S^2/I^2 measure may then be obtained by comparing the power of the higher frequency ac components to the power of the dc and low-frequency components. Such a system will obviously not work when the interference is periodic as, for example, a sine wave carrier interference close in frequency to the desired signal. The S^2/I^2 diversity system is considered further because heuristically it seems to offer optimum results for diversity when considered under all conditions of interference.

For S^2/I^2 diversity it is assumed that a selection giving satisfactory operation can be obtained when the S^2/I^2 output ratio in one or both channels exceeds K^2. If P is the probability of satisfactory operation for nondiversity, then

$$P_d = 2P - P^2 \tag{6}$$

is the probability of satisfactory operation for S^2/I^2 diversity.

For S^2+I^2 diversity it is assumed that a selection giving satisfactory operation can be made when the S^2/I^2 output ratio in one or both channels exceeds K^2. It is necessary then to find the probability that $S_1^2/I_1^2>K^2$ when $S_1^2+I_1^2>S_2^2+I_2^2$ where the subscripts refer to channels 1 and 2 respectively. Since on the average $S_1^2+I_1^2$ will exceed $S_2^2+I_2^2$ as often as $S_2^2+I_2^2$ exceeds $S_1^2+I_1^2$, the total probability of satisfactory operation

---

[2] L. R. Kahn, "Ratio squarer," PROC. IRE, vol. 42, p. 1704; November, 1954.

will be the same as the probability calculated for $S_1^2/I_1^2 > K^2$.

EFFECTS OF S^2/I^2 DIVERSITY

Case I with diversity of the S^2/I^2 type, *i.e.*, a fading signal and nonfading interference, may be calculated by substituting (3) in (6) which gives the probability of satisfactory operation with diversity as

$$P_d = e^{-1/Q^2}(2 - e^{-1/Q^2}). \tag{7}$$

The curve of this function is plotted as No. 3, Fig. 2.

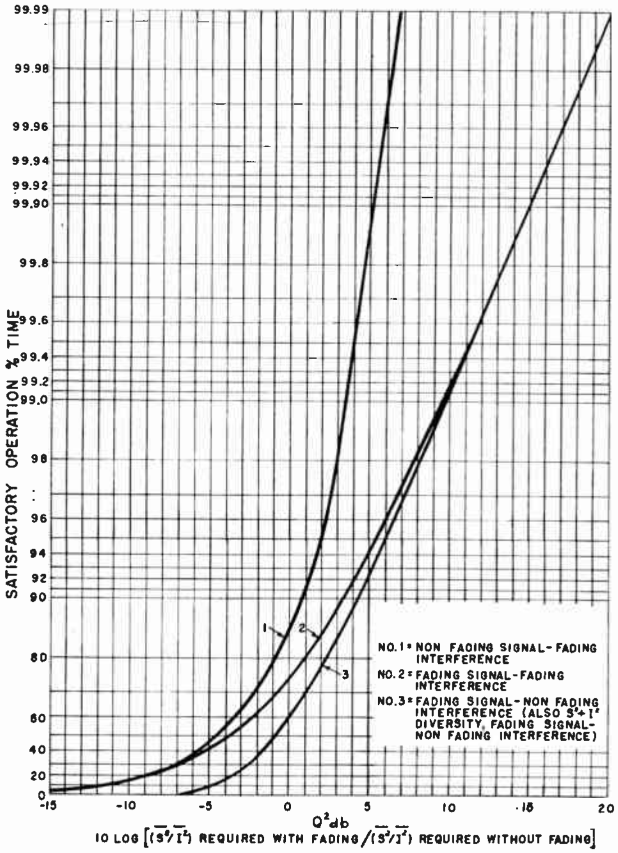


Fig. 2—S^2/I^2 diversity.

Comparing with curve 3, Fig. 1 it may be seen that the improvement due to diversity increases with increasing probability of satisfactory operation and reaches a value of 20 db at 99.99 per cent. This case has been reported previously in the literature with a somewhat different presentation of the results.[3]

Similarly substituting (4) in (6) gives

$$P_d = 1 - e^{-2Q^2} \tag{8}$$

for S^2/I^2 diversity and Case II, a nonfading signal and a fading interference. This function is plotted as curve 1, Fig. 2 and here the diversity gain is much smaller, reaching 2.75 db at 99.99 per cent.

To find the performance for S^2/I^2 diversity in Case III, a fading signal and fading interference, (5) is substituted into (6), giving

$$P_d = \frac{Q^2}{1+Q^2}\left(2 - \frac{Q^2}{1+Q^2}\right). \tag{9}$$

Plotted as curve 2, Fig. 2, it is apparent that the results are intermediate to the other two curves as was found for the nondiversity situation. Again for the condition of high probability of satisfactory operation a fading signal suffers to the same degree whether or not the interference is fading.

EFFECTS OF S^2+I^2 DIVERSITY

In the case of a fading signal and nonfading interference, the interference is an equal constant in both channels. Hence the selection of the channel with the highest S^2+I^2 is equivalent to selecting the channel with the best S^2/I^2. Therefore, S^2+I^2 diversity becomes S^2/I^2 diversity and the results are as given in (7) and curve 3, Fig. 2.[4]

For the case of a nonfading signal and fading interference S^2+I^2 diversity would obviously result in a diversity loss because the channel with the highest S^2+I^2 would have a lower probability of the best S^2/I^2 compared to the channel with the lowest S^2+I^2. The only time that satisfactory operation will be obtained occurs when both channels have an $S^2/I^2 > K^2$. This is the square of (8), or

$$P_d = (1 - e^{-2Q^2})^2. \tag{10}$$

Eq. 10 is not plotted but it should be apparent that better results can be obtained without diversity when this condition exists. It would be possible to arrange the diversity system to select the channel with the lowest S^2+I^2 in which case the results would be the same as S^2/I^2 diversity for a nonfading signal and fading interference and a diversity gain would result.

S^2+I^2 diversity with a fading signal and fading interference is a more complex mechanism. Appendix IV shows that the probability of satisfactory operation is

$$P_d = 2\left[\frac{Q^2}{1+Q^2} - \left(\frac{Q^2}{(1-Q^4K^4)(Q^2(K^2+2)+1)} - \frac{Q^4K^4}{2(K^2(Q^2+2)+1)(1-Q^2K^2)}\right)\right]. \tag{11}$$

---

[3] Z. Jelonek, E. Fitch, and J. H. Chalk; *Wireless Eng.*, vol. 24, pp. 54–62; February, 1947.

[4] Subsequent to the preparation of this paper, a Russian publication on a closely related subject has been brought to the attention of the authors, *i.e.*, V. I. Zhitomirskii, "Determination of the probability of communication interference caused by interfering signals," *Radiotekhnika*, vol. 10, pp. 15–22; 1955.

Zhitomirskii studied the fading signal/fading interference case for for a theoretical dual diversity system. In this system the 4 components S_1, I_1, S_2, I_2 are assumed to be independently available to permit a selection of the diversity channel. Based upon which of the 4 components has the greatest amplitude at a given instant, the diversity channel associated with that component is selected and the probability that S^2/N^2 in the channel will exceed K^2 is computed. The results show that this theoretical diversity system produces a lower percentage of satisfactory operation in the presence of interference than nondiversity operation when $K^2 > 1$.

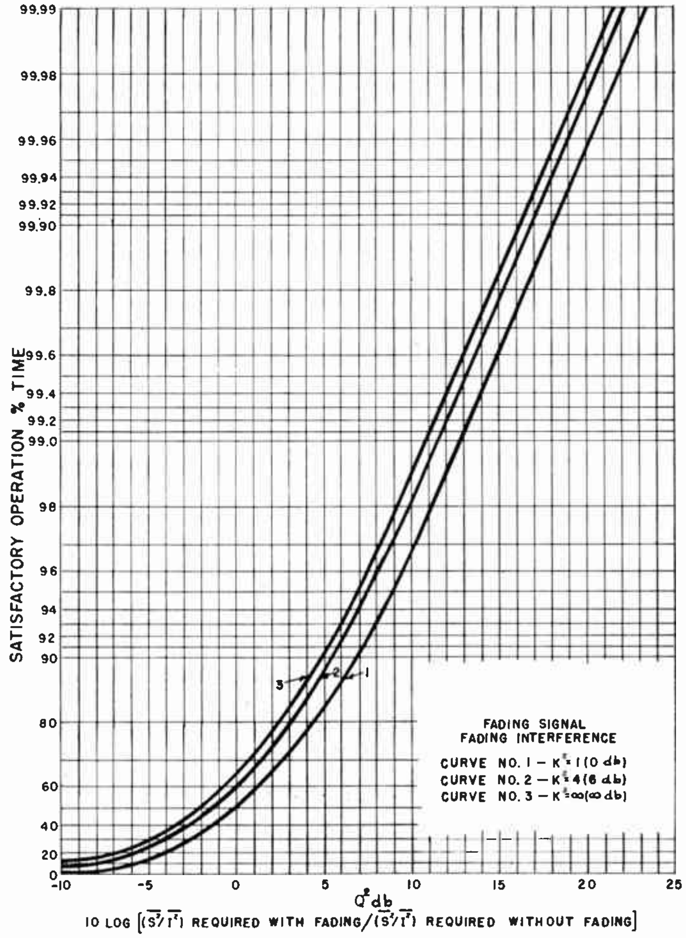


Fig. 3—S^2+I^2 diversity.

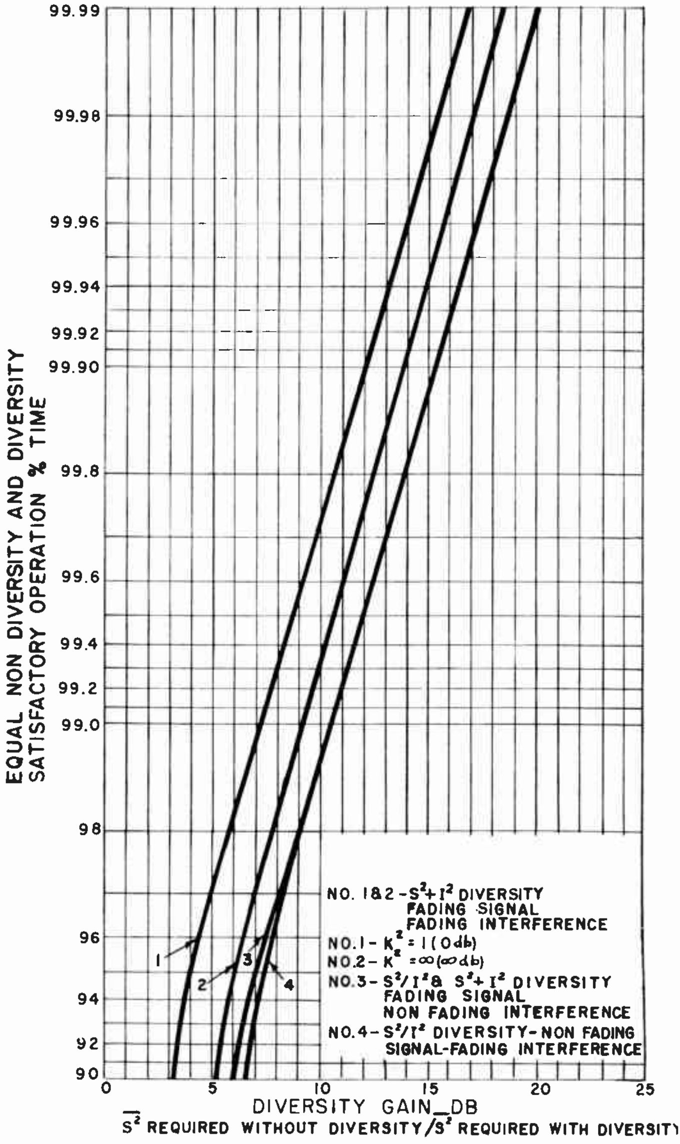


Fig. 4—Diversity gain.

The probability is a function of both Q^2 and K^3. Fig. 3 shows a plot of this function vs Q^2 for values of K^2 equal to 0, 6, and ∞ db. For values of $K^2 > 10$ db the curve approaches the condition $K^2 = \infty$ quite closely. Most communication systems require a value of $K^2 > 10$ db for satisfactory operation and, therefore, the $K^2 = \infty$ curve may be used to a good approximation.

Diversity Gain

Fig. 4 is a plot of the diversity gain vs probability of satisfactory operation from 90 to 99.99 per cent for various diversity systems. Diversity gain is defined as the signal power required with diversity to the signal power required without diversity to give a desired probability of satisfactory operation. For the higher probabilities the diversity gains of the systems maintain essentially a fixed db difference from one another. For the fading signal-fading interference case S^2/I^2 diversity gives 1.5 db more gain than the best S^2+I^2 diversity.

The Meaning of I^2

A tacit assumption was made that I^2 originated completely outside the receiver. In effect this assumes a noiseless receiver. Such an assumption can only be approximated when the mean value of S^2 and I^2 are both very much greater than the equivalent receiver mean noise power N^2. In practice, if K^2 is determined by measurement it will, in general, include the effects of both N^2 and true interference, I_t^2.

In the event of nondiversity, S^2/I^2 diversity, or S^2+I^2 diversity it is apparent that I^2 may be taken as $N^2+I_t^2$ provided I_t^2 is nonfading. For nondiversity or S^2/I^2 diversity with a fading signal and fading interference it has been shown that at the higher probabilities, which are of greatest interest, fading interference acts in the same manner as nonfading interference of the same mean power. Therefore, for this latter situation I^2 may again be taken as $N^2+I_t^2$.

The situation for local noise, fading interference, fading signal, and S^2+I^2 diversity combined is more complex. If I^2 is predominantly N^2 the results will approach closely curve 3, Fig. 2. If I^2 is predominantly I_t^2 the results will tend to follow the appropriate curve of Fig. 3. Remembering that most practical systems will follow the curve $K^2 = \infty$ approximately for fading interference, the question arises as to the difference between this curve and curve 3, Fig. 2. This may be answered by comparing the diversity gain curves Fig. 4, curves 2 and 3. It may be seen that in the region above 90 per cent the two curves are within 1 to 1½ db of each other. Given I^2 then, the results will fall between these limits depending upon the relative contributions of I_t^2 and N^2.

A general observation may be drawn that under all conditions considered there is little difference in performance whether the interference is fading or not fading when the signal is fading and the desired probability of satisfactory operation is greater than 90 per cent. I^2 may be taken for practical purposes as the sum of I_t^2 and N^2. For S^2+I^2 diversity and I_t^2 fading, the use of curve $K^2=\infty$, Fig. 3 will represent conservative practice.

APPENDIX I

Derivation of (3)

The desired distribution is:

$$P\left(\frac{S^2}{I^2} > K^2\right) = P(S > Kb)$$

where:

$$p(S) = \frac{2S}{a^2}\exp\left(-\frac{S^2}{a^2}\right), \qquad a^2 = \bar{S}^2$$

and $I^2=b^2$ (constant envelope power)

$$P(S > Kb) = \int_{Kb}^{\infty} p(S)dS = \exp\left(-\frac{K^2b^2}{a^2}\right).$$

Now if $R^2=a^2/b^2$ and $Q^2=R^2/K^2$ then

$$P\left(\frac{S^2}{I^2} > K^2\right) = \exp\left(-\frac{1}{Q^2}\right)$$

for I^2 constant.

APPENDIX II

Derivation of (4)

The desired distribution is:

$$P\left(\frac{S^2}{I^2} > K^2\right) = P\left(I < \frac{a}{K}\right)$$

where:

$$p(I) = \frac{2I}{b^2}\exp\left(-\frac{I^2}{b^2}\right), \qquad b^2 = \bar{I}^2$$

and $S^2=a^2$ (constant envelope power)

$$P\left(I < \frac{a}{K}\right) = \int_0^{a/K} p(I)dI = 1 - \exp\left(-\frac{a^2}{K^2b^2}\right)$$

$$P\left(\frac{S^2}{I^2} > K^2\right) = 1 - \exp\left(-Q^2\right)$$

for S^2 constant.

APPENDIX III

Derivation of (5)

The desired distribution is

$$P\left(\frac{S^2}{I^2} > K^2\right) = P(S > KI)$$

where

$$p(S) = \frac{2S}{a^2}\exp\left(-\frac{S^2}{a^2}\right)$$

and

$$p(I) = \frac{2I}{b^2}\exp\left(-\frac{I^2}{b^2}\right).$$

Now

$P(S > KI)$

$$= \int_{I=0}^{\infty}\int_{S=KI}^{\infty} p(S, I)dSdI = \int_0^{\infty}\int_{KI}^{\infty} p(S)p(I)dSdI$$

$$= \int_0^{\infty}\left[\frac{2I}{b^2}\exp\left(-\frac{I^2}{b^2}\right)\right]\left[\exp\left(-\frac{K^2I^2}{a^2}\right)\right]dI$$

$$= \left|\frac{\exp - I^2\left[\dfrac{1}{b^2}+\dfrac{K^2}{a^2}\right]}{1+\dfrac{K^2b^2}{a^2}}\right|_0^{\infty}$$

$$= \frac{1}{1+\dfrac{K^2}{R^2}}$$

$$\therefore P\left(\frac{S^2}{I^2} > K^2\right) = \frac{Q^2}{1+Q^2}.$$

APPENDIX IV

Derivation of (11)

Given:

$$p\,(S_i) = \frac{2S_i}{a^2}\exp\left(-\frac{S_i^2}{a^2}\right) \text{ for } i = 1, 2 \qquad (12)$$

$$p(I_i) = \frac{2I_i}{b^2}\exp\left(-\frac{I_i^2}{b^2}\right) \text{ for } i = 1, 2 \qquad (13)$$

and all four variables independently distributed.

The conditional distribution sought is:

$$P\left(\frac{S_1^2}{I_1^2} > K^2 \,\middle|\, S_1^2 + I_1^2 > S_2^2 + I_2^2\right)$$

$$= \frac{P\left(\dfrac{S_1^2}{I_1^2} > K,^2 S_1^2 + I_1^2 > S_2^2 + I_2^2\right)}{P(S_1^2 + I_1^2 > S_2^2 + I_2^2)}. \qquad (14)$$

But the marginal distribution in the denominator is obviously ½. Thus the desired expression reduces to the joint distribution.

$$2P\left(\frac{S_1}{I_1} > K, S_1^2 + I_1^2 > S_2^2 + I_2^2\right)$$

$$= 2\int_0^\infty P\left(\frac{S_1}{I_1} > K, S_1^2 + I_1^2 = v, S_2^2 + I_2^2 < v\right) dv$$

$$= 2\int_0^\infty P\left(\frac{S_1}{I_1} > K, S_1^2 + I_1^2 = v\right) P(S_2^2 + I_2^2 < v)dv$$

$$= 2\int_{u=K}^\infty \int_{v=0}^\infty p\left(\frac{S_1}{I_1} = u, S_1^2 + I_1^2 = v\right)$$

$$\cdot P(S_2^2 + I_2^2 < v)dvdu. \tag{15}$$

The first factor in the integrand is a joint density function $p(u, v)$ which may be evaluated from the densities of S_1 and I_1 with the transformation

$$p(u, v)$$

$$= p(S_1[u, v])p(I_1[u, v])\left|\frac{\partial S_1}{\partial u}\frac{\partial I_1}{\partial v} - \frac{\partial S_1}{\partial v}\frac{\partial I_1}{\partial u}\right|. \tag{16}$$

Now note that

$$v^2 = S_1^2 + I_1^2 \quad \text{and} \quad u = \frac{S_1}{I_1}$$

hence

$$S_1 = u\sqrt{\frac{v}{u^2+1}} \quad \text{and} \quad I_1 = \sqrt{\frac{v}{u^2+1}}.$$

Substituting in (16), using the distributions in (12) and (13),

$$p(u, v) = \frac{2uv}{a^2b^2(u^2+1)^2}$$

$$\cdot \exp\left[-\left(\frac{v}{u^2+1}\right)\left(\frac{u^2}{a^2} + \frac{1}{b^2}\right)\right]. \tag{17}$$

The second factor in the integrand of (15) may be determined by a similar transformation process.

Let

$$W = S_2^2 + I_2^2.$$

Hence

$$I_2 = \sqrt{W - X^2}$$

and $X = S_2$.

Then

$$p(W, X) = p(S_2[W, X])p(I_2[W, X])$$

$$\cdot\left|\frac{\partial S_2}{\partial W}\frac{\partial I_2}{\partial X} - \frac{\partial S_2}{\partial X}\frac{\partial I_2}{\partial W}\right|$$

$$= \frac{2X}{a^2b^2}\exp\left(-\frac{W}{b^2}\right)\exp\left(-X^2\left[\frac{1}{a^2} - \frac{1}{b^2}\right]\right).$$

Then

$$p(W) = \int_{X=0}^{\sqrt{W}} p(W, X)dX$$

$$= \frac{\exp\left(-\frac{W}{b^2}\right) - \exp\left(-\frac{W}{a^2}\right)}{b^2 - a^2}$$

and

$$P(W < v) = \int_0^v p(W)dW$$

$$\therefore P(S_2^2 + I_2^2 < v)$$

$$= 1 - \left[\frac{b^2\exp\left(-\frac{v}{b^2}\right) - a^2\exp\left(-\frac{v}{a^2}\right)}{b^2 - a^2}\right]. \tag{18}$$

Substituting (17) and (18) in (15) integrating with respect to v and using $R^2 = a^2/b^2$ yields

$$2\int_{u=K}^\infty 2\mu R^2\left[\frac{1}{(u^2+R^2)^2} - \frac{1}{(1-R^2)(1+R^2)^2\left(u^2 + \frac{2R^2}{R^2+1}\right)^2} + \frac{R^2}{4(1-R^2)\left(u^2 + \frac{(R^2+1)}{2}\right)^2}\right]du$$

$$= 2R^2\left[\frac{1}{K^2+R^2} - \frac{1}{(1-R^2)}\left\{\frac{1}{(1+R^2)^2\left(K^2 + \frac{2R^2}{R^2+1}\right)} - \frac{R^2}{4\left(K^2 + \frac{R^2+1}{2}\right)}\right\}\right].$$

Then, substituting $R^2 = K^2Q^2$,

$$= 2\left[\frac{Q^2}{1+Q^2} - \left\{\frac{Q^2}{(1-K^4Q^4)(Q^2[K^2+2]+1)} - \frac{Q^4K^4}{2(K^2[Q^2+2]+1)(1-Q^2K^2)}\right\}\right] \tag{19}$$

which is the desired result.

An alternate method of solution was suggested by R. Griel Miller, Jr., of Stanford University in a letter to the authors. It is based on the evaluation of the quadruple integral

$$P\left(\frac{S_1}{I_1} > K, S_1^2 + I_1^2 > S_2^2 + I_2^2\right)$$

$$= \int_0^\infty\int_0^\infty\int_0^\infty\int_{S_1=\max\{KI_1, \sqrt{S_2^2+I_2^2-I_1^2}\}}^\infty$$

$$\cdot p(I_2)p(S_2)p(I_1)p(S_1)dS_1dI_1dS_2dI_2.$$

Microwave Frequency Doubling from 9 to 18 KMC in Ferrites*

J. L. MELCHOR†, SENIOR MEMBER, IRE, W. P. AYRES†, MEMBER, IRE, AND
P. H. VARTANIAN‡, SENIOR MEMBER, IRE

Summary—Frequency doubling in ferrites is theoretically predicted from the equation of motion of the component of magnetization that is along the dc magnetic field direction. The low conversion efficiency previously reported by the authors has been significantly improved. Efficiencies as high as −6 db have now been observed as a result of a lengthy study of geometry effects. For an input power of 32-kw peak at 9 kmc, outputs have been measured as high as 8 kw at 18 kmc. The conversion efficiency is found to depend markedly on the geometry of the ferrite.

INTRODUCTION

IN AN earlier paper,[1] experiments were described which verified predictions that a ferrite excited at high-power level will act as a frequency doubler and generate power at harmonic frequencies. These initial experiments were performed between 3175 and 6350 mc using ferrite disks mounted in cavities and excited with peak-power levels of up to several hundred watts. For this geometry and power level, conversion efficiencies were found to be very low, approximately −60 db.

Since then, measurements have been continued at higher frequencies and higher power levels and significantly improved conversion efficiencies have been observed. Using a fundamental frequency of 9 kmc and a fundamental peak-power level of 32 kw, outputs at 18 kmc were measured to be 8 kw. This represents a doubling conversion efficiency of −6 db. The ability of the ferrite to generate high peak powers constitutes a significant advantage over crystal doublers. This results from the fact that the ferrite effect is a volume one while the crystal depends upon a surface effect.

THEORY

Frequency doubling in ferrites results from the generation of a double frequency component of magnetization along the direction of the dc magnetizing field. The equation of motion for this component of magnetization for the lossless case is written as

$$\dot{m}_z = \gamma(m_x h_y - m_y h_x) \tag{1}$$

where h_x and h_y are the rf magnetic fields inside the ferrite; m_x, m_y, and m_z are the rf magnetizations of the ferrite; γ is 2.8 mc/oersted; and the dc field is applied in the z direction. A solution of the magnetic torque equation for the two components of magnetization normal to the dc magnetizing field yields

$$\begin{aligned} 4\pi m_x &= \chi h_x - j\kappa h_y \\ 4\pi m_y &= j\kappa h_x + \chi h_y \end{aligned} \tag{2}$$

where χ and κ are the usual elements of the tensor susceptibility of ferrites[2] and third-order terms were neglected. No second-order terms exist for these components. In arriving at (2), a time dependence of $e^{j\omega t}$ was assumed for the rf quantities involved. Due to this complex time factor, care must be taken when (2) is substituted into (1). When this is done properly, it is found[1] that the double frequency terms in the magnetization are

$$4\pi \dot{m}_z = -\frac{j\kappa\gamma}{2}(h_x^2 + h_y^2). \tag{3}$$

This equation shows that the rate of change of the z component of magnetization is proportional to the square of the internal magnetic fields. Thus if h_x and h_y vary at a frequency ω and if $h_x \neq jh_y$ (*i.e.*, the magnetic fields are not circularly polarized), then m_z varies at a frequency of 2ω. Since the z component of magnetization has a component oscillating a frequency of 2ω, the ferrite will radiate an electromagnetic wave of frequency 2ω. Also, the output peak power level at the double frequency should vary as the square of the input peak power level at the fundamental frequency. This square law dependence has been found to be essentially correct for input power levels approaching 32 kw. This indicates that the "small signal" theory presented here is substantially correct for these power levels.

The foregoing theory must be extended considerably to take into account the ferrite geometry and the loss in the ferrite. In the experiments it has been found that the conversion efficiency depends markedly upon the ferrite geometry, and the dependence is not one that is amenable to an intuitive analysis. In addition, a number of high-power nonlinear effects[3–5] have been observed

---

* Original manuscript received by the IRE, October 26, 1956; revised manuscript received, January 2, 1957. This work was performed at the Sylvania Mountain View Laboratories, under Signal Corps Contract No. DA 36-039-sc-71053.

† Microwave Eng. Lab., Inc., Palo Alto, Calif. Formerly Electronic Def. Lab., Sylvania Elec. Prods., Inc., Mountain View, Calif.
‡ Microwave Physics Lab., Sylvania Electric Products, Inc., Mountain View, Calif.

[1] W. P. Ayres, P. H. Vartanian, and J. L. Melchor, "Frequency doubling in ferrites," *J. Appl. Phys.*, vol. 27, pp. 188–189; February, 1956.

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

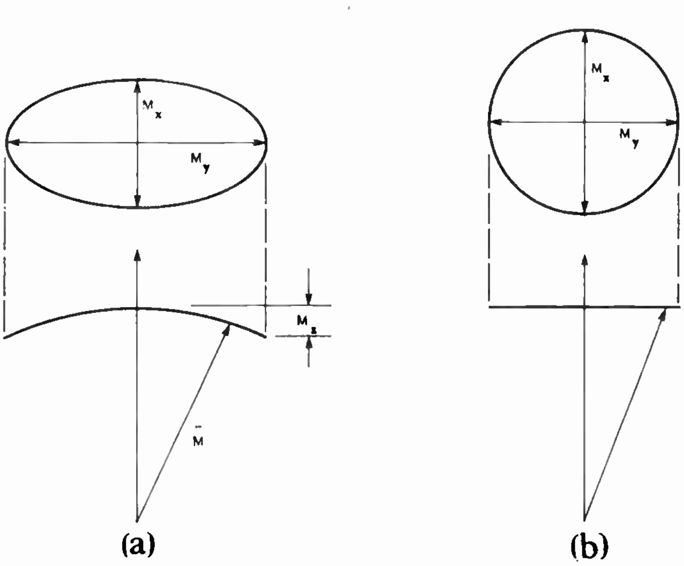
[3] N. Bloembergen and S. Wang, "Relaxation effects in para- and ferromagnetic resonance," *Phys. Rev.*, vol. 93, pp. 77–83; January, 1954.

[4] H. Suhl, "The nonlinear behavior of ferrites at high microwave signal levels," PROC. IRE, vol. 43, pp. 1270–1284; October, 1956.

[5] N. G. Sakiotis, H. N. Chait, and M. L. Kales, "Nonlinearity of propagation in ferrite media," PROC. IRE, vol. 43, p. 1011; August, 1955.

which are not described by this theory and which affect the conversion efficiency in an unknown manner.

Physically, the reason for the generation of the double frequency magnetization is easily seen. The magnetization of the body is precessing about the direction of the dc field. It can be thought of as a constant length vector whose projection on the appropriate plane determines m_x, m_y, and m_z. Since, in general, m_x and m_y are not equal, the magnetization must be precessing in an elliptical orbit as viewed along the dc field direction as shown in Fig. 1(a). But since the magnetization vector must be constant in length, it is easily seen that the projection along the z axis must have a component of rf magnetization at double the frequency of the excitation fields. If m_x and m_y should have the same magnitude (which can occur if the excitation is circularly polarized) then no double frequency output would be expected as shown in Fig. 1(b). This agrees with the results of (3).



(a) (b)

Fig. 1—Precession of the magnetization about the dc magnetic field direction. (a) is for the case $|m_x| \neq |m_y|$ and (b) is for $|m_x| = |m_y|$.

The simplified theory presented here is easily extended to indicate that frequency mixing can also be accomplished using a ferrite. This is seen in (3) if the magnetic field h_x should have two components at different frequencies, then sum and difference frequency terms will be generated. Pippin[6] has elaborated on the implications of this frequency mixing.

EXPERIMENTAL APPARATUS

As has been shown, the requirements for frequency doubling are a magnetized ferrite excited with an rf magnetic field linearly polarized in a plane perpendicular to the dc field. A coupling structure is required which will couple to the harmonic frequency and reject the fundamental frequency. The first structure used in the study of frequency doubling[1] consisted of an S-band cavity to generate high fields in a ferrite disk magnetized perpendicular to its plane, and fastened to one end wall. A wire loop encircled the ferrite, coupling the double frequency energy into a coaxial line. A high-pass waveguide filter eliminated any fundamental frequency energy which was picked up by the coupling loop. Using this setup, double frequency outputs of fractions of a milliwatt were generated from a peak fundamental power of several hundreds of watts. The output power was measured to be very closely a square-law function of the input power over a wide range of power levels. This cavity technique was abandoned because of the added complexity introduced by the requirement that the cavity be matched and tuned to resonance. The ferrite affected both these parameters, making adjustments very difficult.

A very successful configuration for doubling from 9 to 18 kmc is shown in Fig. 2. It consists of a ferrite rod, disk, or slab in an X-band section of waveguide magnetized along the direction of the rf E field. The ferrite generates K-band energy with an electric field polarization in the H plane of the X-band waveguide. A constriction in the E plane of the X-band guide on the generator side of the ferrite prevents the K-band energy from propagating towards the generator. On the load side of the ferrite the X-band waveguide is then narrowed in the H plane through a three-step transition to K-band waveguide, which is parallel but rotated 90° relative to X-band waveguide. All the generated K-band energy must propagate out the K-band waveguide which also filters out any X-band energy. A polystyrene slab in the H plane of the X-band waveguide and located on the generator side of the ferrite acts as a phase shifter for the K-band energy. It is tuned for maximum output from the ferrite.

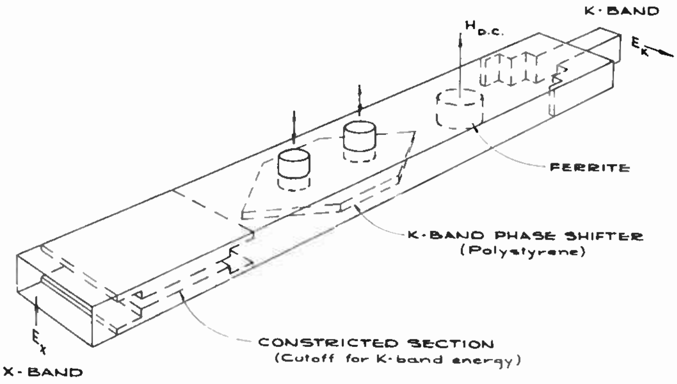


Fig. 2—Microwave plumbing required for the operation of the frequency doubler from X-band to K-band frequencies.

A block diagram of the apparatus is shown in Fig. 3. An isolator is required in the X-band setup to isolate the high vswr presented by the doubler when it is not properly tuned. In taking the measurements three parameters must be adjusted; the 9-kmc tuner, the 18-kmc tuner and the magnetic field.

---

[6] J. E. Pippin, "Frequency doubling and mixing in ferrites," Proc. IRE, vol. 44, pp. 1054–1055; August, 1956.

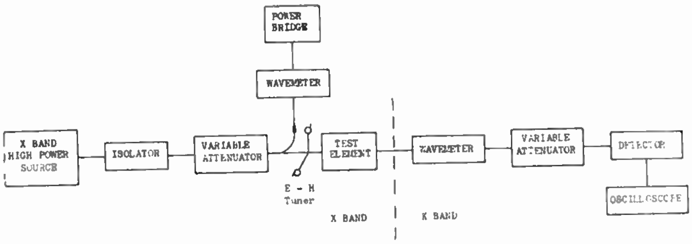


Fig. 3—Block diagram of apparatus for frequency doubling from 9 kmc to 18 kmc.

MEASUREMENTS

Data were taken for each of the ferrite loading configurations indicated in Fig. 4. The thickness, lengths, and heights were varied in each case to maximize conversion efficiency. Also the ferrite material was varied using Ferramic R-1, Ferroxcube 106, and an experimental magnesium aluminate ferrite with a saturation magnetization of approximately 600. Of these, the Ferramic R-1 gave the best conversion efficiency. Using any geometry indicated in Fig. 4 a conversion efficiency of approximately −20 db or better was obtained.

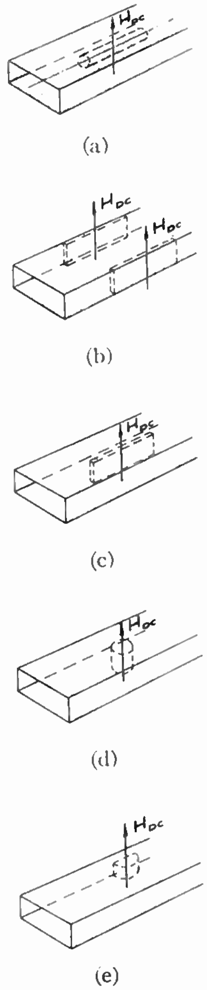


Fig. 4—Ferrite loading configurations used in the experiment. (a) Rod along axis of guide; (b) vertical slabs against sidewalls of guide; (c) vertical slab centered in guide; (d) vertical post centered in guide; and (e) half disk against sidewall of guide.

Data are shown in Fig. 5 for centered posts of Ferramic R-1 as a function of post height for $\frac{1}{4}$- and $\frac{1}{2}$-inch diameters. The data shows that conversion efficiency improves as post height increases and as post diameter increases. For large post heights there does not seem to be an appreciable difference in output when the diameter of the post is changed.

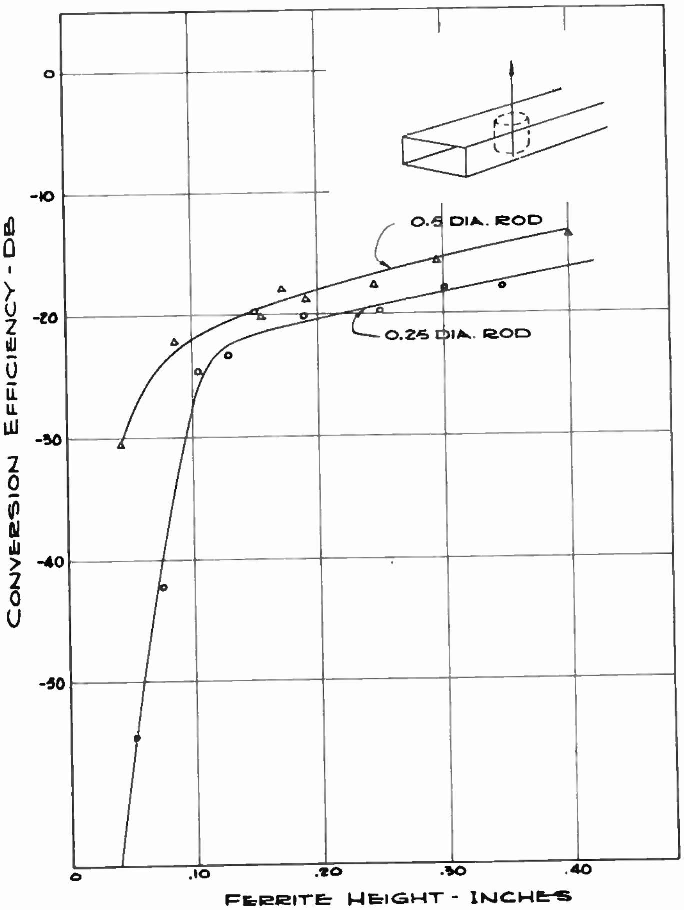


Fig. 5—Frequency doubling conversion efficiency as a function of post height for two post diameters. The input is 32-kw peak, prf—20 cps, and pulse width 0.8 microsecond.

Fig. 6 shows the data for the best geometry of those tried. It is an approximately semicircular segment of a $\frac{1}{2}$-inch diameter 0.20-inch thick Ferramic R-1 disk which is mounted against the side of the waveguide wall. Conversion efficiencies of −6 db were measured repeatedly for a 32-kw peak input. The curve of output power vs average imput power was measured by maintaining a constant peak power level while increasing the pulse repetition frequency. When this is done, it is seen that the peak power output increases slightly and then falls off considerably as the average power is raised. This is a result of heat altering the intrinsic properties of the material.

Doubling in Ferroxcube 106, which has a higher saturation magnetization than Ferramic R-1, was also investigated as a function of increasing average power. The peak output power increased slightly but never approached that obtained using Ferramic R-1. This

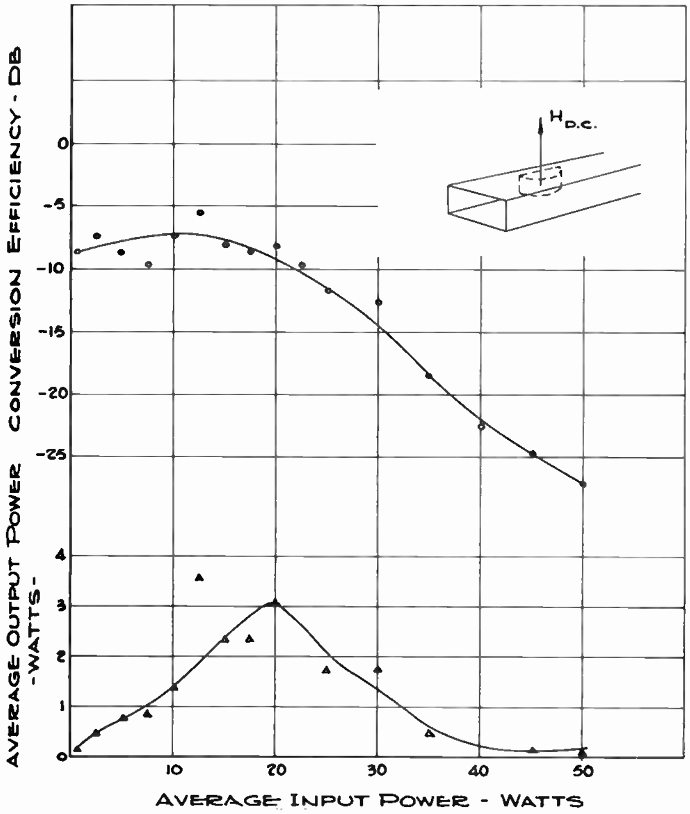


Fig. 6—Frequency doubling conversion efficiency and average power output as a function of average input power. Peak input power is constant at 32 kw. Pulse width is 0.8 microsecond and prf is varied. The geometry is a half disk of ferrite against the sidewall of the waveguide.

may be due to the narrower linewidth of the R-1 material.

The average output power level is also shown in Fig. 6. It is seen that the average power output increases to a maximum of 3 watts at 18 kmc for an average input power of 20 watts at 9 kmc. For greater input power, the output decreases because of heating in the ferrite. In all these measurements, the magnetic field and tuning were optimized at each new average power level. This is necessary since the saturation magnetization of the material is dependent on the temperature and consequently on the average fundamental frequency power.

Fig. 7 shows a curve of the peak power output vs the peak power input, and indicates that the ferrite is operating according to a 1.8 law. At low power levels the doubler acts as a square-law device. This deviation from the square law suggests that a large percentage of energy is being converted to higher order harmonics. Preliminary measurements have verified the presence of these higher harmonics.

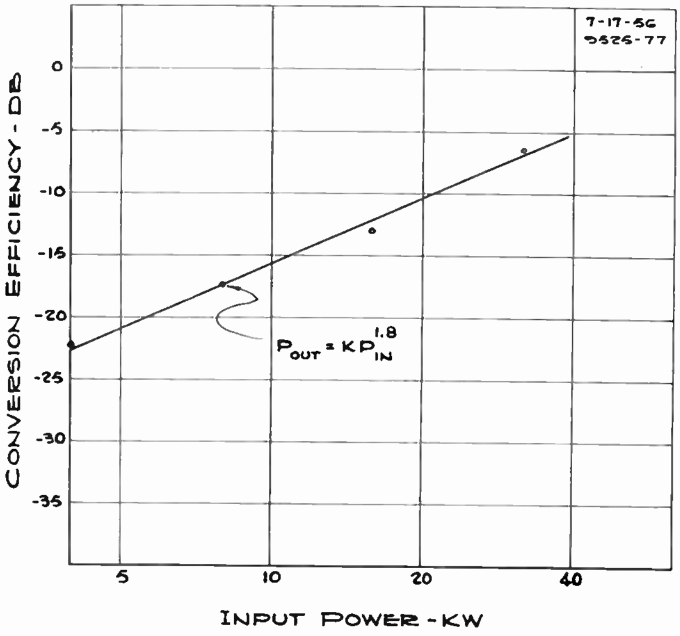


Fig. 7—Conversion efficiency as a function of peak input power. The straight line indicates a 1.8 law for the relation of the output to input peak power. At lower input powers the response is square law. The geometry is a half disk of ferrite against the sidewall of the waveguide.

CONCLUSION

1) At high peak powers, frequency doubling in ferrites can be made more efficient than low-power doubling in crystals. The ferrite will stand higher average power and it is not irreparably damaged if overloaded.

2) The choice of ferrite geometry is extremely important for frequency doubling. The frequency conversion efficiency depends on sample shape and dimensions, as well as on its position in the waveguide.

3) For the geometries studied frequency doubling follows closely a square law response at low power levels and deviates to a 1.8 law response at a conversion efficiency of −7 db.

4) Frequency doubling in ferrites can be a practical means of generating high frequency microwave power.

5) Measurable power can also be generated in higher order harmonics than the second.

ACKNOWLEDGMENT

The authors are indebted to Marlowe Medina and A. B. Howard for making many of the microwave measurements.

Effects of Zero Ferrite Permeability on Circularly Polarized Waves*

B. J. DUNCAN†, MEMBER, IRE AND L. SWERN†, MEMBER, IRE

Summary—**Experimental data is presented describing the propagation characteristics of ferrites in the vicinity of zero permeability as seen by a wave which exhibits a positive sense of circular polarization of its microwave H vector. Detailed results derived in the 9000-mc region are given for a ferrite rod axially located in circular waveguide in which the TE_{11} circularly polarized mode is propagating. A theoretical treatment is also presented which predicts that the behavior of a ferrite rod so located in circular waveguide and biased to the zero permeability region can be made to expel practically all microwave energy from its interior. Experimental results verifying these predictions and an experimental setup used in obtaining a portion of these results are presented in detail. It is shown that similar behavior near zero permeability can be obtained from ferrite rods located in rectangular waveguide. The utilization of ferrites near zero permeability to obtain large nonreciprocal attenuations is discussed for the cases of low, moderate, and high loss ferrites.**

INTRODUCTION

IT HAS BEEN demonstrated by Polder[1] and Hogan[2] that if the imaginary part of the effective wave permeability of a ferrite is negligible at the proper value of magnetic biasing field, the ferrite can be made to exhibit a zero permeability to a wave which has a positive sense of circular polarization[3] (henceforth referred to as a positive wave), and a corresponding nonzero permeability to a wave of a negative sense of circular polarization (henceforth referred to as a negative wave). This would tend to indicate that differential interaction of positive and negative waves with a ferrite can be obtained under certain conditions in the low-field region.

A significant amount of information on field displacement effects of ferrite slabs located in rectangular waveguide near—or adjacent to—the narrow waveguide walls has appeared in the literature.[4–9] No discussion of this particular configuration will be found in this article. Also, some information on the behavior of ferrite rods in circular waveguide operating in the zero permeability region has appeared in the literature[10–13] but has concentrated mainly on the behavior of the negative wave with only limited attention devoted to the propagation of the positive wave. It is this latter wave which principally gives rise to interesting and valuable low-field effects.

A thorough study of the low-field behavior of ferrites on a variety of transmission lines propagating circularly polarized waves has been in progress in the Sperry laboratory.

It is the purpose of this paper to present the more pertinent results derived from this work on ferrites located in circular and rectangular waveguide in the region of microwave H-vector circular polarization.

In particular, the present paper will concentrate on describing the behavior of the positive wave and will also present some of the experimental results on negative wave behavior.

EXPERIMENTAL

The three measurement setups used in this investigation permitted the measurement of ferrite element absorption loss, ferrite reflection and depolarization loss, and waveguide wavelength in ferrite loaded circular waveguide propagating the TE_{11} circularly polarized mode.

Two of these systems are similar to those previously reported[2,14] and will not be described here. It suffices to state that these two systems were designed to permit measurements of losses introduced by the presence of the ferrites, and of ferrite phase shift. Each of the quantities could be measured using these systems, both as a function of externally applied magnetic field H_a and frequency.

The method of measuring the wavelength of circularly polarized waves propagating in a ferrite loaded circular waveguide immersed in a uniform magnetic

---

* Original manuscript received by the IRE, November 6, 1956; revised manuscript received January 18, 1957.

† Microwave Electronics Div., Sperry Gyroscope Co. Div. of Sperry-Rand Corp., Great Neck, N.Y.

[1] D. Polder, "On the theory of ferromagnetic resonance," *Phil. Mag.*, vol. 40, pp. 99–114; January, 1949.

[2] C. L. Hogan, "The ferromagnetic Faraday effect at microwave frequencies and its applications," *Rev. Mod. Phys.*, vol. 25, pp. 253–263, January, 1953.

[3] The notation used here is the one where the positive component is the component which is rotating in the direction of the positive electric current which generates the dc magnetic biasing field.

[4] B. Lax, K. J. Button, and L. M. Roth, "Ferrite phase shifters in rectangular waveguide," *J. Appl. Phys.*, vol. 25, pp. 1413–1421; November, 1954.

[5] S. Weisbaum and H. Boyet, "A double-slab ferrite field displacement isolator at 11 kmc," PROC. IRE, vol. 44, pp. 554–555; April, 1956.

[6] A. G. Fox, S. E. Miller, and M. T. Weiss, "Behavior and applications of ferrites in the microwave region," *Bell Syst. Tech. J.*, vol. 34, pp. 5–103; January, 1955.

[7] C. L. Hogan, "Elements of nonreciprocal microwave devices," PROC. IRE, vol. 44, pp. 1345–1368; October, 1956.

[8] M. L. Kales, "Topics in guided-wave propagation in magnetized ferrites," PROC. IRE, vol. 44, pp. 1403–1409; October, 1956.

[9] B. Lax, "Frequency and loss characteristics of microwave ferrite devices," PROC. IRE, vol. 44, pp. 1368–1386; October, 1956.

[10] A. G. Fox and M. T. Weiss, "Discussion of the ferromagnetic Faraday effect at microwave frequencies and its applications," *Rev. Mod. Phys.*, vol. 25, pp. 262–263; January, 1953.

[11] J. L. Melchor, W. P. Ayres, and P. H. Vartanian, "Energy concentration effects in ferrite loaded waveguides," *J. Appl. Phys.*, vol. 27, pp. 72–77; January, 1956.

[12] P. H. Vartanian, J. L. Melchor, and W. P. Ayres, "Broadband ferrite microwave isolator," IRE TRANS., vol. MTT-4, pp. 8–13; January, 1956.

[13] N. Karayianis, and J. C. Cacheris, "Birefringence of ferrites in circular waveguide," PROC. IRE, vol. 44, pp. 1414–1421; October, 1956.

[14] B. J. Duncan and L. Swern, "Temperature behavior of ferrimagnetic resonance in ferrites located in waveguide," *J. Appl. Phys.*, vol. 27, pp. 209–215; March, 1956.

field will be described in this article. The method to be described applies to a longitudinally magnetized ferrite rod axially located in circular waveguide propagating a TE_{11} circularly polarized mode.

Consider an unmagnetized ferrite located in a section of slotted circular waveguide. If the output end of the slotted line is terminated in a short circuit then, in the presence of an input linearly polarized TE_{11} mode, a large standing wave ratio will be set up in the region of the ferrite. Assuming negligible mode conversion the presence of the slot will not appreciably affect the waves in the vicinity of the ferrite. With the ferrite in the unmagnetized state the wavelength in the ferrite loaded waveguide can be determined by measuring the distance between two adjacent nulls. The wavelength thus obtained will be identical to that for a circularly polarized TE_{11} wave.

However, if the same ferrite is located in circular waveguide propagating the TE_{11} circularly polarized mode and longitudinally magnetized, the wavelength of both positive and negative waves in the section of ferrite loaded waveguide will change with magnetic field. Furthermore, the change will be different for each wave. This change in wavelength will be accompanied by a change in the phase shift of each wave. A measure of the phase shift, correlated with the wavelength at zero magnetic field, permits the determination of the wavelength at any value of H_a.

This can be seen very simply from the following analysis. Let λ_0 represent the ferrite loaded waveguide wavelength for the unmagnetized state. Similarly, let $\lambda_\pm$ be the waveguide wavelength and $\phi_\pm$ the phase shift of a positive and negative wave respectively. Now for H_a equal to zero

$$\lambda_0 = L\frac{360}{\delta}, \tag{1}$$

where L is the physical length of the ferrite in centimeters and δ is the electrical length in degrees of the section of unmagnetized ferrite loaded waveguide.

For H_a greater than zero, and with positive wave propagation, the electrical length δ_+ of the magnetized ferrite, is given as

$$\delta_+ = \delta - \phi_+ \text{ (degrees)}. \tag{2}$$

Hence, λ_+ is given by:

$$\lambda_+ = L\frac{360}{\delta_+} = L\frac{360}{\delta - \phi_+}\cdot \tag{3}$$

From (1) and (3)

$$\lambda_+ = \frac{\lambda_0\delta}{\delta - \phi_+}\cdot \tag{4}$$

Similarly, it can be shown for the negative wave that:

$$\lambda_- = \frac{\lambda_0\delta}{\delta - \phi_-}\cdot \tag{5}$$

The quantities λ_0, δ, and $\phi_\pm$ are easily measurable quantities which can, in general, be obtained with a fair degree of accuracy. It should be noted, however, that ferrite end effects introduce a small error since the wavelength in the waveguide does not change suddenly from its value in the empty waveguide to its value in the ferrite filled region.

THEORETICAL

General

The differential interactions obtainable in the ferrite zero permeability region are directly attributable to the differential permeabilities exhibited by the ferrite to circularly polarized waves.[10,11] However, the magnitude of the interaction of either a positive or negative wave depends not only on the complex permeability of the ferrite but also on its complex dielectric constant. A brief analysis of microwave propagation in a saturated infinite ferromagnetic medium characterized by both a complex microwave permeability and a complex dielectric constant is presented in the following section. This theory is then applied in a general sense to ferrites of finite dimensions in waveguide.

Saturated Infinite Medium

Hogan[2] has shown that for propagation of circularly polarized waves of opposite senses of polarization in an infinite saturated ferromagnetic medium each wave is characterized by a different propagation constant. The equation relating the propagation constant for each of these waves $\Gamma_\pm$ to angular frequency ω, velocity of light c, ferrite dielectric constant ϵ and the effective wave permeabilities $\mu_\pm$ is given as:

$$\Gamma_\pm = \frac{j\omega}{c}(\epsilon\mu_\pm)^{1/2}. \tag{6}$$

Now $\mu_\pm$ and ϵ are both complex. Hence, (6) can be written as

$$\Gamma_\pm = \frac{j\omega}{c}\left[(\epsilon' - j\epsilon'')(\mu_\pm' - j\mu_\pm'')\right]^{1/2}. \tag{7}$$

The quantity $\Gamma_\pm$ can also be expressed in terms of an attenuation constant $A_\pm$ and a phase constant $B_\pm$ as follows:[15]

$$\Gamma_\pm = A_\pm + jB_\pm. \tag{8}$$

By squaring both (7) and (8), and then solving these equations for $A_\pm$ and $B_\pm$, equations relating $A_\pm$ and $B_\pm$ to quantities associated with microwave ferrite behavior are obtained in the following convenient forms:

---

[15] C. L. Hogan, "The ferromagnetic Faraday effect at microwave frequencies and its applications: the microwave gyrator," *Bell Sys. Tech. J.*, vol. 31, p. 1; January, 1952.

$$A_{\pm} = \frac{\omega}{c}\left\{\frac{[(\mu_{\pm}'\epsilon' - \mu_{\pm}''\epsilon'')^2 + (\mu_{\pm}'\epsilon'' + \mu_{\pm}''\epsilon')^2]^{1/2} - (\mu_{\pm}'\epsilon' - \mu_{\pm}''\epsilon'')}{2}\right\}^{1/2} \tag{9}$$

and

$$B_{\pm} = \frac{\omega}{c}\left\{\frac{[(\mu_{\pm}'\epsilon' - \mu_{\pm}''\epsilon'')^2 + (\mu_{\pm}'\epsilon'' + \mu_{\pm}''\epsilon')^2]^{1/2} + (\mu_{\pm}'\epsilon' - \mu_{\pm}''\epsilon'')}{2}\right\}^{1/2}. \tag{10}$$

Eqs. (9) and (10) can be used to describe the microwave propagation in any saturated infinite ferromagnetic medium.

Examination of these equations reveals the factors which determine the interaction of microwave energy with the ferrite. It can easily be seen that if $\mu_+'' \cong 0$, A_+ and B_+ will be zero near that value of magnetic field which renders $\mu_+' = 0$. Since at this same value of field μ_-' is large, B_- will be quite large under these circumstances. On the other hand, if $\mu_+'' \neq 0$, B_+ will never reduce to zero even though $\mu_+' = 0$. From the point of view of differential interaction effects ferrites fall into two main classes: those with $\mu_+'' \cong 0$ when $\mu_+' = 0$ (Class I), and those with $\mu_+'' \neq 0$ when $\mu_+' = 0$ (Class II). The placement of a ferrite in one class or another depends upon the saturation magnetization of the ferrite, its shape and direction of H_a, frequency, and the width of the absorption line. It should be noted that the existence of a dielectric loss does not prevent a ferrite from falling into Class I. As long as $\mu_+' = \mu_+'' = 0$, $A_+ = B_+ = 0$ regardless of the size of ϵ''. It is also significant to note that extremely small values of A_+ and B_+ are obtained in the negative permeability region between $\mu_+' = 0$ and gyromagnetic resonance.

Using (9) and (10) values of $A_{\pm}$ and $B_{\pm}$ were calculated for ferrites closely resembling Ferramics R-1 and H 419; at X band these ferrites fall into Class I. In each case $\mu_{\pm}'$ and $\mu_{\pm}''$ were calculated from equations given by Hogan;[2] in these equations the damping perameter was arbitrarily chosen to be 1.9×10^7 c/sec since in a polycrystalline ferrite no good theoretical method of accounting for effective damping has yet been proposed. While this is probably not the correct value for these ferrites it is sufficiently accurate for its intended use in this paper. The plots of $A_{\pm}$ and $B_{\pm}$ as a function of ferrite internal field H_s for the two mediums are shown in Figs. 1 and 2.

An analysis of these curves shows that practically no propagation of energy associated with a positive wave can occur inside either of the ferrites over a significant range in H_s. However, it is also shown that propagation of a negative wave inside a ferrite can occur. Since A_- is finite, it is expected that the negative wave will be attenuated; the magnitude of the attenuation encountered by this wave will be dependent upon μ_-', ϵ'', μ_-'', and ϵ''.

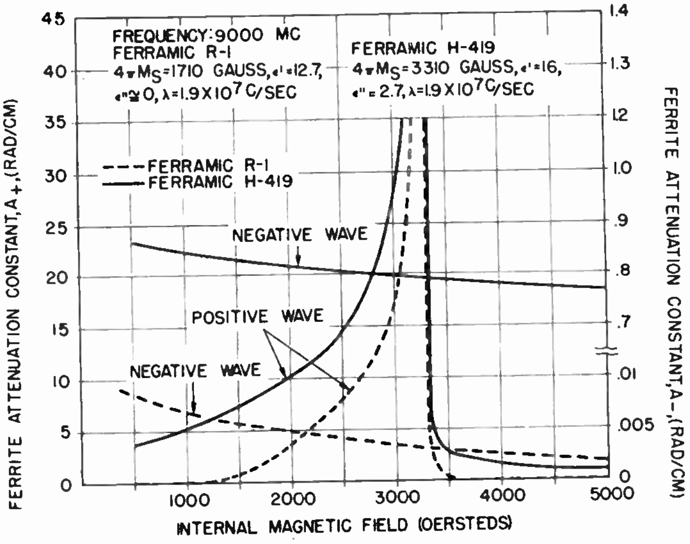


Fig. 1—Dependence of ferrite attenuation constant ($A_{\pm}$) on internal magnetic field (H_s) in ferramics R-1 and H-419.

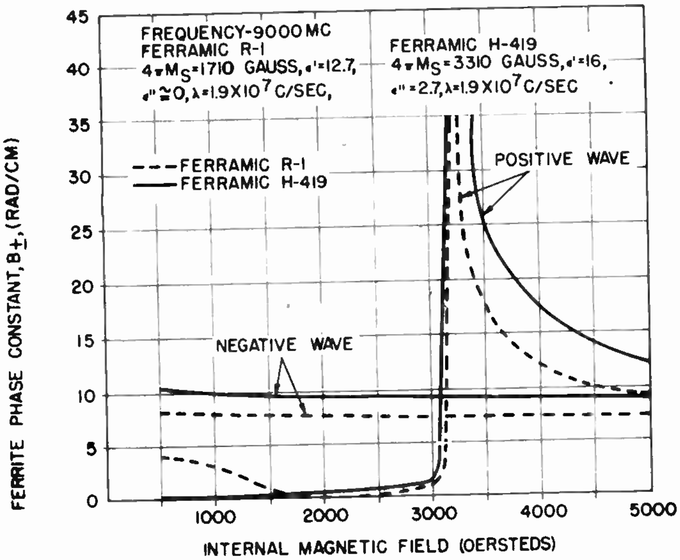


Fig. 2—Dependence of ferrite phase constant ($B_{\pm}$) on internal magnetic field (H_s) in ferramic R-1 and H-419.

At frequencies below approximately 4000 mc the above and similar ferrites may no longer fall into Class I. This stems from the fact that magnetic losses associated with gyromagnetic resonance may be quite large at these frequencies in ferrites characterized by either an appreciable $4\pi M_s$ or a broad resonance linewidth, or both. In addition, when ferrites are operated at low frequencies, resonance may occur before the medium is completely saturated. If this is the case then no true zero or negative permeability effects can take place, and the ferrite may be placed essentially in Class II.

Thus, as pointed out by Hogan[16] the phenomenon of zero permeability is not, in itself, a solution to the low frequency problem in ferrites, since at low frequencies both the positive and negative waves will interact with the ferrite. Only by making both the ferrite $4\pi M_s$ and resonance linewidth extremely small can a ferrite at low frequencies be classified as a Class I material. Of course, at very low frequencies a practical limit is reached beyond which a reduction in $4\pi M_s$ to maintain a low μ_+'' is no longer feasible. This represents the minimum frequency at which operation in the zero permeability region can be affected. No experimental data on Class II ferrites will be included in this article.

Finite Medium—Ferrites in Waveguide

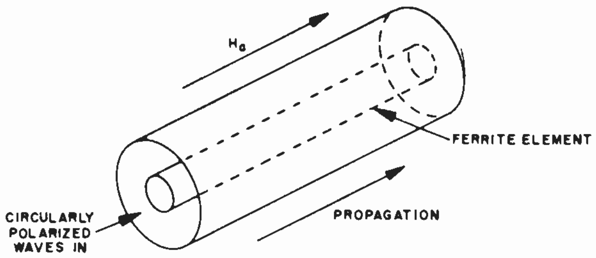
The discussion thus far has dealt exclusively with propagation of circularly polarized waves in a saturated infinite medium. Also, the effects of damping were neglected in all calculations of $\mu_\pm'$. In practice, however, the infinite medium does not exist and, also, damping occurs. Despite these modifications, the above theory can be used in many cases, as those considered herein, to predict qualitative microwave effects which occur in practical applications. In addition, it can be used in many cases to obtain a general rather than a precise description of ferrite behavior under the particular conditions considered.

If infinite medium theory is to be applied as suggested above to the cases treated in this paper then the ferrite must represent only a small perturbation, and it must be located in a region where a sense of circular polarization of the microwave H vector exists. Also, it is required that H_z be replaced by its equivalent in terms of H_a and $4\pi M_s$. Equations relating H_z to these two quantities can be obtained from the literature.[17]

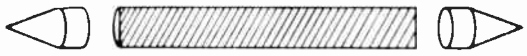
EXPERIMENTAL RESULTS AND DISCUSSION

It is of particular importance to present detailed experimental data on the propagation characteristics of extremely low μ_+'' ferrites in waveguide operating near zero permeability. Even though theory shows that owing to the Poynting vector being extremely small, negligible propagation occurs in the ferrite itself, propagation of microwave energy through ferrite loaded waveguide can readily be made to take place. The behavior of microwave propagation in the ferrite loaded waveguide depends upon the waveguide and ferrite structures. Two cases which are of particular interest will be treated in this article, with the main emphasis on the first of these cases.

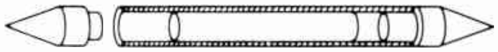
The first of these is the case of a ferrite rod axially located in circular waveguide in which propagation occurs in the TE_{11} circularly polarized mode (Fig. 3). An axial magnetic field of sufficient magnitude to render $\mu_+'=0$ is utilized. Under these conditions it is shown experimentally that almost lossless energy transfer can be accomplished provided a thin ferrite rod is used. It is only required that the ferrite rod diameter be sufficiently small so that, if it were replaced by a metal rod of similar dimensions, propagation in the coaxial line TE_{11} circularly polarized mode could be affected.



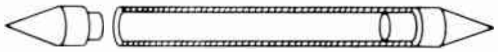
(A) FERRITE LOADED WAVEGUIDE STRUCTURE



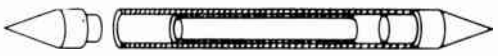
(B) SOLID ROD OF FERRITE



(C) DIELECTRICALLY LOSSY FERRITE ROD INSIDE LOW LOSS FERRITE TUBE



(D) DIELECTRICALLY OR MAGNETICALLY LOSSY MATERIAL INSIDE LOW LOSS FERRITE TUBE



(E) LOW LOSS FERRITE TUBE ENCLOSING FERRITE ROD COATED WITH DIELECTRICALLY OR MAGNETICALLY LOSSY MATERIAL

Fig. 3—Waveguide and ferrite element configurations used for zero ferrite permeability studies.

The prediction that a large portion of the positive wave microwave energy is excluded from the ferrite under these circumstances and propagates almost exclusively in the space around it suggests that this configuration may exhibit certain characteristics similar to those exhibited by a section of coaxial line. To test the validity of this conclusion, a series of experiments was conducted including wavelength measurements in the ferrite loaded guide as previously described. The results obtained on wavelength in waveguide loaded with Ferramics H-419 and R-1, as a function of H_a are shown in Fig. 4. Similar results have been obtained on many additional ferrite samples of various types and diameters.

As suggested in the previous paragraph, for each ferrite λ_+ in the ferrite loaded waveguide passes through that value which characterizes a coaxial line with a metal center conductor whose diameter is equal to that of each ferrite. This is approximately the field at which

---

[16] Private communication between Dr. C. L. Hogan, of Harvard University, and the authors.

[17] C. Kittel, "On the theory of ferromagnetic resonance absorption," *Phys. Rev.*, vol. 73, pp. 155–161; January 15, 1948.

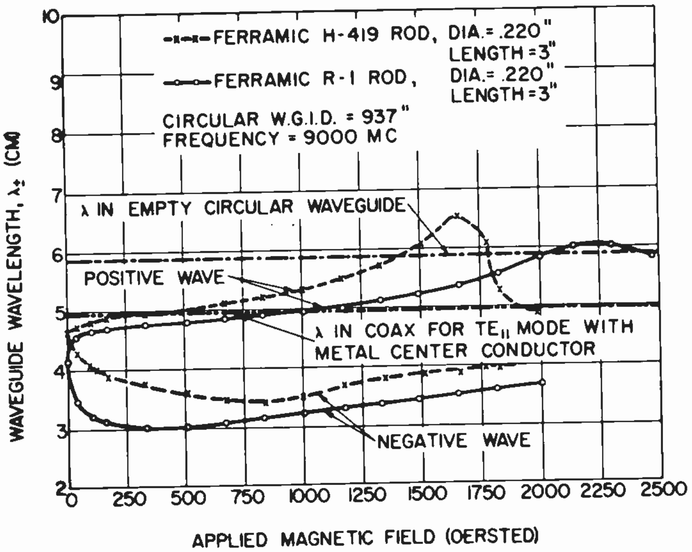


Fig. 4—Dependence on external magnetic biasing field of waveguide wavelength in circular waveguide loaded with ferramic H-419 and R-1.

minimum energy density exists in the ferrite for positive wave propagation. Besides, as H_a is further increased λ_+ eventually reaches and slightly exceeds λ for empty waveguide. This latter condition occurs at fields just below those required to produce gyromagnetic resonance.

The data of Fig. 4 indicates that the positive wave in the zero permeability region is largely excluded from the ferrite and travels in a modified TE_{11} coaxial mode. This is as might be anticipated from infinite medium theory. However, it will be shown later that the wave is not completely excluded since, if it were, it would not be circularly polarized in the vicinity of the ferrite. Thus there can probably only be an incomplete exclusion of this wave; *i.e.*, the tendency of the ferrite to expel the positive wave is not as large as one might anticipate from infinite medium theory, and there is a partial penetration at all fields. Since there is a finite interaction of the positive wave with the ferrite it is possible that perturbation theory might be used to gain a better insight into ferrite behavior in the zero permeability region than can be achieved from infinite medium theory. This is a subject of further investigations being conducted at Sperry. Also, the effects of λ_+ exceeding λ for empty waveguide, and λ_0 for Ferramic H-419 being greater than for Ferramic R-1, shown in Fig. 4 are under investigation.

In spite of the considerations of the previous paragraph it is useful in interpreting the observed ferrite experimental characteristics to regard the ferrite behavior in the zero permeability region as being of a semicoaxial line nature. Data to be presented later will demonstrate the extent to which this picture is valid.

The effect of the ferrite on the negative wave is appreciably different from that of the positive wave. For an H_a of the same value as that required for μ_+' equals zero, μ_-' has some value greater than unity. Also, the complex ϵ of the ferrite may be quite large. Thus it appears reasonable that the negative wave will strongly interact with the ferrite. Such a strong interaction is also clearly indicated by the data in Fig. 4, where it is shown that for negative wave propagation the ferrite loaded waveguide wavelength is much less than for positive wave propagation. One might reasonably expect the differential wavelength $\Delta\lambda$ to be greater in Ferramic H-419 than in Ferramic R-1. The smaller value of $\Delta\lambda$ recorded here for the former is probably owing to the larger mode distortion that might be expected to occur for Ferramic H-419. The anticipated larger mode distortion in this ferrite arise from the larger $\mu_+\epsilon$ product which characterizes it.

Under the most ideal conditions of ferrite diameter and operating frequency it is feasible that the negative wave is almost entirely concentrated inside the ferrite. This can be seen from an analysis of the equation relating effective ferrite rod diameter to its electrical and physical characteristics. It can be shown that a ferrite rod will have an effective propagating diameter a' given by

$$a' = (\epsilon\mu_\pm)^{1/2}a \tag{11}$$

where a is the ferrite diameter and ϵ and $\mu_\pm$ are the quantities previously defined. For a typical ferrite of a diameter approximately one-fourth that of the i. d. of the waveguide in which it is located the effective ferrite propagating diameter and waveguide i. d. will be about the same. Thus, it is to be expected that the ferrite will behave as a waveguide with almost total transmission of microwave energy for the negative wave inside the ferrite in a dielectric mode.

A ferrite will, in general, be characterized by a finite loss. Thus, for propagation of the negative wave in a dielectric mode inside the ferrite, it is anticipated that the wave will be attenuated, the degree of attenuation being dependent upon the dielectric and magnetic lossiness of the medium and the magnitude of the interaction of the negative wave with the ferrite. The attenuation characteristics of a Ferramic H-419 rod (Fig. 3) near zero permeability to positive and negative waves are shown in Fig. 5. The measured differential attenuation $\Delta\alpha$ of the two waves is in excess of 50 db, with only 0.7 db attenuation of the positive wave. The positive wave attenuation (α_+) near zero permeability is small owing to the small energy density of this wave in the ferrite. As in the case of λ_+ in this same region, perturbation theory can possibly be used to calculate α_+ to a reasonable degree of accuracy. Also, some information on α_+ can be obtained from infinite medium theory. However, it should be noted that a true representation of ferrite attenuation in the zero permeability region for the cases considered herein probably cannot be obtained from either perturbation theory or infinite medium theory. Once again, it is convenient to rely on the coaxial line picture to describe the observed results. Using this picture it can be shown that a small microwave energy density exists in the ferrite particularly in the surface region and can, in essence, be considered to

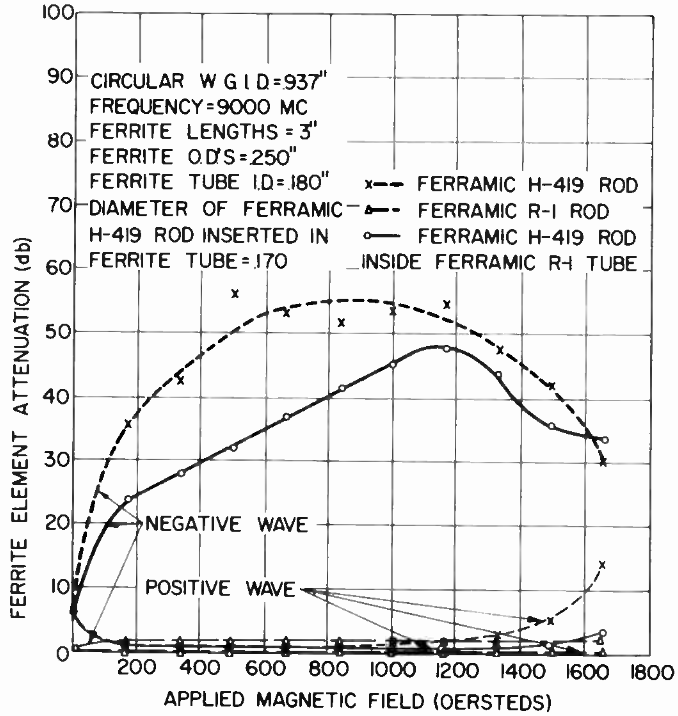


Fig. 5—Dependence of attenuation characteristics of ferrite in circular waveguide on external magnetic biasing field for (a) a solid rod of ferramic H-419, (b) a solid rod of ferramic R-1, and (c) a rod of ferramic H-419 inside a ferramic R-1 tube.

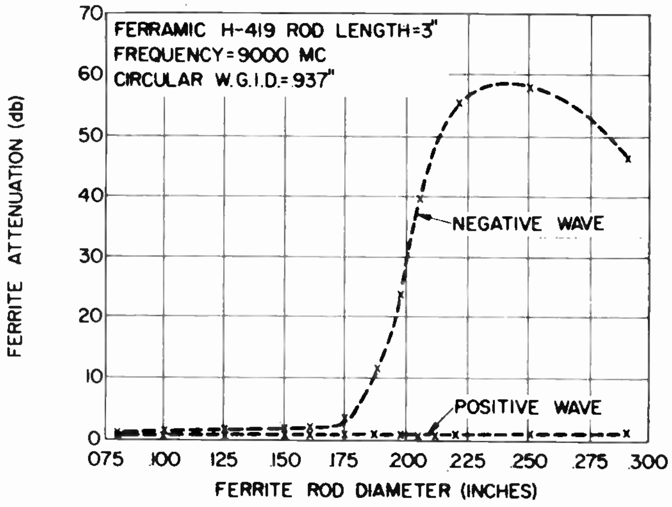


Fig. 6—Dependence on ferrite rod diameter of differential attenuation characteristics of ferramic H-419 in circular waveguide biased near zero permeability.

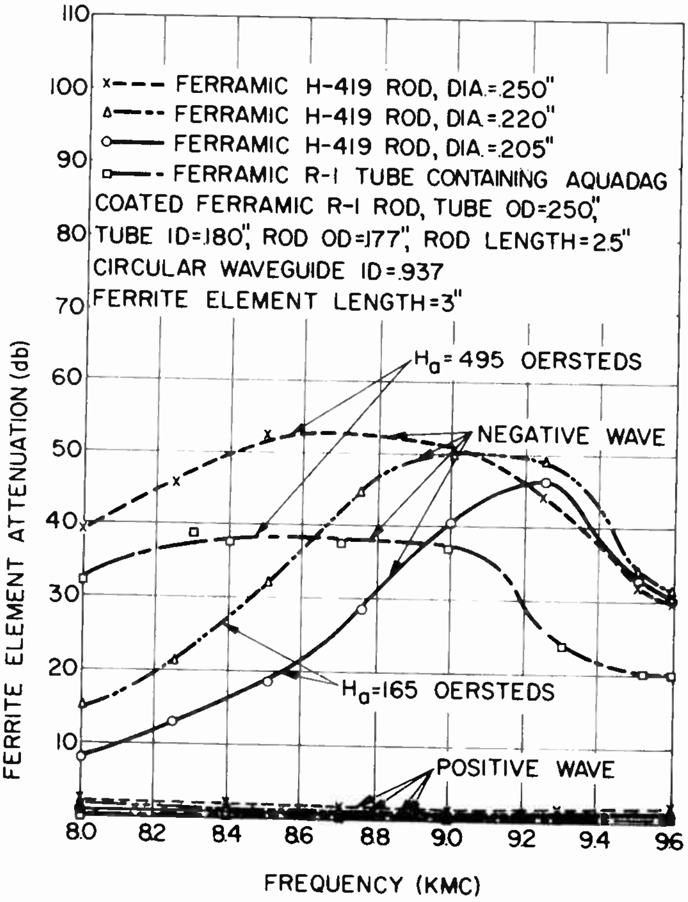


Fig. 7—Dependence on frequency of the differential attenuation characteristics of (a) solid rods of ferramic H-419 of various diameters and (b) a ferramic R-1 tube filled with an aquadag coated rod of ferramic R-1.

correspond to a "skin effect." Correspondingly, the finite α_+ can be considered to be in part a "skin loss" and the depth of interaction a "skin depth." The large negative wave attenuation (α_-) can be attributed to the moderately lossy nature of Ferramic H-419 (*i.e.*, $\epsilon'' > 0$) and the concentration of a propagating wave inside the ferrite.

The dependence of α_+ and α_- on ferrite rod diameter is clearly demonstrated in Fig. 6. It is significant to note the sharp decrease in α_- as the diameter of the ferrite rod is decreased from 0.225 inch to 0.175 inch. This is due to the decrease in microwave energy concentration inside the ferrite. For ferrite rod diameters below 0.175 inch propagation no longer occurs in a dielectric mode and, as a result, $\Delta\alpha$ is drastically reduced for smaller diameter rods.

The frequency dependence of the nonreciprocal attenuation characteristics obtainable in the zero permeability region is demonstrated in Fig. 7. As anticipated from (9) and (10) a rather broad-band effect is obtained provided (11) is satisfied at all frequencies over the band. However, as noted in Fig. 7, the use of an undersized ferrite rod will cause a sharp decrease in α_-. Also, the use of an oversized rod will cause an increase in α_+. Hence, for optimum performance (11) should just be satisfied at a frequency just below the lowest frequency in the desired operating band.

It has been reported previously that the differential attenuation characteristics obtainable in Ferramic H-419 at zero permeability are temperature dependent.[14] Furthermore, it was indicated that this temperature dependence stems chiefly from the dependence of ferrite $4\pi M_s$ and ϵ on temperature. The decrease in $4\pi M_s$ with temperature causes a large decrease in negative wave interaction with the ferrite and hence a decrease in α_-. The increase in ϵ'' causes α_+ to increase. This is chiefly an increase in ferrite skin loss.

Measurements of α_+ and α_- in a Ferramic R-1 rod (Fig. 3) revealed very little attenuation of either wave (Fig. 5). This is due to the practically lossless nature of this ferrite. Thus, even though the negative wave energy density in the ferrite is large it encounters only a very small attenuation; of course, the positive wave is attenuated even less because of its lower energy density.

In order to obtain a more detailed picture of the field distribution inside a ferrite rod in the zero permeability region, a series of experiments were performed with tubes of ferrite filled with various materials. The results of these experiments are described below.

In the first experiment a tube of Ferramic R-1 was filled with a rod of Ferramic H-419 [Fig. 3 (c)]. In this case a large differential loss was obtained, as anticipated, with an extremely low α_+ (Fig. 5). Similar results were obtained when the Ferramic H-419 was replaced by other high ϵ'' ferrites such as Ferramic C-159. The plotted results arise from the fact that Ferramic R-1 is a low-loss ferrite while Ferramic H-419 is characterized only by high dielectric losses. As such, both ferrites are in Class I and tend to exclude a positive wave and enhance the interaction of a negative wave. In addition, the low-loss Ferramic R-1 exhibits an almost undetectable α_+, owing to its practically lossless nature. The data in Fig. 5 verifies the anticipated condition of only a small penetration of the positive wave through the low-loss Ferramic R-1 shell and, therefore, little interaction of this wave with the moderately lossy Ferramic H-419 rod. Conversely, the negative wave penetrates the ferrite shell and interacts strongly with the ferramic H-419 rods. Consequently, it undergoes a large attenuation.

In the second experiment data was obtained on the following four ferrite configurations: a) a tube of Ferramic R-1 coated internally with aquadag, b) a tube of Ferramic R-1 filled with polyiron, c) a tube of Ferramic R-1 filled with an aquadag coated rod of R-1, and d) a tube of Ferramic R-1 filled with a polyiron coated rod of R-1. This experiment was devised to investigate the relative sizes of microwave electric and magnetic fields inside a ferrite rod and to determine the roles played by the ferrite tube and rod in excluding the positive wave energy. The results of this experiment are given in Fig. 8 and will be discussed in the following paragraphs.

Data on α_+ and α_-, each as a function of H_a, for the Ferramic R-1 tube internally coated with aquadag [Fig. 3(a) and (d)] shows some differential attenuation (Fig. 8). However, α_+ for this configuration is quite large. When the aquadag was removed and the tube was filled with powdered polyiron $\Delta\alpha$ was observed to be extremely small and α_+ again was very large. The large α_+ in both cases indicates that the ferrite skin depth exceeds the ferrite wall thickness and, hence, a finite energy exists inside the ferrite tube for the positive wave. The small $\Delta\alpha$ obtained in each case is owing to the small value of the ferrite element $\Delta\mu\epsilon$ product.

The removal of the internal coat of aquadag and the subsequent insertion of an aquadag coated Ferramic R-1 rod inside the ferrite tube [Fig. 3(a) and (c)] results in an appreciable smaller α_+ and an enhanced α_- (Fig. 8). The reduction of α_+ occurs as a result of the rod aiding in the exclusion of the positive wave and, consequently, in the reduction in the ferrite element skin depth. This reduces the interaction of the positive wave with the aquadag and hence reduces the loss. The increase in α_- is due to the ferrite rod enhancing the penetration of the negative wave into the aquadag.

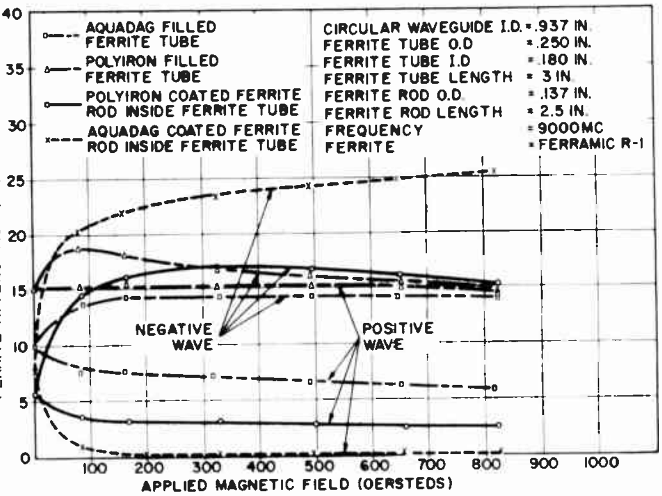


Fig. 8—Attenuation characteristics of (a) a tube of ferramic R-1 filled with aquadag, (b) a tube of ferramic R-1 enclosing an aquadag coated rod of ferramic R-1, (c) a tube of ferramic R-1 filled with polyiron, and (d) a tube of ferramic R-1 enclosing a rod of ferramic R-1 surrounded by polyiron.

Similar tests performed using this same ferrite structure, but with the aquadag coating replaced with powdered polyiron inserted in the region between the ferrite rod and tube [Fig. 3(a) and (e)] revealed a much larger interaction of the positive wave with the ferrite element. This is reflected in the smaller $\Delta\alpha$ and larger α_+ obtained for this case (Fig. 8).

Using the experimental results derived from both the aquadag and the polyiron experiments, coupled with the previously derived theory of ferrite behavior near zero permeability several important conclusions can be derived. It is well known that aquadag is electrically lossy only while polyiron is both electrically and magnetically lossy. Hence, the data in Fig. 8 using aquadag indicates that the microwave electric field is almost totally excluded from a ferrite rod in the zero permeability region. This data alone reveals little or no information on the effects of the ferrite on the positive wave magnetic field. However, the use of the magnetically lossy polyiron indicates a high degree of interaction of the positive wave magnetic field with a ferrite rod even at zero permeability. That this is indeed the case has also been shown theoretically.[18] The magnetic field

---

[18] C. L. Hogan, Progress Rept. No. 2, from Harvard University to AFCRC on Contract No. AF19(604)-1084; August-October, 1955.

quantities inside the ferrite rod associated with positive wave propagation have been calculated and are plotted in Fig. 9. As shown, the microwave magnetic flux B inside the ferrite rod actually passes through zero whereas both the internal microwave magnetic field H and the microwave magnetization M have nonzero values from zero field to resonance. That B actually passes through zero is owing to the 180° phase relationship between M and H. It is also significant to note that B equals zero in a thin ferrite rod at approximately the same applied field as required for μ_+' equals zero in the infinite saturated medium case. Similar results were indicated in Fig. 2 where μ_+' equals zero for Ferramic R-1 is shown to occur in the infinite medium at 1650 oersteds while B_+ approaches zero between 2000 and 2200 oersteds.

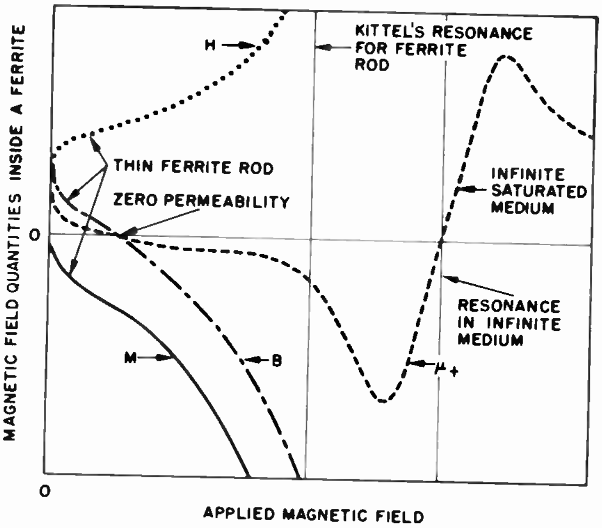
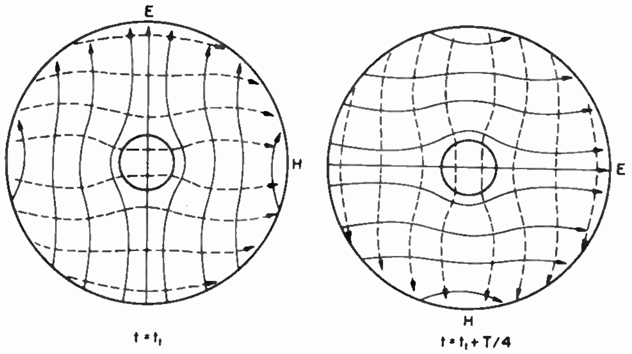


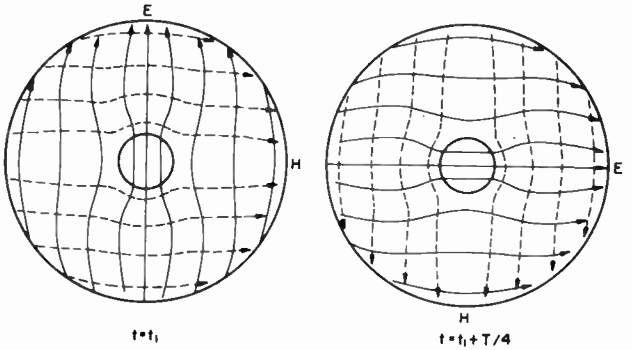
Fig. 9—Typical plot of the dependence of the microwave internal magnetic field (H), flux density (B), magnetization (M), and permeability (μ_+) on H_{dc}.

It is significant to note in Fig. 7 the inherent broadband attenuation characteristics of the ferrite element configuration of Fig. 3(e) when using aquadag. As indicated in the figure α_- remains greater than 20 db and α_+ is less than 0.5 db over the entire frequency range of 8.0 to 9.5 kmc. The magnetic biasing field in this case is approximately 495 oersteds.

By use of the theoretical information and experimental data reported herein an approximate mode configuration in the ferrite loaded waveguide near zero permeability can be derived. Of particular significance in this respect is the data on waveguide wavelength (Fig. 4) and ferrite attenuation (Fig. 8). Since the microwave electric field is excluded from the ferrite and the microwave magnetic field interacts with the ferrite, it is reasonable to expect that these mode configurations will be shown in Fig. 10(a). As shown the microwave magnetic field will be everywhere parallel inside the ferrite rod and everywhere perpendicular to the microwave electric field outside the ferrite except for fringing at the ferrite surface.



(a) POSTIVE WAVE PROPAGATION



(b) NEGATIVE WAVE PROPAGATION

Fig. 10—Probable microwave field configuration in a section of ferrite loaded circular waveguide in which microwave energy is incident in the circularly polarized TE_{11} mode.

The strong negative wave interaction with the ferrite suggests the mode configuration shown in Fig. 10(b). This mode configuration assumes propagation in the TE_{11} circularly polarized mode with negligible higher order mode generation. This mode picture is derived on the basis that the ferrite ϵ is sufficiently large compared with the ferrite μ so as to be the controlling factor in determining the mode configuration. As shown, with $\epsilon \gg \mu$, the microwave H field may actually tend not to concentrate in the ferrite owing to the overriding effect of a large ferrite ϵ.

It is also very significant to examine the above results as related to the manner in which the ferrite near zero permeability affects the microwave H-vector ellipticity across the waveguide. In the absence of the ferrite the axial ratio of the microwave H vector is practically unity over a large cross sectional area near the center of the waveguide (Fig. 11). However, the presence of the ferrite near zero permeability will alter the axial ratio of the microwave H vector, the predicted manner being as also shown in Fig. 11. The increase in wave ellipticity at the ferrite surface can be seen by analyzing the H-vector amplitudes [Fig. 10(a)] at quarter period intervals for any point on the surface. It is immediately evident that the H-vector amplitudes will be different and, hence, the wave will be elliptically polarized.

This predicted field pattern, with an appreciable wave ellipticity at the ferrite surface suggests that there is also some penetration of the positive wave electric field

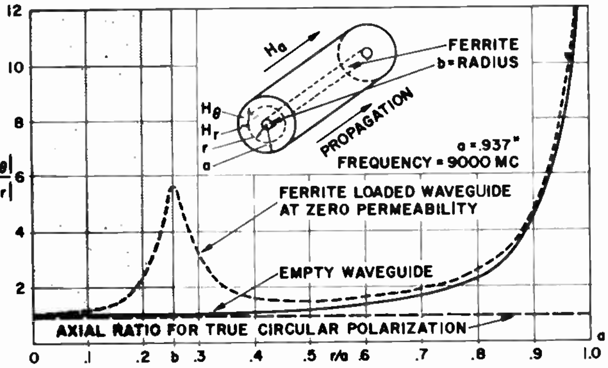


Fig. 11—Axial ratio across a cross section of circular waveguide of the microwave *H*-vector components giving rise to a sense of circular polarization along the direction of propagation of the circularly polarized TE_{11} mode.

into the ferrite surface even in the $\mu_+'=0$ region. This suggestion is confirmed by the data shown in Fig. 8. Using the coaxial line picture, this finite penetration can, in essence, be considered as a "skin effect." It is the presence of this skin effect, and a finite ϵ'', in Ferramic H-419 that in part gives rise to a finite α_+ (Fig. 5). Similarly, if the Ferramic R-1 tube wall thickness is very thin (Figs. 5 and 8) this "skin effect" will serve to enhance α_+. This is due, in this case, to the presence of aquadag near the ferrite surface.

It should also be noted that, in most cases reported herein, brass metal tapers were used on the ends of each ferrite element (Fig. 3). In each case the tapers aided in the reduction of forward wave loss by helping launch the modified coaxial line TE_{11} circularly polarized mode. This served to reduce reflection loss and TM_{01} mode generation. These tapers can likewise be constructed of soft iron plated with a metallic conductor, or of permanent magnet material likewise metallic plated. When so constructed, they tend to reduce the applied field required for $B_+ \cong 0$.

Differential attenuation characteristics similar to those obtained in circular waveguide likewise can be made to exist in rectangular waveguide. It is only necessary that a low μ_+'' and a moderate to high ϵ'' ferrite be located in one of the planes of circular polarization of the microwave *H* vector, and subsequently magnetized to zero positive wave permeability by a magnetic field oriented parallel to the microwave *E* vector.

The results obtained for a pencil rod of Ferramic H-419 in rectangular waveguide are shown in Fig. 12. The data, for a 0.125 inch diameter rod, selected from a large group of ferrites to obtain the largest $\Delta\alpha$, adequately demonstrates the zero permeability effect. As indicated, optimum attenuation characteristics are obtained for an H_a of approximately 2000 oersteds. The difference in the values of H_a for the circular and rectangular waveguide cases are due to the different demagnetizing factors which characterize the two situations. Even more significant differential attenuation characteristics than those shown in Fig. 12 have been obtained without ferrite selection with a low loss—large ϵ—dielectric material located in the vicinity of the ferrite in a manner similar to that suggested by Weiss.[19]

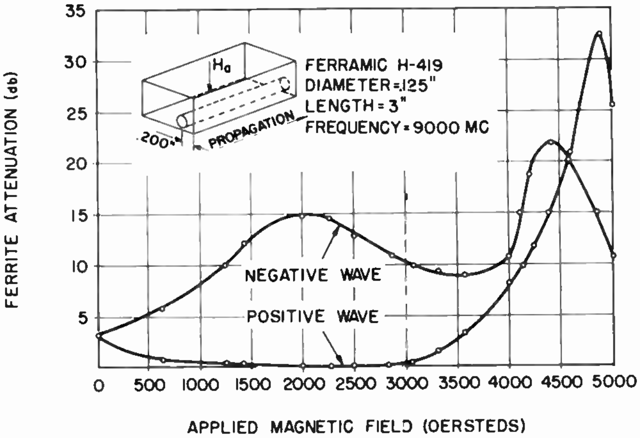


Fig. 12—Attenuation characteristics near zero permeability of ferramic H-419 in rectangular waveguide.

Conclusion

A ferrite located in a region of microwave *H*-vector circular polarization, and magnetized near zero permeability, can, subject to the conditions previously described, be regarded as behaving similar in certain respects to that of a metal; *i.e.*, it can be made to exclude a microwave electric field and to exhibit a skin effect and skin loss. This is especially true for the case of a ferrite rod when used as a center conductor in coaxial line propagating a TE_{11} circularly polarized mode. A ferrite so located can be made to almost completely expel a positive wave, *i.e.*, reduce the Poynting vector inside the ferrite to a very small value, whereas a negative wave can be made to interact very strongly with the ferrite. In fact, the negative wave can be made to propagate in a dielectric mode inside the material.

The above ferrite behavior can be used in conjunction with microwave dielectrically lossy materials to obtain large nonreciprocal attenuations at low applied fields with very low forward (positive) wave loss. This behavior can be obtained over large bandwidths due to inherent broad-band behavior of the ferrite element. These effects can be obtained in both circular and rectangular waveguide. In actuality, they can probably be obtained in any structure exhibiting positive and negative senses of circular polarization in the ferrite region.

Acknowledgment

The authors wish to express their indebtedness to Dr. K. Tomiyasu and Dr. R. E. Henning for their generous contributions, and to Professor C. L. Hogan for his very enlightening contribution in discussions on this subject. Gratitude is also expressed to R. Mangiaracina and P. Iassogna for significant contributions in obtaining much of the experimental data reported herein.

---

[19] M. T. Weiss, "Improved rectangular waveguide resonance isolators," IRE Trans., vol. MTT-4, pp. 240–243; October, 1956.

Binary Data Transmission Techniques for Linear Systems*

M. L. DOELZ†, SENIOR MEMBER, IRE, E. T. HEALD†, AND D. L. MARTIN†, ASSOCIATE, IRE

Summary—The linearity and highly stable frequency characteristics of modern single-sideband equipment make possible improvements in the frequency spectrum utilization and performance of binary data transmission systems.

Problems associated with fully utilizing the binary data transmission potential of an SSB voice channel are discussed. These problems include consideration of frequency and phase stability of the SSB equipment and the propagation media, multipath reception of signals, delay distortion within the voice channel, maximum performance in the presence of noise, and maximum spectrum utilization.

Equipment designed to transmit 3000 bits per second over a SSB voice channel is described. Comparative performance data with standard systems are included.

RECENT DEVELOPMENTS in radio communication systems permit a change in data transmission philosophy, allowing the system design to be primarily concerned with the propagation media without the many compromises previously required to accommodate the deficiencies of the associated radio equipment.

In particular, recent advances in single-sideband transmission techniques provide practical radio circuits of greatly improved linearity and frequency precision. Oscillators with stabilities of approximately 1 part in 10^8 per day are in use, linear amplifiers providing high power with low distortion have been designed, special filters have been developed for sideband separation, and methods have been devised to stabilize the heterodyne frequencies by locking them to precision oscillators.

Single-sideband systems can now provide a linear communication link between two points, and the precision oscillators make it possible to establish time and frequency synchronization at both terminals, permitting the use of improved methods of binary data transmission.

Of the many factors governing the choice of modulation methods for long range high frequency (hf) communications the following are among the most important:

1) Performance in noise and interference.
2) Ability to work through multipath.
3) Spectrum conservation.

All three of these are improved by narrowing the received band to a minimum consistent with the information content and coding of the transmitted information.

The nature of binary transmission is such that the only information which needs to be transmitted is that of MARK or SPACE for each element, since the length of time, shape, or nature of each element is pre-established for a given system. Binary information may be encoded in the plus or minus variations of a single parameter of the signal. The object of the receiving terminal therefore need be only to determine whether a MARK or SPACE has been transmitted.

Optimum filtering of a pulse in the presence of white noise is obtained by multiplying the pulse by a stored weighting function identical in form to the transmitted pulse and coincident with it in received time. Integration of this product over the period of the weighting function yields a result proportional to and having the sign of the transmitted pulse.

Weighting functions most commonly used are those of LC or mechanical filters and necessarily only approximate the desired form. W. H. Wirkler has suggested[1] kinematic and hybrid kinematic and dynamic methods for construction of the receiving weighting function.

The use of kinematic filtering methods provides the designer with complete control of the weighting function. This control has been used to provide matching of the incoming signal for performance in noise and to provide nominally zero crosstalk between properly placed keyed tones in a frequency division system. This allows the construction of practical equipment capable of approaching closely both the theoretical transmission limit of $2B$ measurements per second in band B and the theoretical limit for performance in white noise.[2]

In the system to be described, information is encoded in the transmitted signal in the form of phase reversals or lack of reversals between subsequent elements of a pulse train.[3] A gated resonator is used to accumulate and properly weight plus and minus contributions of the received signal within each pulse. The relative phase of adjacent pulses is obtained by comparing the after-rings of a pair of resonators storing these pulses.[4]

High frequency SSB signals suffer distortion resulting from multipath and from unequal delays across the pass band of the sideband separation filters. To cope with this distortion it is necessary to transmit pulses which are long compared with the distortion expected. Typical hf

---

* Original manuscript received by the IRE, September 4, 1956; revised manuscript received February 1, 1957.

† Collins Radio Co., Burbank, Calif.

[1] An unpublished paper of W. H. Wirkler (April 12, 1949) discussed detection methods applied to telegraph signaling.

[2] B. M. Oliver, J. R. Pierce, and C. E. Shannon, "The philosophy of pcm," PROC. IRE, vol. 36, pp. 1324–1331; November, 1948.

[3] M. L. Doelz, "Special Techniques for Detection in Noise," Collins Eng. Rep. (CER-W272), Burbank, Calif., presented at IRE Subsection, Monmouth County, N. J.; January 21, 1953.

[4] A. A. Collins, "Predicted Wave Signalling-Kineplex," presented at IRE Section, Dallas, Texas; December 16, 1954.

multipath distortions of 1 to 3 milliseconds make pulse lengths of 10 to 20 milliseconds desirable.

Where the radio frequency channels are restricted to a relatively narrow bandwidth, as is the case in hf and wire line systems, frequency division multiplexing offers the greatest data carrying capacity by minimizing the required guard bands at the channel edges, while synchronous detection within the band permits close spacing and independent separation of the multiplexed tones.

A binary communication system has been designed based on these ideas, capable of providing 3000 bits per second of data in an SSB voice channel. The name Kineplex has been adopted for the system because of the kinematic aspect of the filtering and detecting process. The receiving equipment has stored in it detailed information as to the form of the expected signal. This information is used in the detection process to an extent consistent with the characteristics of hf propagation. Data is transmitted by means of multiple tones in the voice band, each tone carrying two independent subchannels. A separate tone is transmitted to provide synchronizing information.

Information is contained in the relative phase of two adjacent pulses (Fig. 1). Subchannel 1 is carried as a phase reversal between adjacent pulses (0° for a MARK and 180° for a SPACE). The second subchannel is carried in a 90°, or quadrature, relation to the first (+90° for a MARK and −90° for a SPACE). The resultant signal has an amplitude of $\sqrt{2}$ times either subchannel and one of the four possible values of phase shown. The output signal for one or for two channels is a tone of constant center frequency with phase discontinuities occurring between pulses. Twenty tones, at different frequencies, are multiplexed to provide the 3000 bit per second capacity. The frequency spacing between tones is determined by the detector characteristics. The tones are at audio frequency and the composite output may be fed directly to the voice channel input of an SSB exciter.

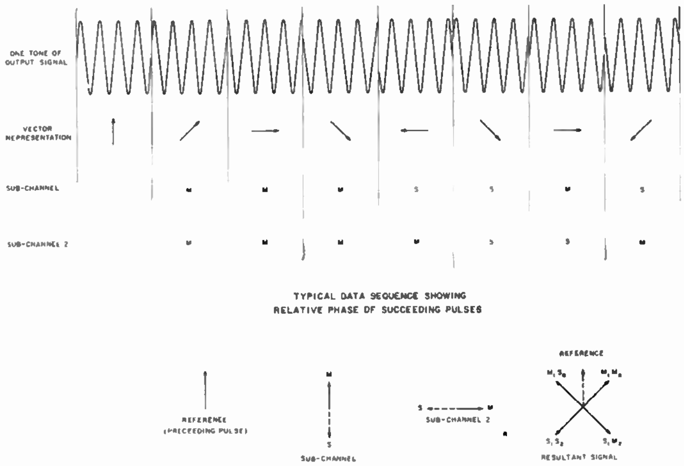


Fig. 1—Phase coding scheme.

At the receiver the SSB equipment translates the received signal back to audio frequency. Detection circuitry at each tone frequency measures the relative phase of successive pulses and reforms the MARK-SPACE code as it appeared at the transmit terminal input.

The method used to make this phase comparison is shown in Fig. 2. Starting at rest, with no previous information in storage, the first received pulse is gated into the high Q resonant circuit, resonator 1. The circuit responds to the signal energy at the resonator frequency and at the end of the received pulse period has an amplitude proportional to the input pulse amplitude and a phase corresponding to the phase of the input signal. The input gate is then closed and the resonator used to store this amplitude and phase information.

The second pulse is admitted to resonator 2 which accumulates the amplitude and phase information associated with the second pulse. At the end of this pulse the

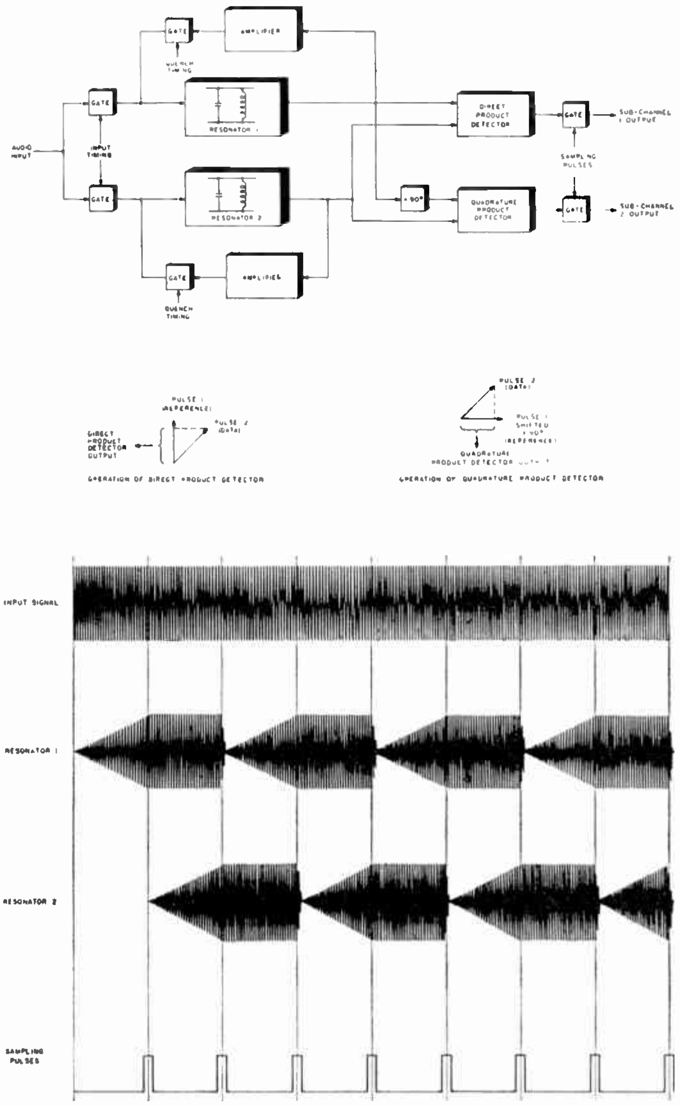


Fig. 2—Detection system.

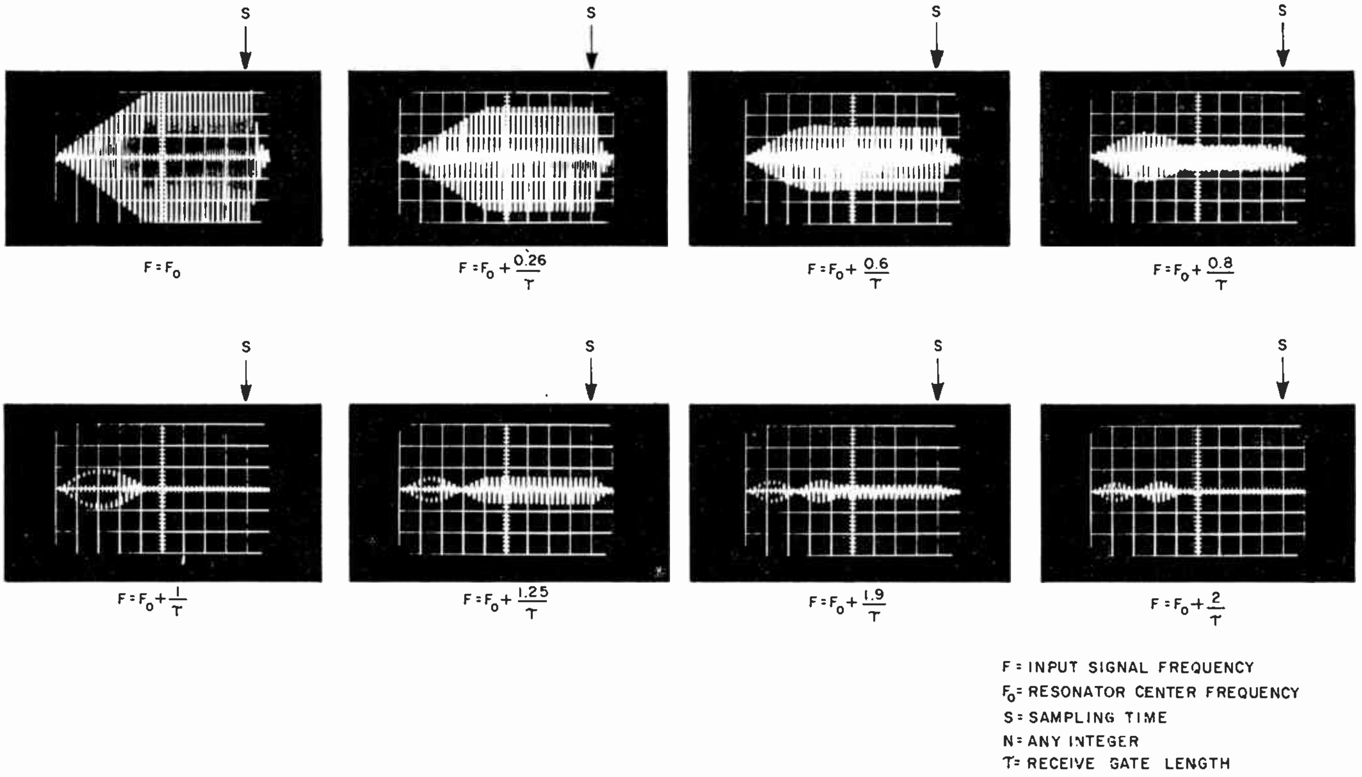


Fig. 3—Effect of variation of input frequency on resonator amplitude at sampling—orthogonal points at f_0+N/γ.

input gate is closed. The two resonators now store the integrated amplitude and phase information associated with the first and second pulses respectively.

At this instant the product detectors which are connected between resonators 1 and 2 are sampled. The direct product detector output is the projection of the second pulse on the first pulse as shown in Fig. 2. It can be noted that signal energy in the second pulse shifted ±90° with respect to the first pulse makes no contribution to the output of the direct product detector.

The quadrature product detector, with the first pulse shifted +90° takes the projection of the second pulse on this +90° shifted reference. This product detector is insensitive to signal energy at 0° or 180° with respect to the first pulse.

Immediately following the sampling pulse the quench gate is opened around resonator 1 causing strong negative feedback to drive the stored energy to essentially zero in a time quite short compared with the transmitted pulse length. The quench gate is then closed and the input gate opened to admit the third pulse to the resonator. The comparisons between the second and third pulses are then made and resonator 2 quenched prior to admitting the fourth pulse. This procedure is continued on down the incoming pulse chain. An auxiliary circuit is used to permit the reference and data pulses alternately to be shifted 90° in the quadrature channel rather than to provide gating to switch reference pulses to one input. It should be noted that each pulse affects only two successive measurements, thus requiring phase continuity over only this period of time.

In determining the frequency spacing to be used between the multiple tones it is necessary to observe an additional characteristic of the detector. As the input frequency is varied from the center frequency of the resonator the phase change during the pulse period causes interference between the instantaneous driving signal and the signal stored in the resonator by earlier contributions. This is shown in Fig. 3. At a frequency separated from the resonator center frequency by the reciprocal of the receive gate length, τ, this interference causes the stored energy to be zero at the time the gate closes. This phenomena is repeated at frequency differences of $2/\tau$, $3/\tau$, $\cdots$, etc. If additional tones are placed at frequencies corresponding to these zeros, or orthogonal points, no crosstalk results between channels. The system could then use tones spaced at frequency intervals corresponding to $1/\tau$ cycles per second (cps) with each tone carrying $2/\tau$ bits per second. Thus in a bandwidth B, $B\tau$ tones could be placed, neglecting guard bands. In time t the potential data rate of the system is then $2Bt$ bits. This corresponds to the maximum number of independent measurements in band B and time t given by Oliver, Pierce, and Shannon.[2]

A part of the potential data rate is used to provide tolerance for reception of signals distorted by multipath and by the unequal delays across the pass band of sideband separation filters. This is accomplished by making the receive gate-open period shorter than the length of the transmitted pulse by approximately 3 ms. This time is used for sampling and quenching the resonators as well as being available for distortion tolerance. As the tone spacing is dependent on the length of the receive gate, the tones become separated more widely than

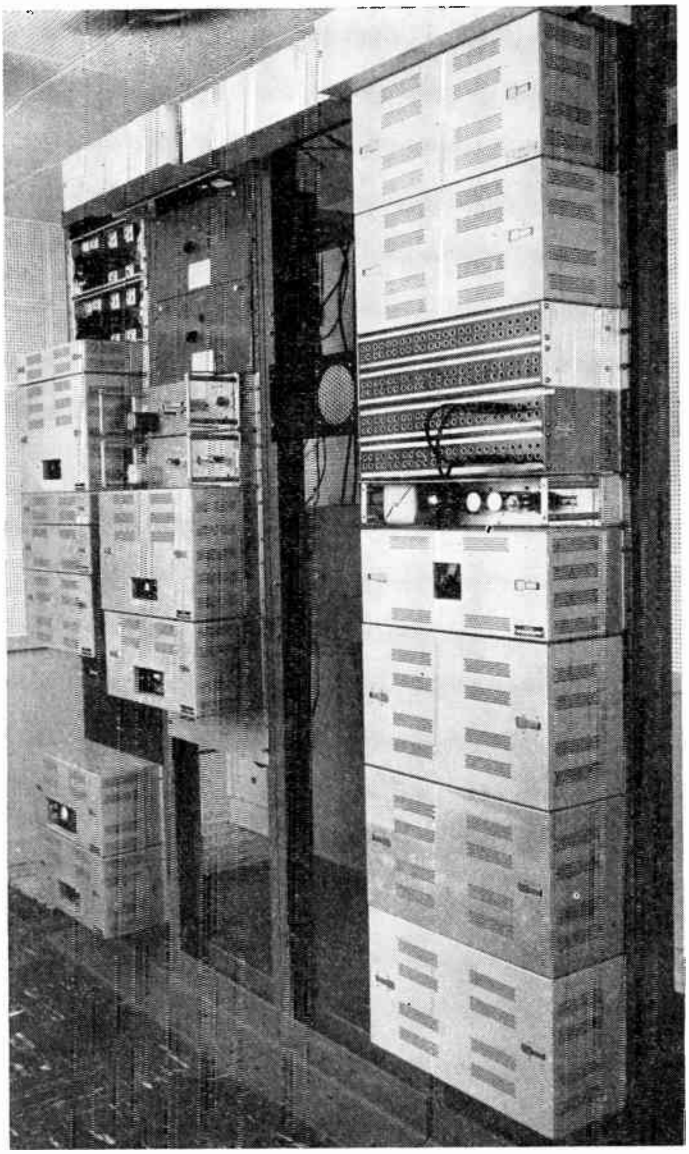
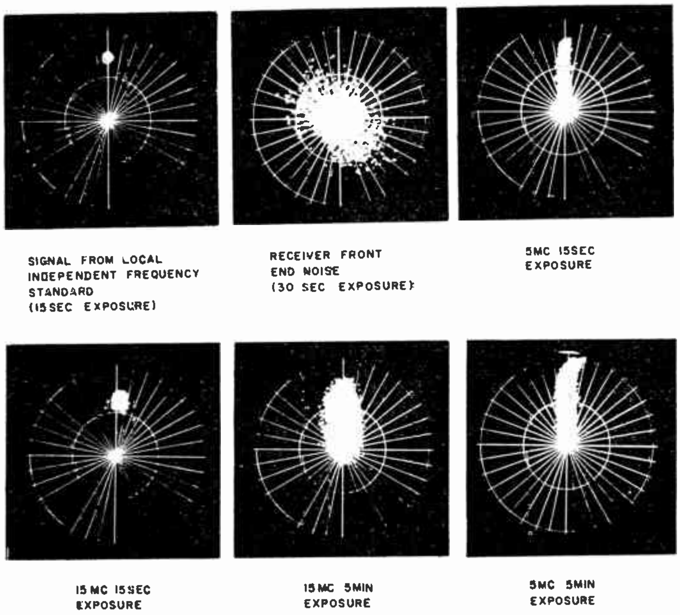


Fig. 8—HF receive terminal.

The WWV carrier transmission may be thought of as a long series of 22 millisecond pulses with successive pulses in phase, providing a maximum output on the direct product detector (Fig. 2) and a zero output on the quadrature product detector. The direct product detector output was connected to the vertical plates of an oscilloscope, and the quadrature product detector output was connected to the horizontal plates. Equal gains were used on the two axes. Z-axis (intensity) modulation was used to turn on the beam only at the sampling time. The number of samples per photograph was then varied by changing exposure time.

The first photograph shows the response of the detector to a signal derived from a local frequency standard. This is of constant amplitude and shows no phase difference between pulses. The second photograph shows the response to amplified receiver noise indicating an essentially random distribution of amplitude and phase. Typical samples of received data are shown in the remaining photographs.



SIGNAL FROM LOCAL INDEPENDENT FREQUENCY STANDARD (15SEC EXPOSURE)

RECEIVER FRONT END NOISE (30 SEC EXPOSURE)

5MC 15SEC EXPOSURE

15MC 15SEC EXPOSURE

15MC 5MIN EXPOSURE

5MC 5MIN EXPOSURE

Fig. 9—Polar display of incremental phase shift.

Especially important is the shape of the pattern of samples. Additive noise would cause the X-axis deflection to be independent of signal amplitude on the Y axis and result in an essentially rectangular pattern. Phase shift in the propagation path due to rapid path length changes, etc., would result in phase shifts which would tend to be independent of signal amplitude. This would cause the pattern to lie along lines of constant phase shift in a pie-shaped segment.

As may be seen, the test patterns are narrow and nearly rectangular, indicating good relative phase stability between adjacent pulses.

Test transmissions of the data system have been carried out over the path between Cedar Rapids, Iowa, and Canoga Park, California. The received audio frequency signals are transmitted over approximately 30 miles of class C telephone circuit to the Burbank laboratory before detection. Tests to date have used teleprinter data to provide input and output signals. Twelve channels operating on six adjacent tones have been used for test and evaluation purposes. Forty channel circuit loading has been tested using four data channels plus 18 additional unkeyed tones. Preliminary results have been favorable and confirm conclusions based on system characteristics and propagation measurements.

BIBLIOGRAPHY

[1] Davey, J. R., and Matte, A. L. "Frequency-Shift Telegraphy-Radio and Wire Applications," *Bell System Technical Journal,* Vol. 27 (April, 1948), pp. 265–304.

[2] Nyquist, H. "Certain Factors Affecting Telegraph Speed," *Bell System Technical Journal,* Vol. 3 (April, 1924), p. 342; also "Certain Topics in Telegraph Transmission Theory," *Transactions of the AIEE,* Vol. 47 (April, 1928), p. 617.

[3] Hartley, R. V. L. "Transmission of Information," *Bell System Technical Journal,* Vol. 7 (July, 1928), p. 535.

[4] Doelz, M. L. "Predicted Wave Radio Teleprinter," *Electronics,* Vol. 27 (December, 1954), pp. 166–169.

[5] Doelz, M. L., and Heald, E. T. "Predicted Wave Radio Teletype System," 1954 IRE CONVENTION RECORD, Part 8, pp. 63–69.

[6] Collins, A. A., and Doelz, M. L. "Predicted Wave Signalling (Kineplex)," Collins Technical Report CTR-140, Burbank, Calif., (June 20, 1955).

Temperature Dependence of Junction Transistor Parameters*

WOLFGANG W. GÄRTNER†, MEMBER, IRE

Summary—**Based on existing design theories and the known temperature behavior of the semiconductor properties, the temperature variations of transistor characteristics are calculated for four representative types. The results, expressed in terms of four-pole parameters and equivalent circuits, may serve as a guide line in transistor design and temperature compensation of transistor circuits.**

I. INTRODUCTION[1]

THE TEMPERATURE variation of the electrical characteristics of transistors has always been a major problem. Guide lines are needed for proper temperature compensation in transistor circuits and for the proper design of types which will operate at substantially higher temperatures than present day units. The question has been given some consideration.[2–7] It is the purpose of this paper to point out additional phases of the general problem and provide some of the needed theoretical background.

In view of the complexity of the problem, a theoretical approach was developed as a first step. Such an approach shows what temperature dependence should be expected of the semiconductor itself, and helps to separate it from any influence which may be due to the construction of the particular type under investigation.

A theoretical attack carries with it the danger of too great generality. We tried to avoid this by calculating in detail four representative types instead of permuting all possible structures and material properties. Graphical presentation of the results has been used for all quantities.

The temperature T which appears throughout the paper is the junction temperature, or better, the temperature of the whole semiconductor. It depends on the ambient temperature and the heat dissipation of the unit which is a function of internal and external mounting, structure and material of the encapsulation, and cooling measures.

Several sets of parameters have been used to characterize the transistor. This has become necessary because the final h parameters are too complicated for their temperature behavior to be understood directly. With the help of the intermediate steps of the y and h' parameters, however, the picture becomes much clearer.

II. DESIGN DATA

The theoretical expressions for the transistor characteristics are generally too complicated for their temperature behavior to be obvious. Four types of transistors, which are believed to be representative of many audio transistors, have been chosen, therefore, as examples and will be discussed in detail. On the basis of their analysis, conclusions may be drawn as to the temperature behavior of transistors in general. The four types mentioned are: *a germanium p-n-p alloy junction transistor, germanium n-p-n junction transistors of the regular grown and the rate grown types, and a silicon n-p-n grown junction transistor.* Their assumed structures and the room temperature values of their material properties and electrical characteristics are given in Figs. 1 and 2, opposite, and in Table I on pp. 664–665. The electrical characteristics refer to the semiconductor structure itself. Parasitic influences have been neglected.

III. DESIGN THEORY AND EQUIVALENT CIRCUITS

Design theory provides the connection between the physical properties of the transistor and its electrical behavior. Electrical characterization of the device may be achieved through four-pole parameters or equivalent circuits together with some additional quantities like collector reverse current or alpha cut-off frequency. To provide a good understanding, we shall calculate the temperature dependence for several representations.

The design theory[8–11] yields directly the y' parameters of a transistor model which accounts for diffusion effects and depletion layer capacitances and neglects the base spreading resistance r_b'. These parameters are defined by (see Fig. 3)

$$\begin{aligned} i_e &= y_{11}'v_e + y_{12}'v_c \\ i_c &= y_{21}'v_e + y_{22}'v_c. \end{aligned} \tag{1}$$

---

* Original manuscript received by the IRE, March 15, 1956; revised manuscript received, December 27, 1956.

† Signal Corps Eng. Labs., Fort Monmouth, N. J.

[1] A considerably more detailed discussion of the problem is contained in SCEL Tech. Memo. No. 1849.

[2] A. Coblenz and H. L. Owens, "Variation of transistor parameters with temperature," PROC. IRE, vol. 40, pp. 1472–1481; October, 1952.

[3] R. F. Shea, "Principles of Transistor Circuits," John Wiley and Sons, New York, N. Y.; 1953.

[4] E. Groschwitz, "Zum theoretischen Temperaturkoeffizient von Halbleitern," *Z. Angew. Phys.*, vol. 7, pp. 245–249; May, 1955.

[5] E. Groschwitz, "Zum theoretischen Temperaturkoeffizienten eines Flächentransistors," *Z. Angew. Phys.*, vol. 7, pp. 280–282; June, 1955.

[6] A. W. Lo, *et al.*, "Transistor Electronics," Prentice-Hall, Englewood, N. J.; 1955.

[7] R. J. Kircher, "Properties of junction transistors," IRE TRANS., vol. AU-3, pp. 107–124; July–August, 1955.

[8] W. Shockley, "The theory of p-n junctions in semiconductors and p-n junction transistors," *Bell Sys. Tech. J.*, vol. 28, pp. 435–489; July, 1949.

[9] W. Shockley, M. Sparks, and G. K. Teal, "*P-N* junction transistors," *Phys. Rev.*, vol. 83, pp. 151–162; July, 1951.

[10] J. Early, "Design theory of junction transistors," *Bell Sys. Tech. J.*, vol. 32, pp. 1271–1312; November, 1953.

[11] R. J. Pritchard, "Frequency variations of junction-transistor parameters," PROC. IRE, vol. 42, pp. 786–799; May, 1954.

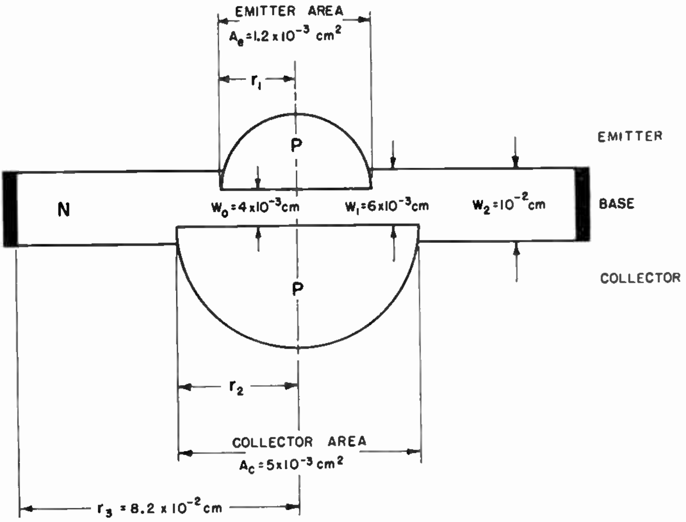


Fig. 1—Geometry for model of *p-n-p* alloy junction transistor (cross section of structure with cylindrical symmetry; not drawn to scale).

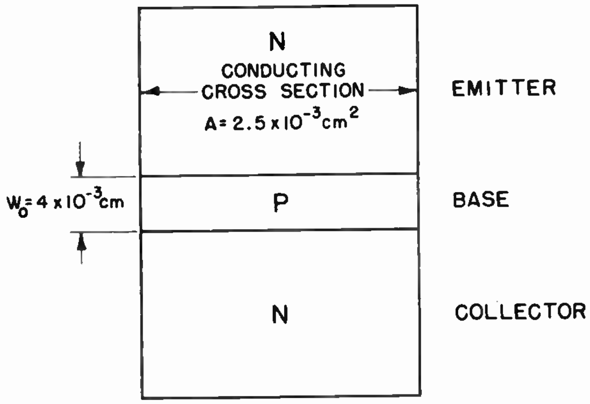


Fig. 2—Geometry for models of *n-p-n* grown junction transistors (not drawn to scale).

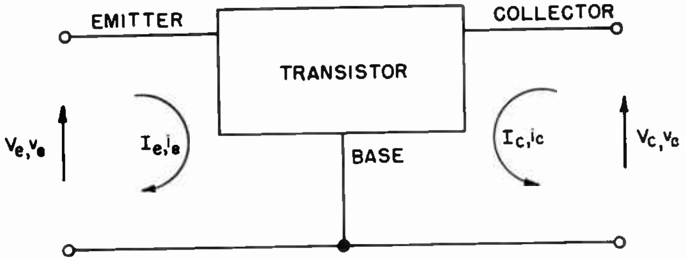


Fig. 3—Sign convention for the four-pole representations.

The "hybrid" h' parameters are defined by

$$\begin{aligned} v_e &= h_{11}'i_e + h_{12}'v_c \\ i_c &= h_{21}'i_e + h_{22}'v_c \end{aligned} \tag{2}$$

and are related to the y''s by

$$h_{11}' = 1/y_{11}' \tag{3a}$$

$$h_{12}' = -y_{12}'/y_{11}' \tag{3b}$$

$$h_{21}' = y_{21}'/y_{11}' \tag{3c}$$

$$h_{22}' = y_{22}' - y_{12}'y_{21}'/y_{11}'. \tag{3d}$$

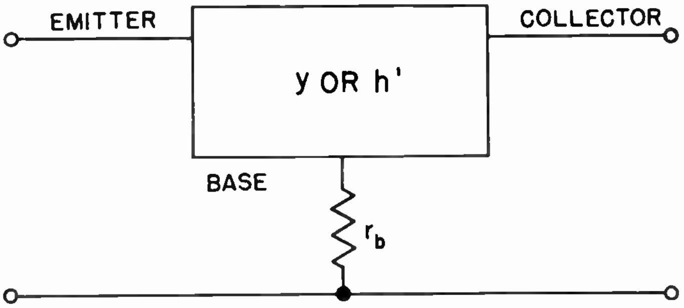


Fig. 4—Inclusion of the base resistance. The over-all four-pole is then characterized by the h parameters.

If the base spreading resistance is included (see Fig. 4), one arrives at realistic h parameters given by

$$\begin{aligned} h_{11} &= h_{11}' + r_b'(1 + h_{21}')(1 - h_{12}')/(1 + r_b'h_{22}') \\ h_{12} &= (h_{12}' + r_b'h_{22}')/(1 + r_b'h_{22}') \\ h_{21} &= (h_{21}' - r_b'h_{22}')/(1 + r_b'h_{22}') \\ h_{22} &= h_{22}'/(1 + r_b'h_{22}'). \end{aligned} \tag{4}$$

DC Relationships

The dc currents and voltages in a *p-n-p* transistor having $r_b' = 0$ are related by

$$\begin{aligned} I_e = {} & Aq(e^{qV_e/kT} - 1)\left[(D_{pb}p_{ob}/L_{pb}) \coth (w_o/L_{pb}) \right. \\ & \left. + (D_{ne}n_{oe}/L_{ne})\right] - Aq(e^{qV_c/kT} - 1) \\ & \cdot \left[(D_{pb}p_{ob}/L_{pb}) \operatorname{csch} (w_o/L_{pb})\right] \end{aligned} \tag{5a}$$

$$\begin{aligned} I_c = {} & Aq(e^{qV_c/kT} - 1)\left[(D_{pb}p_{ob}/L_{pb}) \coth (w_o/L_{pb}) \right. \\ & \left. + (D_{nc}n_{oc}/L_{nc})\right] \\ & - Aq(e^{qV_e/kT} - 1)\left[(D_{pb}p_{ob}/L_{pb}) \operatorname{csch} (w_o/L_{pb})\right]. \end{aligned} \tag{5b}$$

The equations apply to *n-p-n* transistors by providing q with a minus sign and substituting p to n and vice versa. Setting $I_e = 0$ and using the resulting V_e in the expression for I_c, one obtains the collector reverse current for zero emitter current, I_{co}.

AC Parameters

The y' parameters defined by (1) are for the *p-n-p* transistor

$$\begin{aligned} y_{11}' = {} & Aq \frac{D_{pb}p_{ob}}{L_{pb}} \frac{q}{kT} e^{qV_e/kT}(1 + j\omega\tau_{pb})^{1/2} \\ & \times \coth\left(\frac{w_0}{L_{pb}} \sqrt{1 + j\omega\tau_{pb}}\right) \\ & + Aq \frac{D_{ne}n_{oe}}{L_{ne}} \frac{q}{kT} e^{qV_e/kT}(1 + j\omega\tau_{ne})^{1/2} + j\omega C_e \end{aligned} \tag{6a}$$

$$\begin{aligned} y_{12}' = {} & -Aq \frac{D_{pb}p_{ob}}{L_{pb}^2}\left[(e^{qV_e/kT} - 1) \operatorname{csch} \frac{w_o}{L_{pb}} + \coth \frac{w_o}{L_{pb}}\right] \\ & \times \left(\frac{\partial w}{\partial V_c}\right)(1 + j\omega\tau_{pb})^{1/2} \operatorname{csch}\left(\frac{w_o}{L_{pb}} \sqrt{1 + j\omega\tau_{pb}}\right) \end{aligned} \tag{6b}$$

$$y_{21}' = -Aq \frac{D_{pb}p_{ob}}{L_{pb}} \frac{q}{kT} e^{qV_e/kT}(1 + j\omega\tau_{pb})^{1/2}$$

TABLE I

DESIGN DATA AND PROPERTIES OF MODELS FOR JUNCTION TRANSISTORS AT ROOM TEMPERATURE

Geometry

	Ge p-n-p Alloy	Ge n-p-n Grown	Ge n-p-n Rate Grown	Si n-p-n Grown
Base width, w_o/cm	4×10^{-3}	4×10^{-3}	4×10^{-3}	4×10^{-3}
Emitter area, A_e/cm^2	1.2×10^{-3}	—	—	—
Collector area, A_c/cm^2	5×10^{-3}	—	—	—
Conducting cross section, A/cm^2	—	2.5×10^{-3}	2.5×10^{-3}	2.5×10^{-3}

Junctions

	Ge p-n-p Alloy		Ge n-p-n Grown		Ge n-p-n Rate Grown		Si n-p-n Grown	
	Emitter	Collector	Emitter	Collector	Emitter	Collector	Emitter	Collector
Graded Junction			X	X		X	X	X
Step Junction	X	X			X			

Material Properties

Properties	Ge n-p-n Alloy	Ge n-p-n Grown	Ge n-p-n Rate Grown	Si n-p-n Grown
Impurity content				
emitter				
N_a/cm^{-3}	1.55×10^{19}		1.2×10^{16}	
N_d/cm^{-3}		1.25×10^{18}	3.5×10^{16}	6.25×10^{18}
(N_d-N_a)/cm^{-3}			2.3×10^{16}	
base				
N_d/cm^{-3}	8.7×10^{14}		8.1×10^{15}	
N_a/cm^{-3}		4.57×10^{15}	1.2×10^{16}	1.87×10^{16}
(N_a-N_d)/cm^{-3}		3.7×10^{15}	3.9×10^{15}	1.5×10^{16}
collector				
N_a/cm^{-3}	1.55×10^{19}		1.2×10^{16}	
N_d/cm^{-3}		8.7×10^{14}	3.5×10^{16}	3.7×10^{15}
$(N_d-N_a$/cm$^{-3})$			2.3×10^{16}	
Equilibrium carrier densities				
emitter				
electrons, n_{oe}/cm^{-3}	3.3×10^{7}	1.25×10^{18}	2.3×10^{16}	6.25×10^{18}
holes, p_{oe}/cm^{-3}	1.55×10^{19}	4.12×10^{8}	2.24×10^{10}	5.23×10^{2}
base				
electrons, n_{ob}/cm^{-3}	8.7×10^{14}	1.4×10^{11}	1.32×10^{11}	2.18×10^{5}
holes, p_{ob}/cm^{-3}	5.9×10^{11}	3.7×10^{15}	3.9×10^{15}	1.5×10^{16}
collector				
electrons, n_{oc}/cm^{-3}	3.3×10^{7}	8.7×10^{14}	2.3×10^{16}	3.7×10^{15}
holes, p_{oc}/cm^{-3}	1.55×10^{19}	5.9×10^{11}	2.24×10^{10}	8.4×10^{5}
Mobilities μ and Diffusion Constants D				
emitter				
electrons				
μ_{ne}/cm^2 V^{-1} sec^{-1}	123	866	2660	112
D_{ne}/cm^2 sec^{-1}	3.2	—	—	—
holes				
μ_{pe}/cm^2 V^{-1} sec^{-1}	61.4	200	975	62
D_{pe}/cm^2 sec^{-1}	—	5.15	25	1.59
base				
electrons				
μ_{nb}/cm^2 V^{-1} sec^{-1}	3700	3350	2822	782
D_{nb}/cm^2 sec^{-1}	—	84	72	20
holes				
μ_{pb}/cm^2 V^{-1} sec^{-1}	1700	1570	1340	426
D_{pb}/cm^2 sec^{-1}	43	—	—	—
collector				
electrons				
μ_{nc}/cm^2 V^{-1} sec^{-1}	123	3700	2660	971
D_{nc}/cm^2 sec^{-1}	3.2	—	—	—
holes				
μ_{pc}/cm^2 V^{-1} sec^{-1}	61.4	1700	975	450
D_{pc}/cm^2 sec^{-1}	—	43.7	25	11.5

TABLE I—(*continued*)

Material Properties

Properties	Ge *p-n-p* Alloy	Ge *n-p-n* Grown	Ge *n-p-n* Rate Grown	Si *n-p-n* Grown
Resistivities				
emitter, ρ_e/ohm-cm	0.0066	0.0058	0.1	0.009
base, ρ_b/ohm-cm	1.9	1.1	1.2	0.978
collector, ρ_c/ohm-cm	0.0066	1.95	0.1	1.75
Lifetimes				
electrons in emitter, τ_{ne}/μ sec	0.06	—	—	—
holes in base, τ_{pb}/μ sec	60	—	—	—
electrons in collector, τ_{nc}/μ sec	0.06	—	—	—
holes in emitter, τ_{pe}/μ sec	—	0.1	1.9	0.56
electrons in base, τ_{nb}/μ sec	—	14	11	20.8
holes in collector, τ_{pc}/μ sec	—	59	1.9	50
Diffusion Lengths				
electrons in emitter, L_{ne}/cm	4.5×10^{-4}			
holes in base, L_{pb}/cm	5.1×10^{-2}			
electrons in collector, L_{nc}/cm	4.5×10^{-4}			
holes in emitter, L_{pe}/cm		7.2×10^{-4}	6.9×10^{-3}	9.4×10^{-4}
electrons in base, L_{nb}/cm		3.4×10^{-2}	2.8×10^{-2}	6.47×10^{-2}
holes in collector, L_{pc}/cm		5.2×20^{-2}	6.9×10^{-3}	2.4×10^{-2}
Electrical Properties				
DC Biases				
emitter current, I_e/ma	1	−1	−1	−1
collector voltage, V_c/volts	−5	5	5	5
Small Signal Four-Pole Parameters at 1 kc				
h_{11}/ohms	25.9	28	38	30
h_{12}	2×10^{-4}	8.6×10^{-5}	1.2×10^{-4}	9×10^{-5}
h_{21}	−0.99	−0.99	−0.96	−0.98
h_{22}/mhos	5×10^{-8}	4.2×10^{-8}	1.5×10^{-7}	10^{-7}
Alpha Cut-Off Frequency, $f_{\alpha co}$/cycles/sec	10^{6}	2×10^{6}	1.75×10^{6}	4.9×10^{5}
Collector Capacitance, $C_c/\mu\mu$f	22	6.3	6	5.2

$$\times \operatorname{csch}\left(\frac{w_0}{L_{pb}}\sqrt{1+j\omega\tau_{pb}}\right)\left(1+\frac{n_{oc}\mu_{nc}}{p_{oc}\mu_{pc}}\right) \tag{6c}$$

$$y_{22}' = \left\{Aq\,\frac{D_{pb}p_{ob}}{L_{pb}{}^2}\left[(e^{qV_e/kT}-1)\operatorname{csch}\frac{w_0}{L_{pb}} + \coth\frac{w_o}{L_{pb}}\right]\right.$$

$$\times\left(\frac{\partial w}{\partial V_c}\right)(1+j\omega\tau_{pb})^{1/2}\coth\left(\frac{w_o}{L_{pb}}\sqrt{1+j\omega\tau_{pb}}\right)$$

$$\left. + j\omega C_c\right\}\left(1+\frac{n_{oc}\mu_{nc}}{p_{oc}\mu_{pc}}\right). \tag{6d}$$

For step junctions

$$\frac{\partial w}{\partial V_c} = -\frac{1}{2V_c}\left(\frac{2\kappa\epsilon_o V_c}{qn_{ob}}\right)^{1/2} \tag{6e}$$

(for our geometry

$$\partial w/\partial V_c = 9.38\times 10^2 n_{ob}{}^{-1/2} cmV^{-1}).$$

If, in (6a) to (6d) q is provided with a minus sign and p is substituted to n and vice versa, these expressions apply to *n-p-n* transistors. However, since the *n-p-n* transistors are of the grown type, we have

$$\left|\frac{\partial w}{\partial V_c}\right| = \left|\frac{1}{6V_c}\left(\frac{3\kappa\epsilon_o V_c}{qa}\right)^{1/3}\right| \tag{7}$$

(for our geometry

$$|\partial w/\partial V_c| = 1.18\times 10^{-5} cmV^{-1}).$$

The barrier capacitances C_e and C_c are given by

$$C = A\kappa\epsilon_o[q\,|N_d - N_a|/(2\kappa\epsilon_o V')]^{1/2} \tag{8}$$

for step junctions, and by

$$C = \frac{A\kappa\epsilon_o}{2}\left(\frac{2q\,|a|}{3\kappa\epsilon_o V'}\right)^{1/3} \tag{9}$$

for graded junctions. V' stands for the electrostatic potential across the depletion layer.[10]

The base spreading resistance[10] r_b' for the structure in Fig. 1 is

$$r_b' \simeq \rho_b[1/(8\pi w_o) + 1/(2\pi w_1)\times \ln(r_2/r_1) + 1/(2\pi w_2)\times\ln(r_3/r_2)] \tag{10}$$

and for the structure of Fig. 2

$$r_b' \simeq \rho_b/w_o. \tag{11}$$

The h' and h for both types may now be calculated using (3), (4), and (6)–(11).

Important for the characterization of the frequency behavior of a transistor is the alpha cut-off frequency given by

$$f_{\alpha co} = 2.43 D_b/(2\pi w_o{}^2). \tag{12}$$

In addition to this four-pole representation, we want to describe the temperature behavior in terms of a simplified[10] equivalent circuit (see Fig. 5).

$$g_{ee} = Aq\frac{D_{pb}p_{ob}}{L_{pb}}\frac{q}{kT}e^{qV_e/kT}\frac{L_{pb}}{w_o} \tag{13}$$

$$g_{cc} = Aq\frac{D_{pb}p_{ob}}{L_{pb}^2}\left[(e^{qV_e/kT}-1)\operatorname{csch}\frac{w_o}{L_{pb}} + \coth\frac{w_o}{L_{pb}}\right]\left(\frac{\partial w}{\partial V_c}\right)\frac{L_{pb}}{w_o} \tag{14}$$

$$\omega_\alpha = 2D_{pb}/w_o^2 \tag{15}$$

for the *p-n-p*, and corresponding equations for the *n-p-n* transistor.

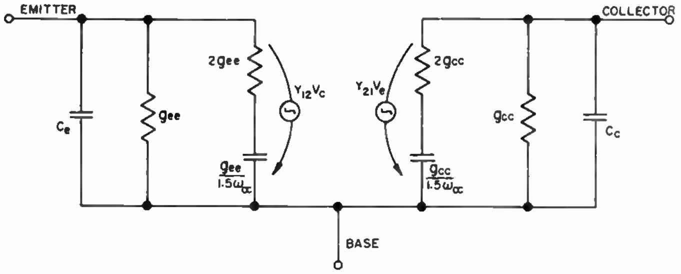


Fig. 5—Simplified equivalent circuit for junction transistor.

IV. TEMPERATURE DEPENDENCE OF SEMICONDUCTOR PROPERTIES

The design equations of the previous section contain the properties of the semiconducting material, and the temperature behavior of the electrical device characteristics is completely determined by the temperature dependence of these material properties which will be discussed individually in this section. These properties are the carrier densities, mobilities and diffusion constants, resistivities, lifetimes, diffusion lengths, and dielectric constants.

Carrier Densities

The majority and minority carrier densities in a region with a density N_a of ionized acceptors and a density N_d of ionized donors are calculated from the condition for electrical neutrality which is satisfied in any homogeneous semiconductor

$$p_o - n_o + N_d - N_a = 0 \tag{16}$$

and the relationship

$$n_o \cdot p_o = n_i^2 \tag{17}$$

between the equilibrium carrier densities in the extrinsic semiconductor, n_o, p_o and the equilibrium carrier densities n_i in the intrinsic semiconductor at the same temperature.

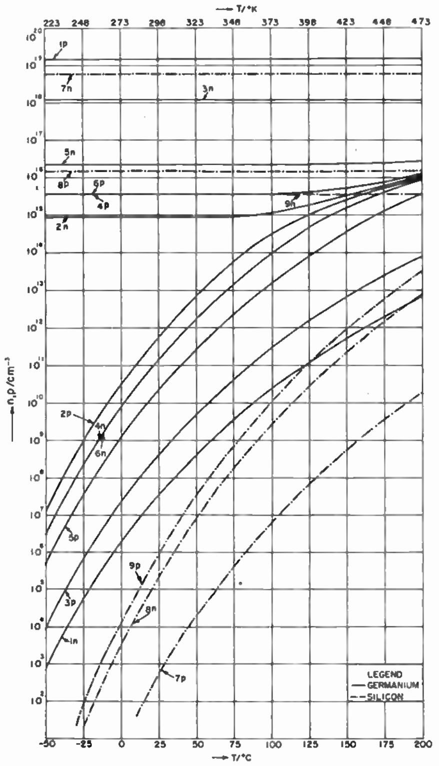
The values for n_i are given by[12]

$$n_i^2 = 9.3 \times 10^{31} \times T^3 \times e^{-8700/T} \text{ cm}^{-6} \tag{18}$$

for germanium, and

$$n_i^2 = 7.8 \times 10^{32} \times T^3 \times e^{-12900/T} \text{ cm}^{-6} \tag{19}$$

for silicon, corresponding to energy gaps of 0.75 ev and 1.12 ev respectively. The expressions are empirical and the temperature dependence of the energy gaps themselves, which has been found to be linear,[13] is absorbed in the constants multiplying the exponentials. Plots of n_o, p_o in the emitter, base, and collector regions of the various models are shown in Fig. 6.



CURVE NO.	GERMANIUM PNP ALLOY JUNCTION TRANSISTOR
1n	n_{oe}, n_{oc}
1p	p_{oe}, p_{oc}
2n	n_{ob}
2p	p_{ob}
	GERMANIUM NPN GROWN JUNCTION TRANSISTOR
3n	n_{oe}
3p	p_{oe}
4n	n_{ob}
4p	p_{ob}
2n	n_{oc}
2p	p_{oc}
	GERMANIUM NPN RATE GROWN JUNCTION TRANSISTOR
5n	n_{oe}, n_{oc}
5p	p_{oe}, p_{oc}
6n	n_{ob}
6p	p_{ob}
	SILICON NPN GROWN JUNCTION TRANSISTOR
7n	n_{oe}
7p	p_{oe}
8n	n_{ob}
8p	p_{ob}
9n	n_{oc}
9p	p_{oc}

Fig. 6—Carrier densities in germanium and silicon as a function of temperature.

The basic picture is the same in germanium and silicon, but due to the wider energy gap, the increase of the minority carrier density in the extrinsic region is faster in silicon than in germanium. However, the minority carrier densities start as much lower values so that the transition to intrinsic behavior occurs at higher temperatures in silicon.

Mobilities

In transistors only scattering by thermal lattice vibrations, charged impurities, and free carriers must be considered in the calculation of drift mobilities. Prince[14,15] has determined the temperature dependence

---

[12] E. S. Rittner, "Extension of the theory of the junction transistor," *Phys. Rev.*, vol. 94, pp. 1161–1171; June, 1954.

[13] E. M. Conwell, "Properties of silicon and germanium," PROC. IRE, vol. 40, pp. 1327–1337; November, 1952.

[14] M. B. Prince, "Drift mobilities in semiconductors, I. Germanium," *Phys. Rev.*, vol. 92, pp. 681–687; November, 1953.

[15] M. B. Prince, "Drift mobilities in semiconductors, II. Silicon," *Phys. Rev.*, vol. 93, pp. 1204–1206; March, 1954.

of the lattice mobilities μ_L for electrons and holes in germanium and silicon using samples with resistivities higher than a few ohm-cm. The information on silicon is not as complete and accurate as for germanium, but probably sufficient for the purpose of this paper.[16] Prince found

$$\mu_{nL} = 9.1 \times 10^8 \times T^{-2.3} \text{ cm}^2 V^{-1} \text{ sec}^{-1} \tag{20}$$

for electrons in germanium,[14]

$$\mu_{pL} = 3.5 \times 10^7 \times T^{-1.6} \text{ cm}^2 V^{-1} \text{ sec}^{-1} \tag{21}$$

for holes in germanium,[14]

$$\mu_{nL} = 5.5 \times 10^6 \times T^{-1.5} \text{ cm}^2 V^{-1} \text{ sec}^{-1} \tag{22}$$

for electrons in silicon,[15] and

$$\mu_{pL} = 2.4 \times 10^8 \times T^{-2.3} \text{ cm}^2 V^{-1} \text{ sec}^{-1} \tag{23}$$

for holes in silicon.[15] These findings deviate from the results of a simplified theory[17] of lattice scattering, and have to be interpreted on the basis of more complicated considerations.[18,19]

Coulomb scattering by charged impurities and free carriers of the opposite sign is theoretically described by the Conwell-Weisskopf formula[20]

$$\mu_I = \frac{8\sqrt{2}k^{3/2}}{m^{1/2}\pi^{3/2}q^3} \, \frac{\kappa^2 m^{1/2} T^{3/2}}{m_{\text{eff}}^{1/2} N_I} \cdot \left\{ \ln\left[1 + \left(\frac{3k}{q^2}\right)^2 \frac{\kappa^2 T^2}{N_I^{2/3}}\right]\right\}^{-1} \tag{24}$$

to which quantum mechanical corrections have been added.[21,22] The experimental curves, however, are usually well approximated by (24). (For a discussion see Prince[14] and Debye.[23])

The mass ratios in (24) have been chosen to be[14,24] $m/m_{\text{eff}} = 4$ for electrons in germanium, $m/m_{\text{eff}} = 1/3$ for holes in germanium, $m/m_{\text{eff}} = 1$ for both electrons and holes in silicon.

The combination of the effects of lattice and coulomb scattering is achieved by the relationship[23,25,26]

$$\mu = \mu_L[1 + M^2\{C_iM \cos M + S_iM \sin M - \tfrac{1}{2}\pi \sin M\}] \tag{25}$$

where $M^2 = 6\mu_L/\mu_I$ which is a better approximation than the customary way of summing the reciprocals of the individual mobilities. A plot of relation (25) for graphical addition is found by Conwell.[13]

On the basis of these considerations, the mobilities in the various regions of the transistor models are calculated and shown in Fig. 7.

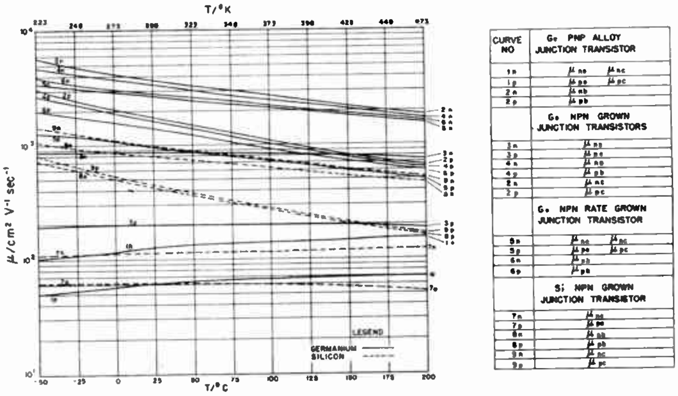


Fig. 7—Carrier drift mobilities in germanium and silicon as a function of temperature.

Diffusion Constants

The diffusion constants D of mobile carriers are connected with their mobilities μ by the Einstein relationship[27,28]

$$D = (kT/q)\mu \tag{26}$$

which is assumed to be valid in all the regions of the models considered. The diffusion constants of the minority carriers in each region which alone enter the design equations are shown in Fig. 8. The numbering of the curves corresponds to the numbering of the mobility curves in Fig. 7.

Resistivities

The electrical resistivity ρ of a piece of semiconductor with the carrier densities n_o, p_o and the mobilities μ_n, μ_p is given by

$$\rho = (qn_o\mu_n + qp_o\mu_p)^{-1}. \tag{27}$$

It enters explicitly only the expressions for the base spreading resistance, and it has, therefore, been calcu-

---

[16] After this paper had been prepared it was brought to the author's attention that recently the following values have been measured (G. W. Ludwig and R. L. Watters, "Drift and conductivity mobility in silicon," to be published)

$$\mu_{nL} = (2.1 \pm 0.2) \times 10^9 \times T^{-2.5 \pm 0.1} \text{ cm}^2 V^{-1} \text{ sec}^{-1}$$
$$\mu_{pL} = (2.3 \pm 0.1) \times 10^9 \times T^{-2.7 \pm 0.1} \text{ cm}^2 V^{-1} \text{ sec}^{-1}.$$

Compare also F. J. Morin and J. P. Maita, "Electrical properties of silicon containing arsenic and boron," *Phys. Rev.*, vol. 96, pp. 28–35; October, 1954.

[17] J. Bardeen and W. Shockley, "Deformation potentials and mobilities in nonpolar crystals," *Phys. Rev.*, vol. 80, pp. 72–80; October, 1950.

[18] F. Herman and J. Callaway, "Electronic structure of the germanium crystal," *Phys. Rev.*, vol. 89, pp. 518–519; March, 1953.

[19] F. Herman, "Calculation of the energy band structures of the diamond and germanium crystals by the method of orthogonalized plane waves," *Phys. Rev.*, vol. 93, pp. 1214–1225; March, 1954.

[20] E. Conwell and V. F. Weisskopf, "Theory of impurity scattering in semiconductors," *Phys. Rev.*, vol. 77, pp. 388–390; February, 1950.

[21] H. Brooks, "Scattering by ionized impurities in semiconductors," *Phys. Rev.*, vol. 83, p. 879; August, 1951.

[22] C. Herring (personal communication).

[23] P. P. Debye and E. M. Conwell, "Electrical properties of n-type germanium," *Phys. Rev.*, vol. 93, pp. 695–706; February, 1954.

[24] P. P. Debye and T. Kohane, "Hall mobility of electrons and holes in silicon," *Phys. Rev.*, vol. 94, pp. 724–725; May, 1954.

[25] H. Jones, "The hall coefficient of semiconductors," *Phys. Rev.*, vol. 81, p. 149; June, 1951.

[26] V. A. Johnson and K. Lark-Horovitz, "The combination of resistivities in semiconductors," *Phys. Rev.*, vol. 82, pp. 977–978; June, 1951.

[27] A. Einstein, "Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegg. von in ruhenden Flüssigkeiten suspendierten Teilchen," *Ann. der. Phys.*, vol. 17, p. 549; 1905.

[28] W. Shockley, "Electrons and holes in semiconductors," D. van Nostrand, New York, N. Y., p. 299, 1950.

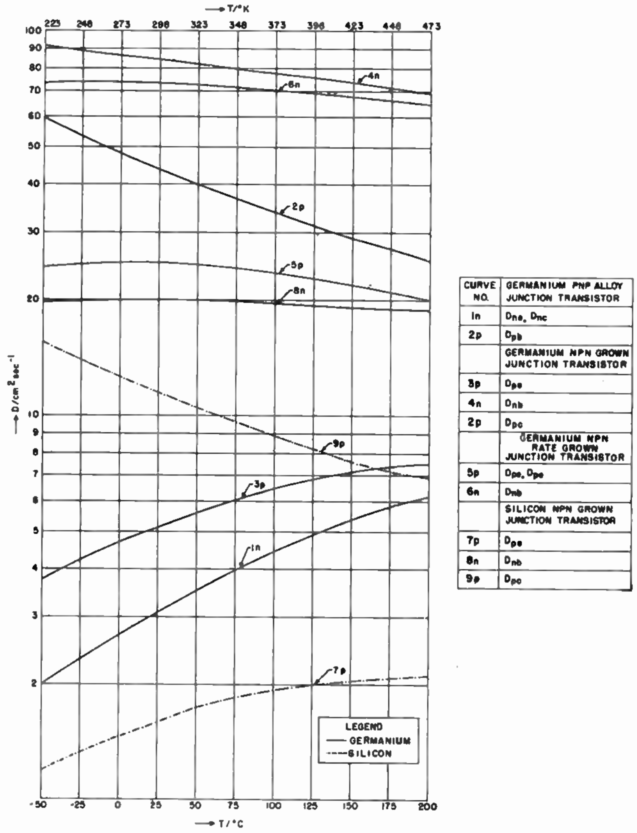


Fig. 8—Diffusion constants in germanium and silicon as a function of temperature.

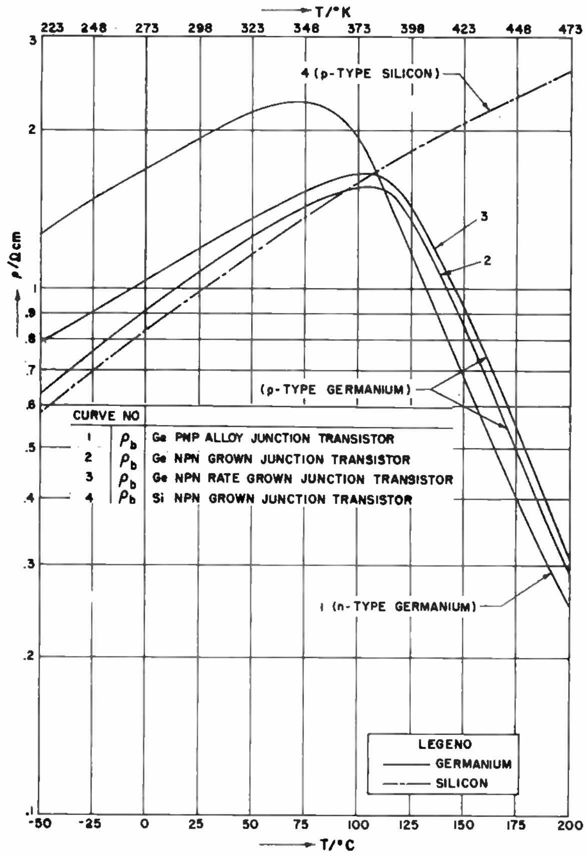


Fig. 9—Resistivities in germanium and silicon as a function of temperature.

lated for the base regions of the four models using the carrier densities and mobilities of Figs. 6 and 7. The results are shown in Fig. 9. The crossing of curve 1 for the *n*-type base of the *p-n-p* transistor with curves 2 and 3 for the *p*-type bases of the *n-p-n* transistors portrays the fact, noticed earlier,[29,30] that *n*- and *p*-type samples approach the intrinsic curve from different sides.

Lifetimes

The temperature variation of lifetime, the theoretical description of which follows the Hall[31] and Shockley-Read[32] theories of lifetime, depends on the carrier densities in the sample and on the density and nature of the recombination centers, in particular, on the position of the recombination level as is seen from the equation.

$$\tau = \tau_{po}(n_o + n_i)/(n_o + p_o) + \tau_{no}(p_o + p_i)/(n_o + p_o) \quad (28)$$

on which the following analysis is based. It is well known that the lifetime picture in semiconductors may be much more complicated,[33] but for transistor grade material, (28) seems to describe the recombination phenomenon very well. In (28) n_o and p_o are the equilibrium carrier densities given by[34]

$$n_o = N_c e^{(E_F - E_c)/kT} \quad (29a)$$

$$p_o = N_v e^{(E_v - E_F)/kT} = n_i^2/n_o; \quad (29b)$$

n_1 and p_1 are the equilibrium carrier densities that would prevail if the Fermi level fell at the recombination level E_t and are given by

$$n_1 = N_c e^{(E_t - E_c)kT} \quad (30a)$$

$$p_1 = N_v e^{(E_v - E_t)/kT} = n_i^2/n_i; \quad (30b)$$

τ_{no} and τ_{po} are the lifetimes of electrons injected into highly *p*-type material and of holes injected into highly *n*-type material, respectively. Based on reported measurements[35,36] the recombination level was chosen to lie

---

[29] At very high frequencies which are not considered in this paper, the resistances of the other regions are also of importance (personal communication by J. M. Early).

[30] P. G. Herkart and J. Kurshan, "Theoretical resistivity and Hall coefficient of impure germanium near room temperature," *RCA Rev.*, vol. 14, pp. 427–440; September, 1953.

[31] R. N. Hall, "Electron-hole recombination in germanium," *Phys. Rev.*, vol. 87, p. 387; July, 1952.

[32] W. Shockley and W. T. Read, Jr., "Statistics of the recombinations of holes and electrons," *Phys. Rev.*, vol. 87, pp. 835–842; September, 1952.

[33] See *e.g.*, H. Y. Fan, "Effect of traps on carrier injection in semiconductors," *Phys. Rev.*, vol. 92, pp. 1424–1428; December, 1953.

H. Y. Fan, D. Navon and H. Gebbie, "Recombination and trapping of carriers in germanium," *Physica*, vol. 20, pp. 885–872; 1954.

A. Rose, "Recombination processes in insulators and semiconductors," *Phys. Rev.*, vol. 97, pp. 322–333; January, 1955.

[34] Shockley, *op. cit.*, p. 240.

[35] R. Wiesner and E. Groschwitz, "Zur Temperaturabhängigkeit des Photostromes in P-N Ubergängen," *Z. ang. Phys.*, vol. 7, p. 496; 1955. The author is indebted to Drs. Wiesner and Groschwitz for making their work available to him prior to publication.

[36] G. Bemski, "Lifetime of electrons in *p*-type silicon," *Phys. Rev.*, vol. 100, pp. 523–524; October, 1955. The author is indebted to Dr. Bemski for making his work available to him prior to publication.

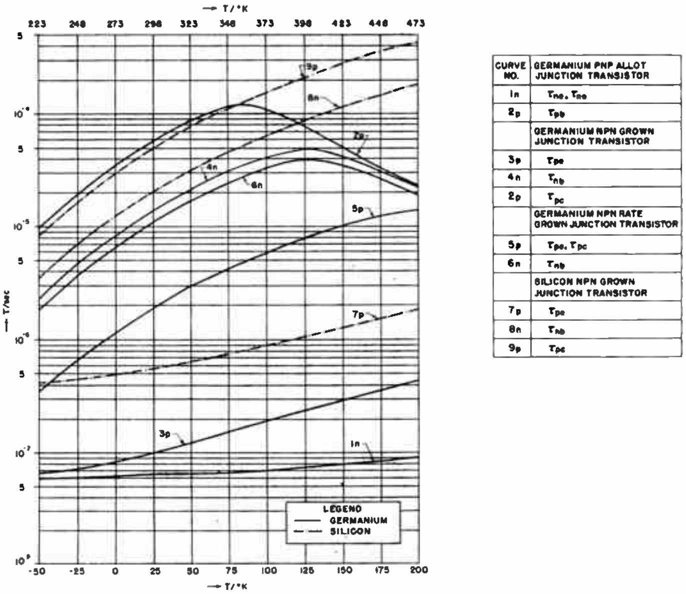


Fig. 10—Lifetimes in germanium and silicon as a function of temperature.

0.2 ev above the valence band in both materials. For the ratio τ_{po}/τ_{no}, widely differing values have been reported,[35–37] but as it fortunately does not enter the calculations in a critical way, the ratio was chosen equal to 1. τ_{po} and τ_{no} are then determined by the room temperature lifetimes for which typical values have been assumed (see Table I). Calculations carried out on this basis yield the curves of Fig. 10.

Diffusion Lengths

The quantities L entering the design equations are the so-called diffusion lengths of the minority carriers defined as $L=(D\tau)^{1/2}$. Their temperature dependence results from a combination of the previously described behavior of diffusion constants and lifetimes (Fig. 11).

Dielectric Constants

The dielectric constants of the materials enter the design equations (*e.g.*, in the capacitances and through the formulas for the scattering processes). They were measured by various authors[38–42] and the values $\kappa=16$ for germanium and $\kappa=12$ for silicon were assumed constant over the whole temperature range considered here.

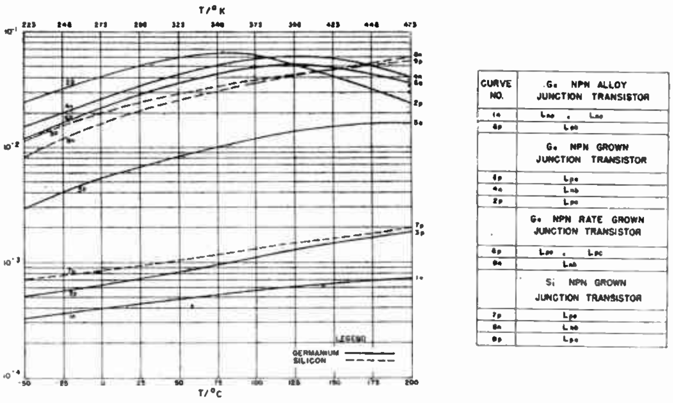


Fig. 11—Diffusion lengths in germanium and silicon as a function of temperature.

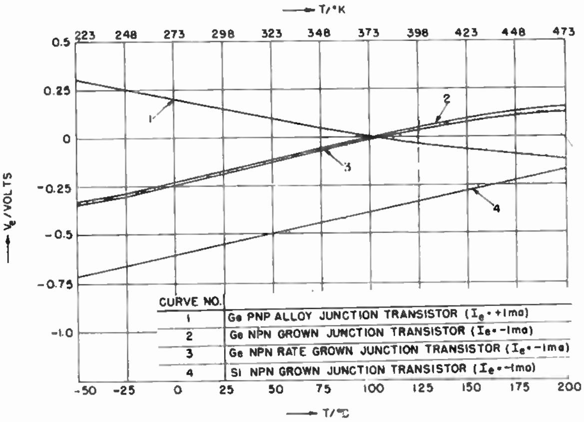


Fig. 12—Emitter voltage V_e for $I_e=(\pm)1$ ma as a function of temperature.

V. TEMPERATURE DEPENDENCE OF THE TRANSISTOR CHARACTERISTICS

Prepared with the knowledge of the temperature behavior of the material properties, one can calculate the temperature variation of the electrical characteristics with the help of the design equations of the third section. The analysis is carried out for common base operation from which conclusions about other configurations can be drawn.

DC Currents and Voltages

If the dc bias conditions of $I_e=\pm 1$ ma and $V_c=\mp 5$ volts (upper sign for *p-n-p*, lower sign for *n-p-n* transistors) are maintained throughout the whole temperature range, the voltage V_e across the emitter junction and the collector current I_c will undergo changes with temperature.

The absolute value of the emitter junction voltage, V_e, which is shown in Fig. 12 decreases initially with increasing temperature. As seen from (5a) and Fig. 6, this is necessary to offset the fast increase with temperature of the minority carrier density in the base region, p_{ob} in the *p-n-p*, and n_{ob} in the *n-p-n* transistor (curves 2*p*, 4*n*, 6*n*, 8*n* of Fig. 6). At lower temperatures (and thus higher absolute bias voltages) the first term in the

---

[37] J. A. Burton, G. W. Hull, F. J. Morin, and J. C. Severiens, "Effect of nickel and copper impurities on the recombination of holes and electrons in germanium," *J. Phys. Chem.*, vol. 57, pp. 853–859; November, 1953.

[38] H. B. Briggs, "Optical effects in bulk silicon and germanium," *Phys. Rev.*, vol. 77, p. 287; January, 1950.

[39] T. S. Benedict and W. Shockley, "Microwave observation of the collision frequency of electrons in germanium," *Phys. Rev.*, vol. 89, pp. 1152–1153; March, 1953.

[40] W. C. Dunlap, Jr. and R. L. Watters, "Direct measurement of the dielectric constants of silicon and germanium," *Phys. Rev.*, vol. 92, pp. 1396–1397; December, 1953.

[41] G. C. Dacey, "Space-charge limited hole current in germanium," *Phys. Rev.*, vol. 90, pp. 759–763; June, 1953.

[42] The author is indebted to Prof. H. Y. Fan for a personal communication regarding measurements of the temperature dependence of the dielectric constants of germanium and silicon at Purdue University

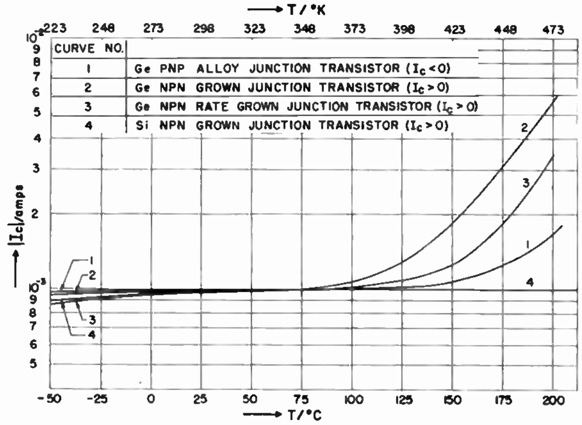


Fig. 13—Collector current I_c under ordinary bias conditions as a function of temperature.

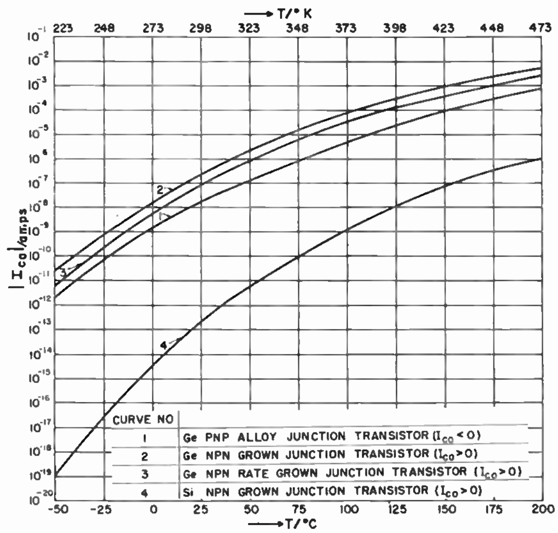


Fig. 14—(Theoretical) collector reverse current I_{co} as a function of temperature.

expression for I_e is dominant, the second term negligible At higher temperatures, however, the second term which is not controlled by the emitter voltage gains in importance until finally the emitter voltage has to change sign. The emitter junction is then biased slightly in reverse and transition from injection to a different kind of operating condition, related to extraction[43–46] has occurred in which the dc bias reduces the minority carrier density in the base region.

The collector current I_c under ordinary bias conditions [Fig. 13, (5b)] is determined in its low temperature range by the dc current amplification factor $\alpha = -h_{21}$, and is usually a few per cent less than the emitter current. This is the region where the term containing V_e (the second term in the expression for I_c) is dominant. At higher temperatures, however, the dc collector current increases to values higher than the emitter current (for the silicon model—curve 4—this transition occurs above 200°C.). This is due to different effects. In the regular grown junction germanium transistor (curve 2) with the high resistivity collector region which shows the largest increase, the major portion of the excess current is carried by (minority) holes, p_{oc}, from the collector into the base but also the (minority) electrons in the base, n_{ob}, contribute more than 1 ma to the collector current at the highest temperature point. For the rate grown *n-p-n* transistor (curve 3) with the much lower collector resistivity (Table I), a little more than half the collector current is carried by holes from the collector, the rest by electrons from the base. Despite their lower equilibrium density, the minority carriers in the collector region p_{oc} are more effective because equilibrium electron density in the base n_{ob} is multiplied by

$$\coth (w_o/L_{nb}) + (e^{-qV_e/kT} - 1) \operatorname{csch} (w_o/L_{nb}) \quad (31)$$

which has a value of about 0.5 at 200°C. In the *p-n-p* alloy transistor, the minority carrier current from the collector is negligible ($n_{oc} = 6.5 \times 10^{12}$ cm^{-3} at 200°C.) and I_c is only carried by (minority) holes from the base. In silicon, similar considerations apply but only at temperatures above the 200°C. which was assumed as the upper limit in this paper. To achieve small I_c, low resistivity in the collector region is important. A further reduction in collector current, even for highly doped collector regions, may be obtained by a low base resistivity.

Considerations very similar to those employed for the collector current I_c under ordinary bias conditions apply to the collector current I_{co} for open circuit emitter ($I_e = 0$). Its theoretical value starts at very low values as seen from Fig. 14. For silicon (curve 4) it never attains any appreciable value up to 200°C. In the germanium transistors I_{co} becomes large at the high temperatures. It is composed of minority carriers from both sides of the collector junction, but the collector region is more effective than the base for a reason similar to the case of the regular I_c above. In order that no current flows across the emitter junction, a certain (reverse) voltage V_{eo} is developed across it (Fig. 15) and the multiplication factor (31), or its analog for the *p-n-p* transistor, may be smaller than 0.1 at the higher temperatures. The temperatures at which I_{co} becomes appreciable correspond to the temperatures at which I_c becomes noticeably larger than 1.

The difference between emitter and collector currents (with the sign convention of Fig. 3, it is actually the sum) flows through the base lead as base current. For ordinary operating conditions, it is plotted in Fig. 16. I_b changes sign wherever the collector current goes from a smaller to a higher value than the emitter current.

---

[43] P. C. Banbury, "Carrier injection and extraction in lead sulphide," *Proc. Phys. Soc.* (London), vol. B66, pp. 50–53; January, 1953.

[44] A. F. Gibson, "Carrier extraction in germanium," *Physica*, vol. 20, pp. 1058–1059; 1954.

[45] A. F. Gibson, J. W. Granville, and W. Bardsley, "A germanium point-contact transistor to operate at high ambient temperatures," *Brit. J. Appl. Phys.*, vol. 6, pp. 251–254; July, 1955.

[46] J. B. Arthur, W. Bardsley, M. A. C. S. Brown, and A. F. Gibson, "Carrier extraction in germanium," *Proc. Phys. Soc.* (London), vol. B68, pp. 43–50; January, 1955.

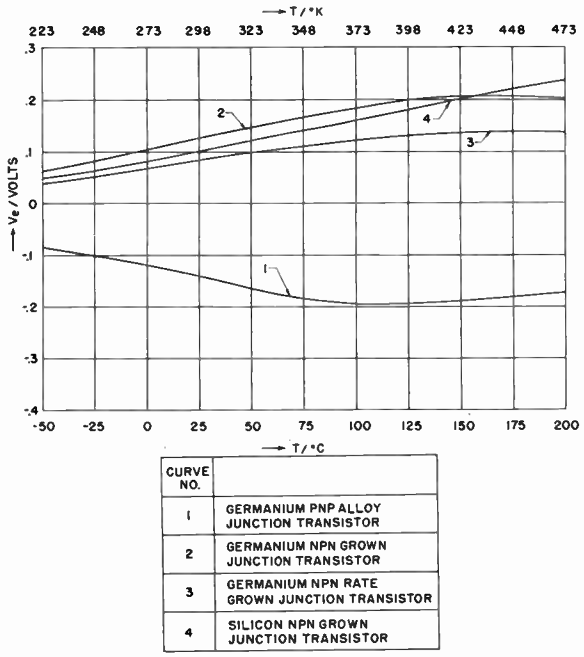


Fig. 15—Emitter voltage V_{eo} for $I_e=0$ as a function of temperature.

This occurs at lower temperatures for higher collector currents, and any reduction in collector current will lead to the same reduction in base current. For the silicon model, the crossover point again lies above 200°C.

Small-Signal Four-Pole Parameters

The small-signal y' parameters as defined by (1) and given by (6) and (7) depend on temperature as shown in Figs. 17 through 20, pp. 672–673.

The emitter and collector barrier capacitances which enter the higher frequency expressions of the four-pole parameters (6) are found to be practically constant with temperature.

y_{11}': The temperature behavior of the low frequency y_{11}' [Fig. 17(a)] can be understood by comparing (6a) with (5a). Since all the emitter regions are well doped for injection efficiency considerations the (low frequency) y_{11}' is practically given by

$$y_{11}' \simeq I_e \frac{q}{kT}\left[\frac{e^{qV_e/kT}\cdot\coth(w_o/L_{pb})}{e^{qV_e/kT}\coth(w_o/L_{pb}) - \coth(w_o/L_{pb}) + \operatorname{csch}(w_o/L_{pb})}\right]. \tag{32}$$

At lower temperatures and high-forward emitter voltages the bracketed factor which depends on the emitter voltage and the diffusion lengths in the base is practically equal to 1. This gives a $1/T$ dependence for y_{11}'. At the higher temperatures these factors increase, however, leading to the increase of y_{11}' in Fig. 17(a). Only for the rate grown transistor with its relatively high resistivity emitter region does the hole current from base to emitter help to increase y_{11}'. In the case of silicon, the emitter voltage does not become small enough to show any of the above effects below 200°C.

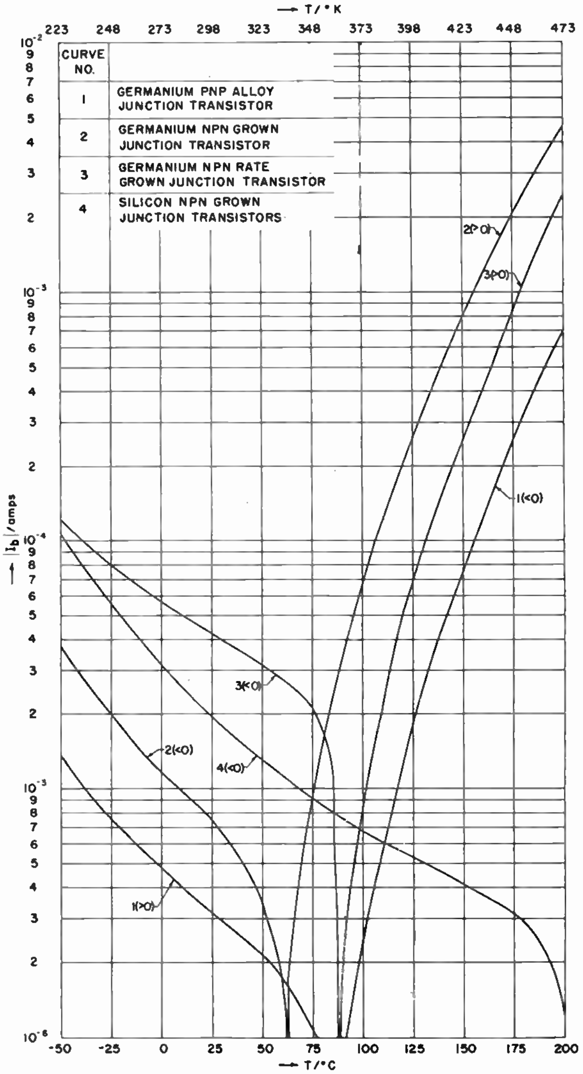


Fig. 16—Base current I_b under ordinary bias conditions as a function of temperature.

At the higher frequencies [Fig. 17(b)], the real part of y_{11}' is not greatly affected unless the frequency exceeds the alpha cut-off frequency (as curves 4b for the silicon transistor), and the temperature dependence closely resembles the low-frequency curves. The imaginary part of y_{11}' shows a similar behavior as the real part, only modified by a factor which is essentially proportional to $1/D_b$. Thus, where D decreases approximately as $1/T$ (p-n-p alloy junction transistor, curve 2p of Fig. 8) the low temperature portion of the curve is almost constant. Where D, however, shows little tem-

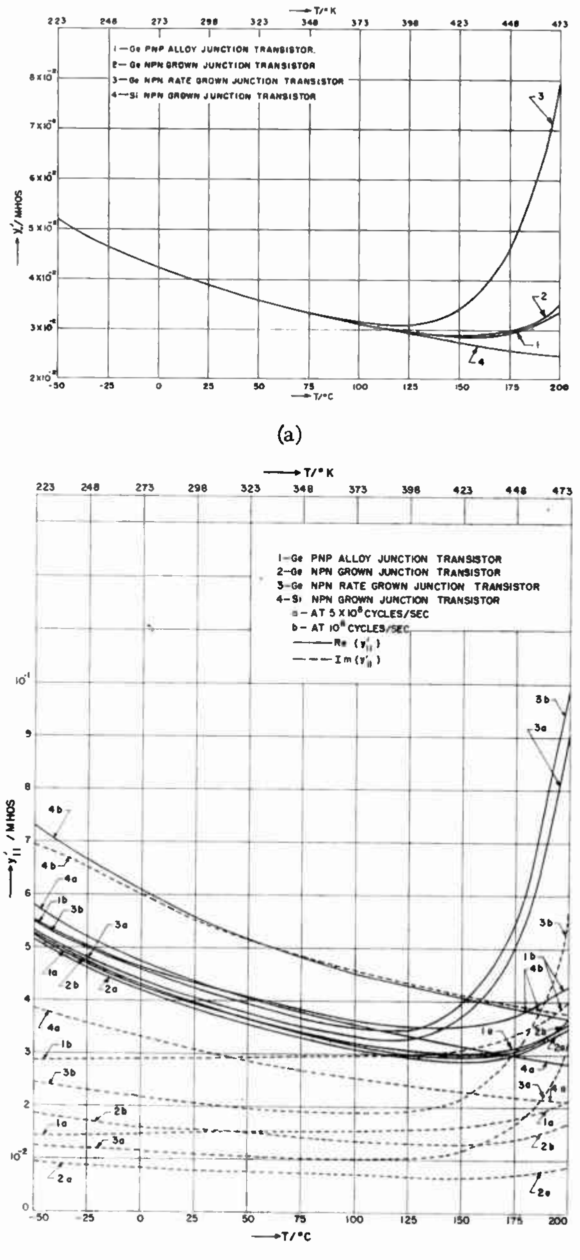


Fig. 17—(a) Four-pole parameter y_{11}' as a function of temperature (frequency $f=0$ cps); (b) four-pole parameter y_{11}' as a function of temperature.

perature variation (silicon transistor, curve 8a of Fig. 8), the low temperature decrease of the imaginary y_{11}' curve is close to the $1/T$ behavior of the real part [curves 4 of Fig. 17(b)]. The other cases are intermediate.

y_{12}': The temperature dependence of the low frequency y_{12}' is shown in Fig. 18(a). The constancy of the lower temperature portions of the curves for the three *n-p-n* transistors is understood on the basis of the almost constant collector hole current to which y_{12}' is proportional. The three grown junction transistors (curves 2, 3, 4) also have the identical space charge widening factor $(\partial w/\partial V_c)$ (for graded junctions) so that they differ only by their low-frequency current amplification factors, and diffusion lengths in the base. At higher temperatures, the values increase (sign!) in keeping with the trend in I_c (see Fig. 13). The *p-n-p*

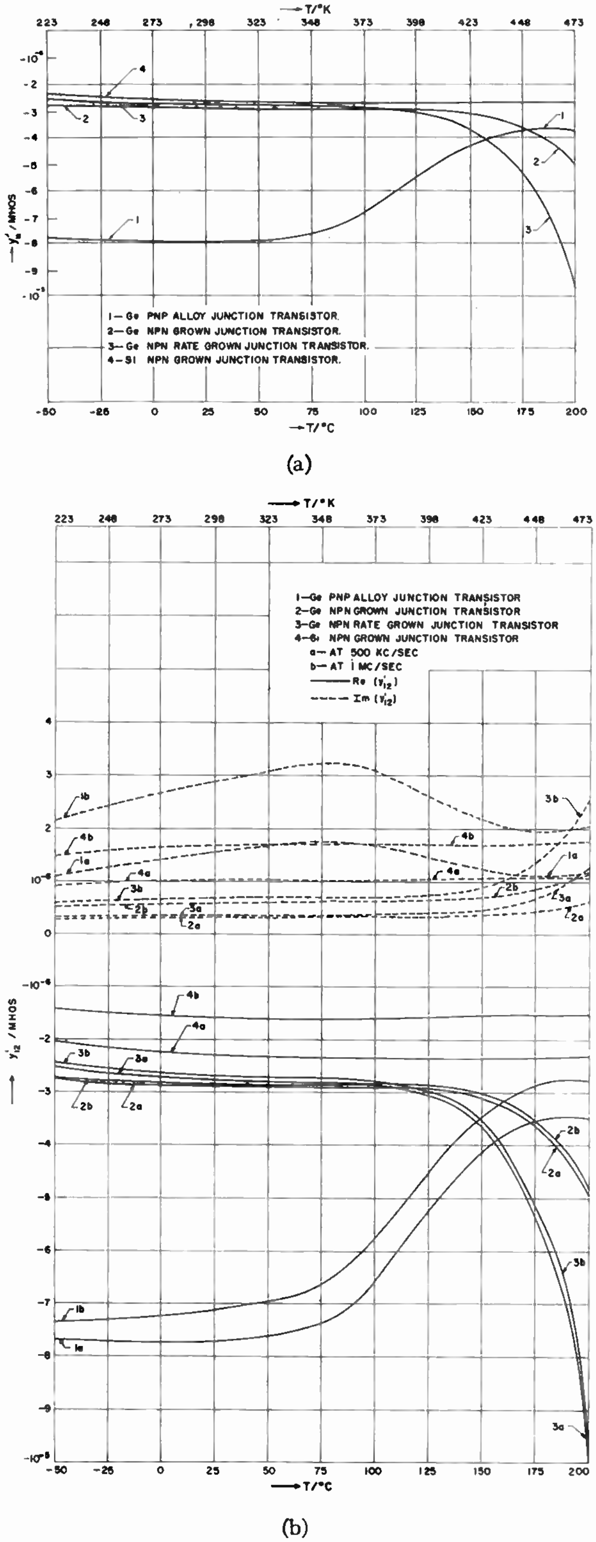


Fig. 18—(a) Four-pole parameter y_{12}' as a function of temperature (frequency $f=0$ cps); (b) four-pole parameter y_{12}' as a function of temperature.

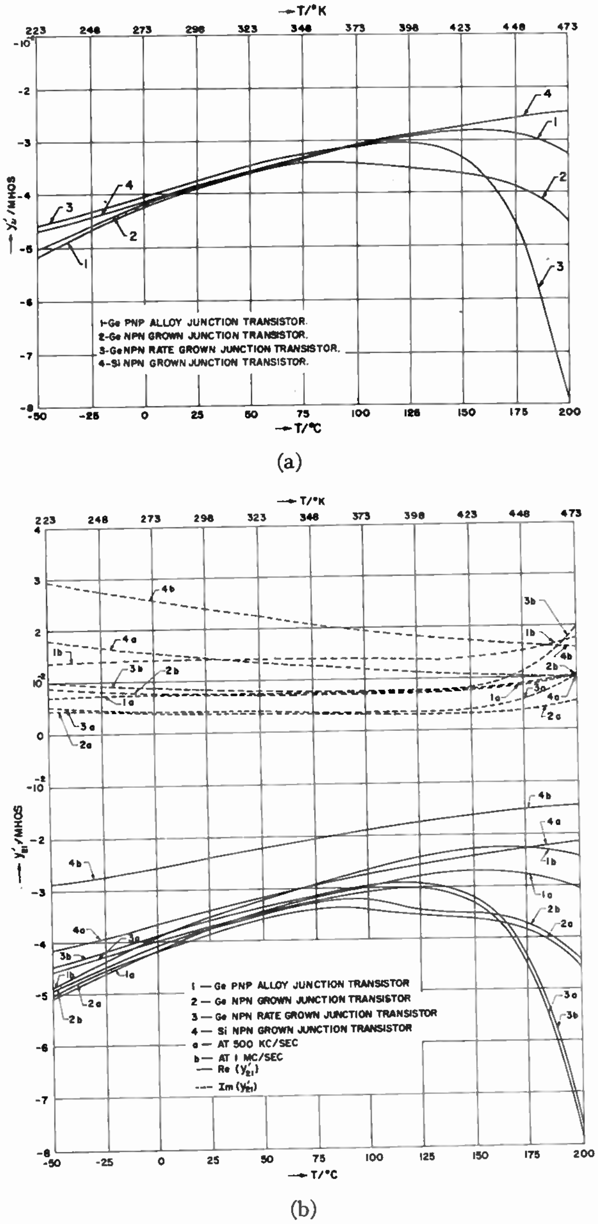


Fig. 19—(a) Four-pole parameter y_{21}' as a function of temperature (frequency $f=0$ cps); (b) four-pole parameter y_{21}' as a function of temperature.

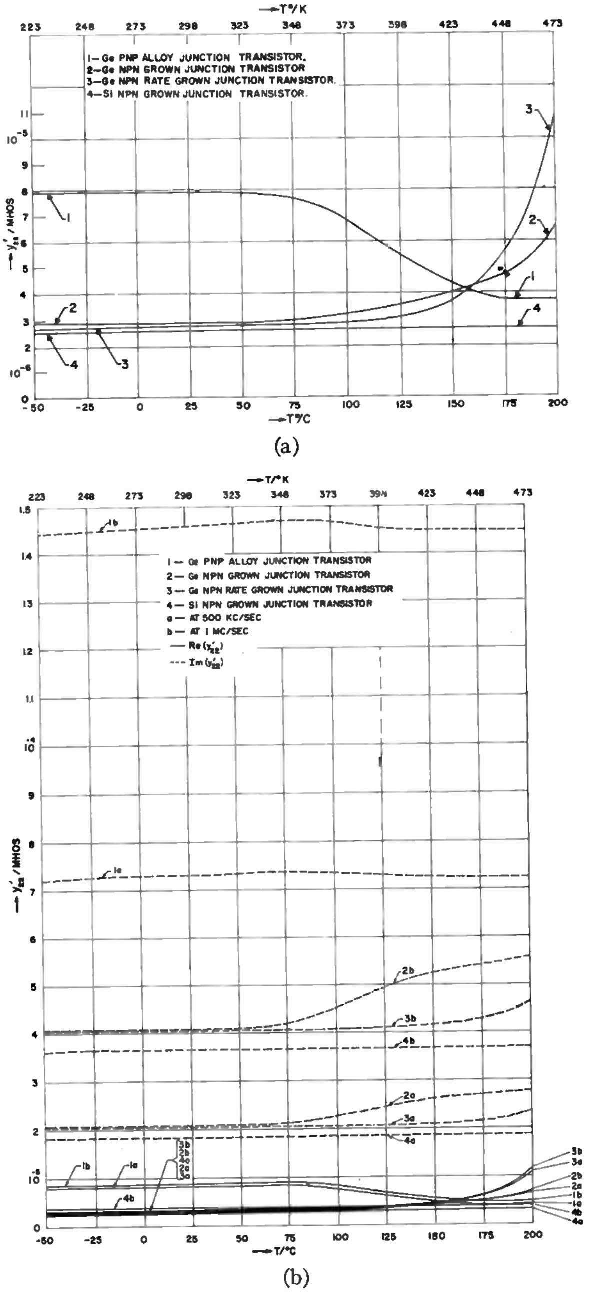


Fig. 20—(a) Four-pole parameter y_{22}' as a function of temperature (frequency $f=0$ cps); (b) four-pole parameter y_{22}' as a function of temperature.

alloy transistor (curve 1) has a different $(\partial w/\partial V_c)$, for step junctions, which changes proportional to $n_{ob}^{-1/2}$ and accounts for most of the differences in the temperature behavior as compared to the graded junction transistors. The low temperature constancy of the y_{12}' is here due to the almost constant collector hole current [compare (6b) and (5b)] and the practically constant majority carrier density, n_o, in the base. As soon as n_o increases (see Fig. 6), y_{12}' starts to decrease, but at the highest temperatures, the increase in I_c finally leads to an increase in y_{12}' also for the *p-n-p* alloy transistor. No changes occur for the silicon model because of its constant collector current (Fig. 13, curve 4).

The temperature behavior of y_{12}' at the higher frequencies is shown in Fig. 18(b). With the operating frequency below the alpha cut-off frequency, the real parts show no great differences as compared to the low-frequency behavior of Fig. 18(a). The imaginary part of y_{12}' shows the same general trend, but modified by a factor essentially proportional to the diffusion constant in the base (Fig. 8). Correspondingly, the *p-n-p* alloy junction transistor is most affected (see curves 2p, 4n, 6n, 8n in Fig. 8) whereas the other curves are only slightly modified.

y_{21}': Very similar considerations apply to the low frequency y_{11}' and y_{12}' as is seen by comparing (6c) with

(5a) and looking at the curves of Fig. 19(a) (note that $y_{21}'<0$). The differences at the low-temperature end stem from the differences in the coth and csch functions. The high-temperature curves, too, are similar to the ones for y_{11}' except for the grown *n-p-n* transistor where the collector multiplication is noticeable due to the high-collector resistivity.

At the higher frequencies [Fig. 19(b)], we find the same picture as previously, namely, slightly changed real parts and the imaginary parts modified by the diffusion constant in the base.

y_{22}': The low frequency y_{22}' [Fig. 20(a)] is very similar to y_{12}' except for the slight differences in the csch and coth functions. The collector multiplication factor which is of influence only in the grown junction germanium transistor raises y_{22}' faster than y_{12}' [curves 2 in Figs. 18(a) and 20(a)].

At the higher frequencies [Fig. 20(b)], the real part is not changed appreciably and the imaginary part is dominated by the essentially constant collector capacitance.

h′ parameters: The h' parameters which are calculated from the y's according to (3), are shown in Figs. 21 through 24, pp. 675–677, and can be understood on the basis of these conversion equations.

As we go from the y' to the h' and h parameters, the mathematical expressions become more involved and limitations in space prohibit discussion of all the details. h_{11}' (Fig. 21) is simply the reciprocal of y_{11} (Fig. 17). h_{12}' is equal to $-y_{12}'\cdot h_{11}'$ so that a comparison with Figs. 18 and 21 explains Fig. 22. The temperature dependence of h_{21}', given by $y_{21}'\cdot h_{11}'$ and shown in Fig. 23, may be understood by comparing Fig. 23 with Figs. 19 and 21. h_{22}' is shown in Fig. 24. The low temperature curve is easily understood if (3d) is written in the form of $h_{22}'=y_{22}'-y_{12}'\cdot h_{21}'$ (see Figs. 18, 20, and 23). At the higher frequencies, the imaginary part of h_{22}' is dominated by the collector capacitance.

Base Spreading Resistance, r_b': As mentioned in the third section, the description of the transistor is not complete without considering the base spreading resistance r_b', (Fig. 25, p. 678). As seen from (10) and (11) r_b' is proportional to the resistivity of the base region and Fig. 25 is easily explained by comparison with Fig. 9. The values of r_b' are now combined with the h' to yield the actual h parameters.

h parameters: The h parameters are given by (4) and calculations show that at low frequencies only h_{11} (Fig. 26, p. 678) and h_{12} (Fig. 27, p. 679) are noticeably affected by r_b' whereas changes occur in all four parameters at the higher frequencies. h_{11} is shown in Fig. 26(a) and (b). The additional term as compared to h_{11}' [see (4)] raises the low temperature portion of the low frequency h_{11} curves [Fig. 26(a)] with respect to h_{11}' [Fig. 21(a)]. Especially interesting is curve 2 of Fig. 26(a) where h_{11} goes to negative values causing instability in some circuits. This is due to the fact that for the regular grown germanium *n-p-n* transistor h_{21} exceeds 1 (see Fig. 23). With decreasing base spreading resistanc the effect is diminished and h_{11} returns to positive value Fig. 27(a) and 27(b) shows the temperature behavior o the h_{12} parameter which is most affected by the bas spreading resistance. Looking at (4), the curves can b understood by comparing them with Fig. 25 (r_b') an Fig. 24(b) (h_{22}'). Little influence of r_b' on h_{21} and h [Figs. 23(a)–(d); 24(a)–(c)] is noticed even at th higher frequencies [compare Figs. 23(b), 24(b) wit 23(c), 24(c)]. Since it is customary to represent $h_{21}=-$ by magnitude and phase rather than by real and imaginary parts such a plot has been included [Fig. 23(d)]

The alpha cut-off frequency is an important quantit in the characterization of the frequency behavior of transistor. It is given by (12) and shown in Fig. 28, p 679. Since there is direct proportionality with the diffusion constants, curves 1, 2, 3, 4 of Fig. 28 may b understood by comparing them with curves 2p, 4n, 6n 8n respectively of Fig. 8.

Early[10] has pointed out that there exists a base resistance modulation feedback, μ_{bc}, in the transistor. I is given by

$$\mu_{bc}\simeq I_b\rho_b\left(\frac{1}{8\pi w_1^2}+\frac{1}{2\pi w_2^2}\ln\frac{r_2}{r_1}\right)\frac{\partial w}{\partial V_c} \qquad (34$$

for the *p-n-p* and by

$$\mu_{bc}\simeq I_b(r_b/w)(\partial w/\partial V_c) \qquad (35)$$

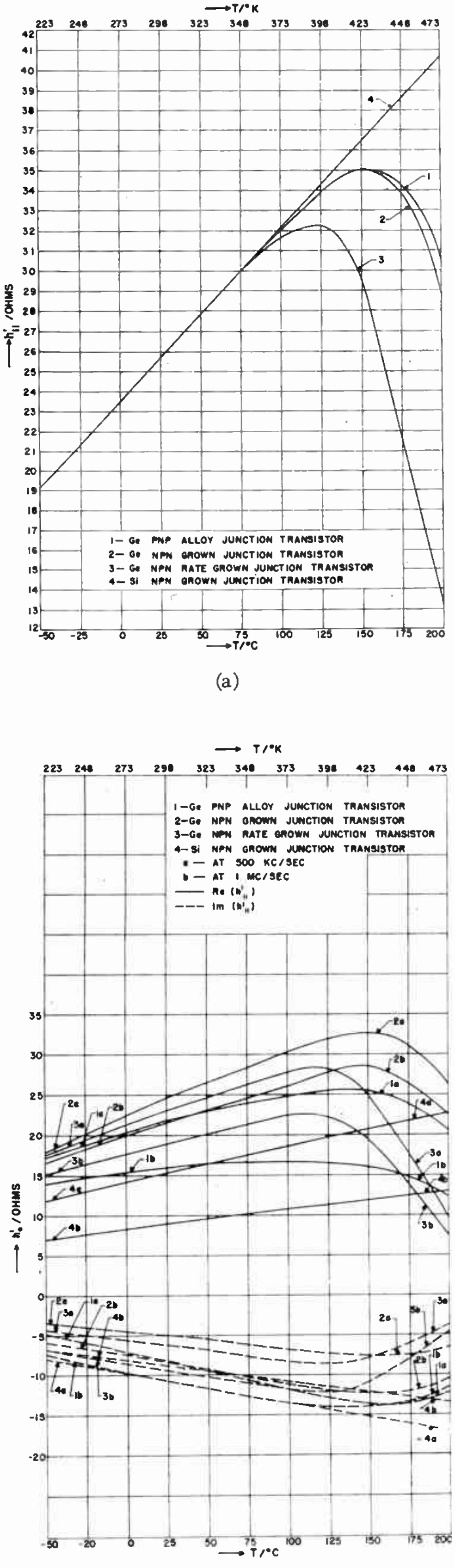
for the *n-p-n* transistor. It is shown in Fig. 29, p. 679. The curves follow the general pattern of the I_b curve (Fig. 16) modified by the temperature behavior of the base resistivity (Fig. 9).

Equivalent Circuits

The temperature variations of the parameters for the simplified equivalent circuit [Fig. 5, (13) through (15)] are easy to understand on the basis of the previous discussions because of the mathematical similarities between g_{ee} and y_{11} [Fig. 17(a)], between g_{ce} and y_{22} [Fig. 20(a)], and between ω_α and $f_{\alpha co}$ (Fig. 28).

VI. CONCLUSION

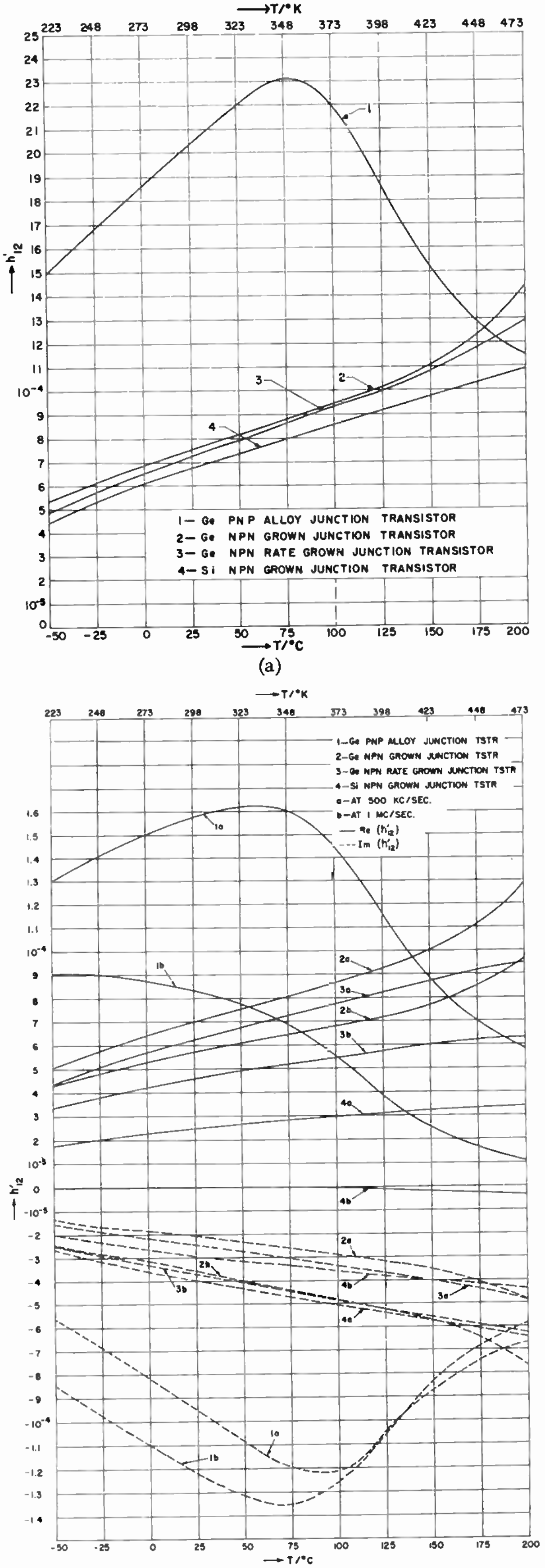
Some general conclusions as to the construction of high-temperature transistors may be drawn from the above considerations. Particular applications may require special designs, but for general purposes the following guide lines will yield satisfactory results: low collector resistivity reduces I_{co} and prevents alpha from becoming greater than 1. For a further reduction in I_{co} the base should be doped as highly as emitter efficiency and alpha cut-off frequency permit. On the other hand, if the small signal parameters rather than bias problems are the major consideration, base doping for temperature insensitive diffusion constant (different for *p-n-p* or *n-p-n* transistors) seems more desirable. Graded collector junctions appear superior to step junctions.



(a)

(b)

Fig. 21—(a) Four-pole parameter h_{11}' as a function of temperature (frequency $f=0$ cps); (b) four-pole parameter h_{11}' as a function of temperature.



(a)

(b)

Fig. 22—(a) Four-pole parameter h_{12}' as a function of temperature (frequency $f=0$ cps); (b) four-pole parameter h_{12}' as a function of temperature.

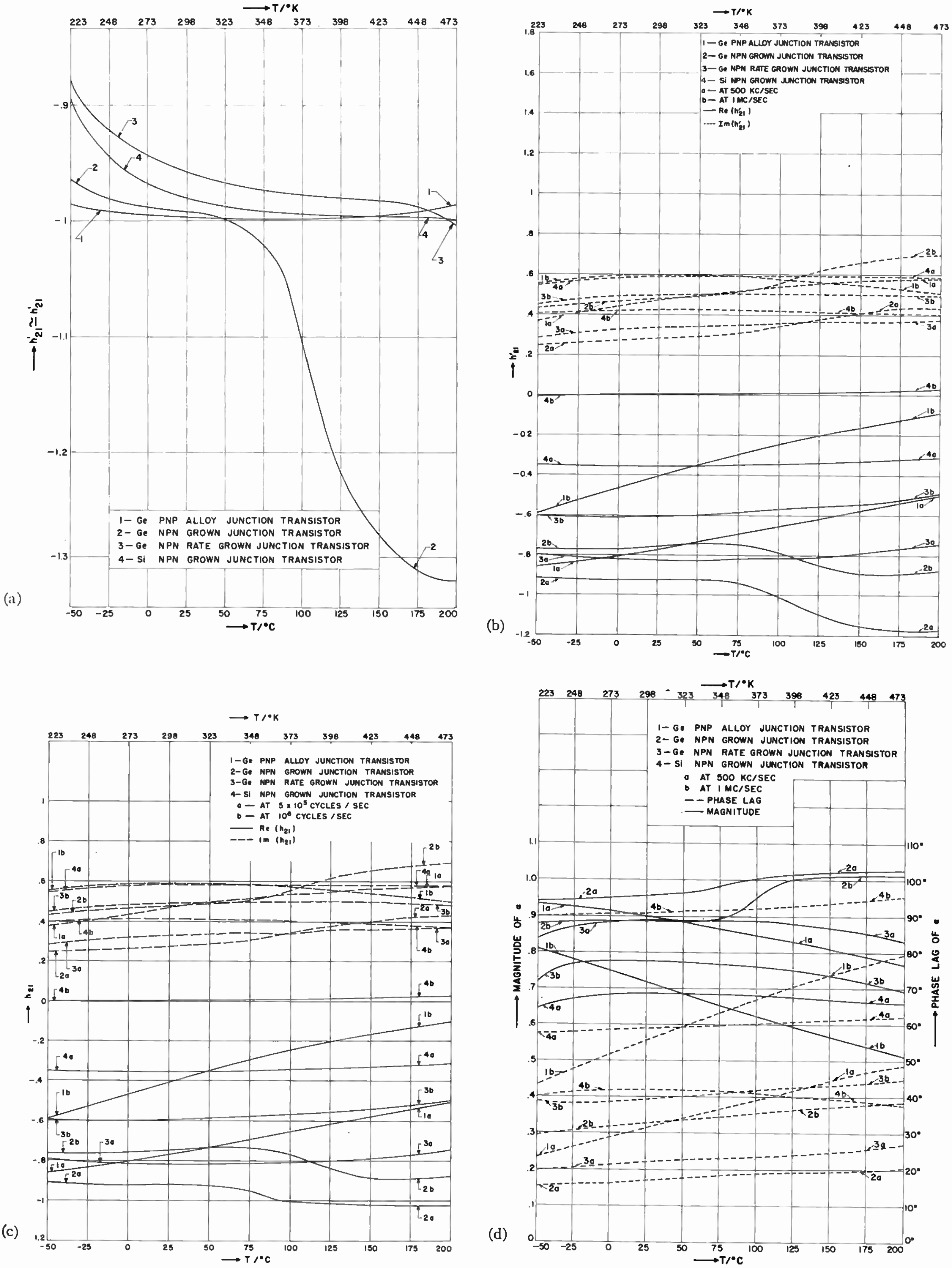
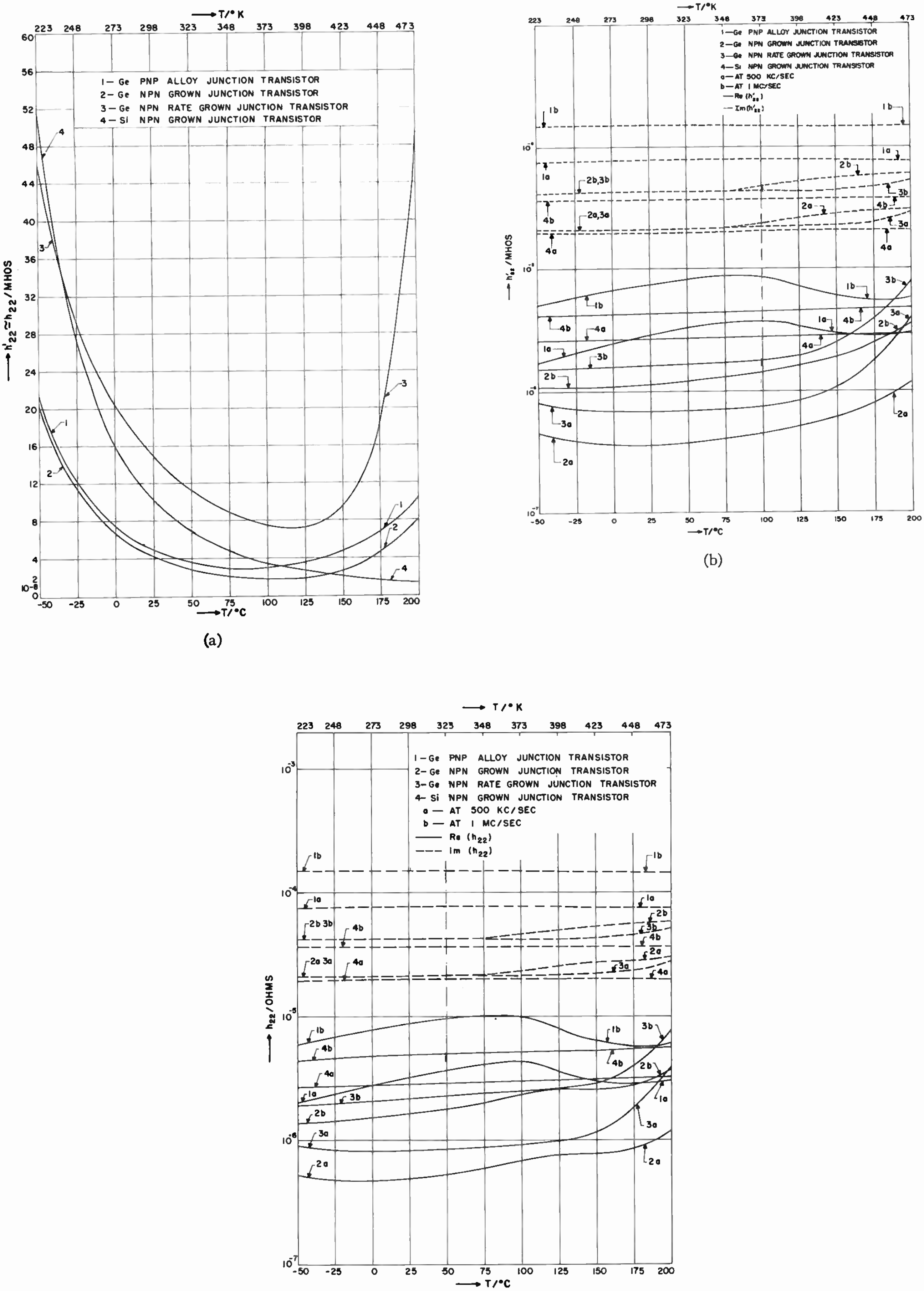


Fig. 23—(a) Four-pole parameter $h_{21}' \simeq h_{21}$ as a function of temperature (frequency $f = 0$ cps); (b) four-pole parameter h_{21}' as a function of temperature; (c) four-pole parameter h_{21} as a function of temperature; (d) short circuit current amplification factor $\alpha = -h_{21}$ as a function of temperature.



(a)

(b)

(c)

Fig. 24—(a) Four-pole parameter $h_{22}' \simeq h_{22}$ as a function of temperature (frequency $f = 0$ cps); (b) four-pole parameter h_{22}' as a function of temperature; (c) four-pole parameter h_{22} as a function of temperature.

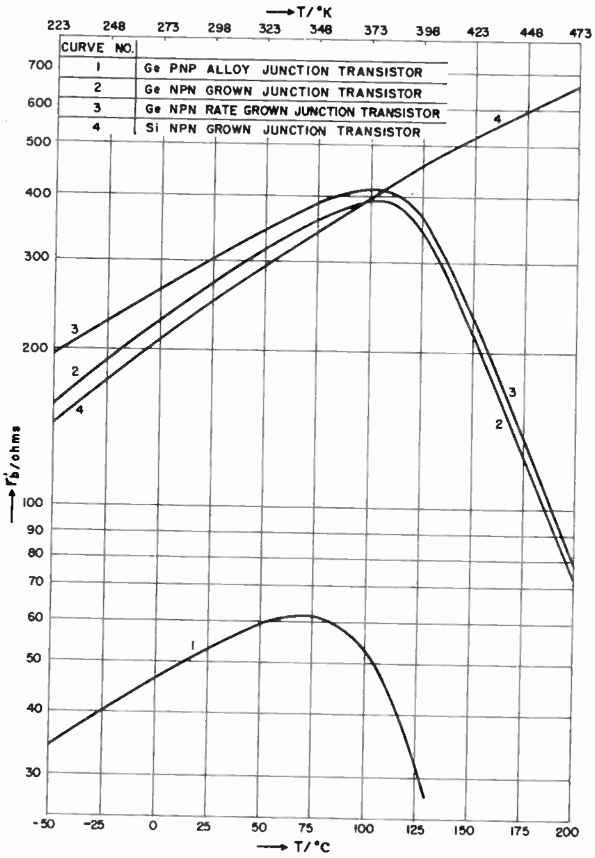


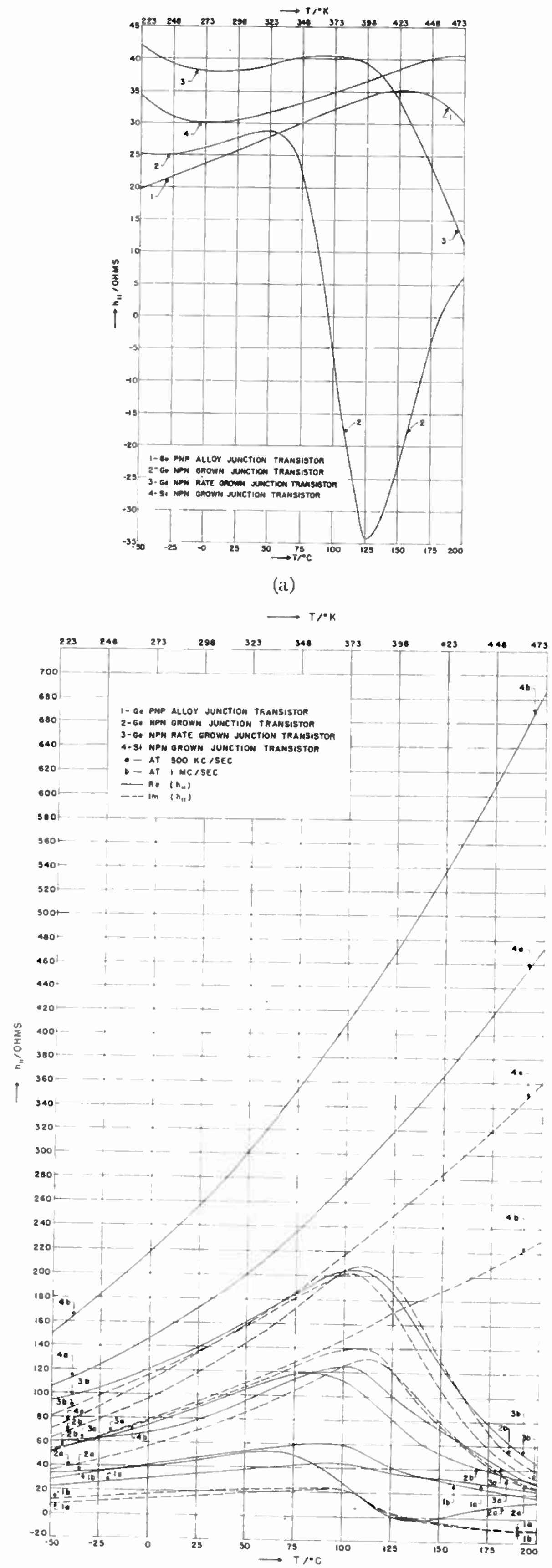
Fig. 25—Base spreading resistance r_b' as a function of temperature.

The question of upper limit of performance of a transistor depends on what deviations from room temperature values one wants to allow and to what extremes of stabilization one wants to go.

Although each case has to be investigated separately, the foregoing analysis seems to show that germanium units incorporating the "high temperature design" features will operate satisfactorily above 100°C, possibly up to 150°C, whereas it should be possible to build silicon transistors which operate well in excess of 200°C, if operation with slightly reverse emitter voltage is excluded because of the radical changes which then occur in the small signal parameters.

The calculations also show that the theoretical collector current does not become large enough to cause runaway by internal heating.

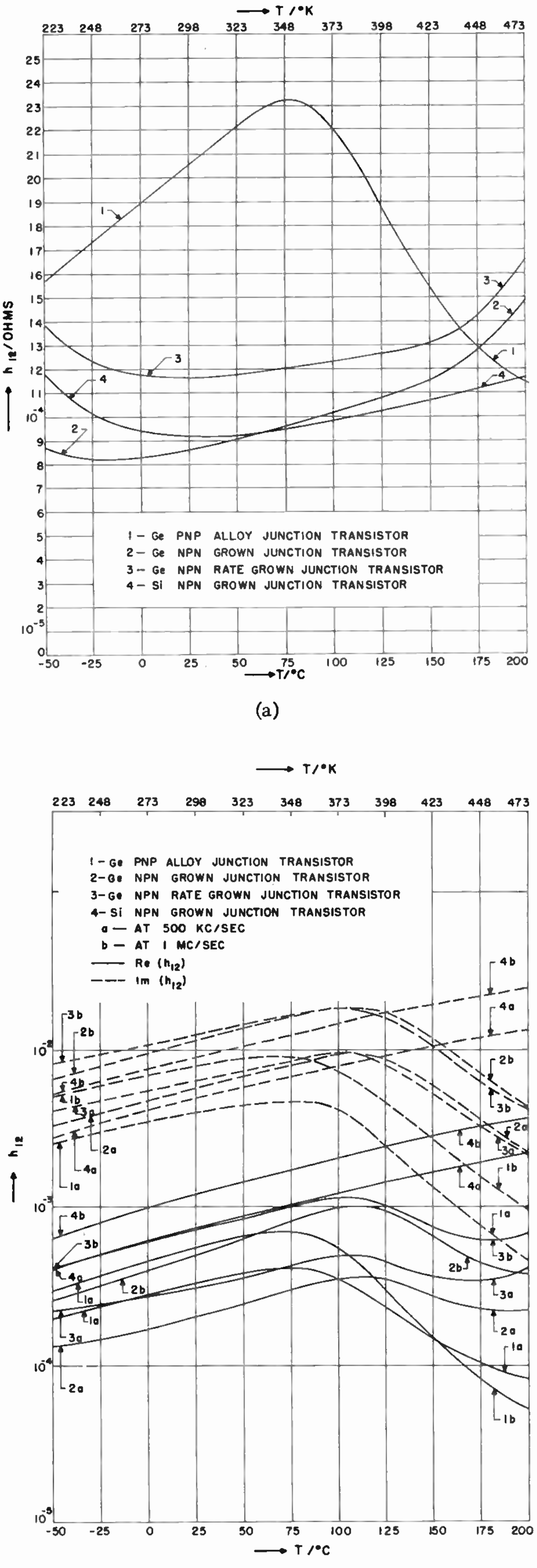
This accentuates an important result of the above considerations: the semiconductor nucleus of the transistor can be designed to operate at high temperatures and the actual performance of a finished unit will depend upon how carefully the junctions have been prepared and to what degree it has been possible to avoid the deleterious effects of solders, fluxes, moisture, gaseous ambients, potting compounds, etc. on the temperature characteristics. Next to proper design these problems have to be given the greatest attention because they are equally essential to the construction of a high temperature transistor.



(a)

(b)

Fig. 26—(a) Four-pole parameter h_{11} as a function of temperature (frequency $f=0$ cps); (b) four-pole parameter h_{11} as a function of temperature.



(a)

(b)

Fig. 27—(a) Four-pole parameter h_{12} as a function of temperature (frequency $f=0$ cps); (b) four-pole parameter h_{12} as a function of temperature.

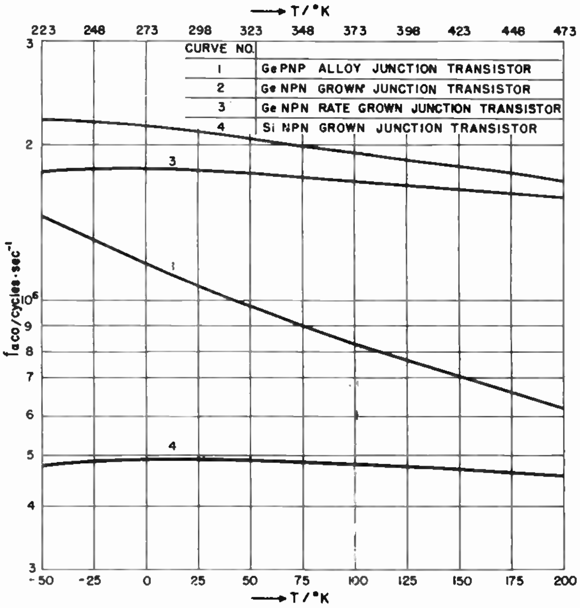


Fig. 28—Alpha cut-off frequency $f_{\alpha co}$ as a function of temperature.

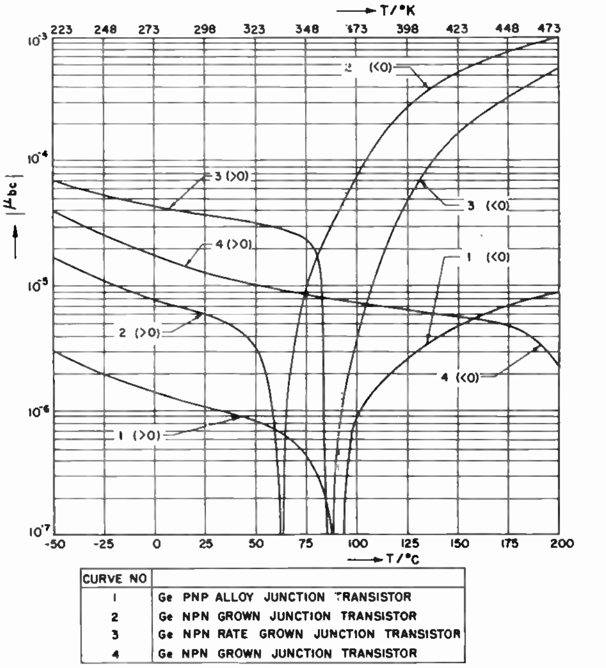


Fig. 29—Base resistance modulation feedback μ_{bc} as a function of temperature.

LIST OF SYMBOLS

A	Conducting cross section of semiconductor bar.
A_c	Collector area of alloy junction transistor.
A_e	Emitter area of alloy junction transistor.
a	Gradient of total impurity density across junction.
C_c	Collector capacitance.
C_e	Emitter capacitance.

D_{nb}	Diffusion constant of electrons in base region.
D_{nc}	Diffusion constant of electrons in collector region.
D_{ne}	Diffusion constant of electrons in emitter region.
D_{pb}	Diffusion constant of holes in base region.
D_{pc}	Diffusion constant of holes in collector region.
D_{pe}	Diffusion constant of holes in emitter region.
E_c	Lower edge of conduction band.
E_f	Fermi level.
E_t	Recombination level.
E_v	Upper edge of valence band.
$f_{\alpha co}$	Alpha cut-off frequency
g_{cc}	Conductance in equivalent circuit (Fig. 5) given by (14).
g_{ee}	Conductance in equivalent circuit (Fig. 5) given by (13).
h_{11}, h_{12}, h_{21}, h_{22}	Four-pole parameters defined by (4).
h_{11}', h_{12}', h_{21}', h_{22}'	Four-pole parameters defined by (3).
I_c	DC Collector current (for $I_e = \pm 1$ ma).
I_{co}	DC Collector current for $I_e = 0$.
I_e	DC emitter current.
i_c	AC collector current.
i_e	AC emitter current.
k	Boltzmann constant.
L_{nb}	Diffusion length of electrons in base region.
L_{nc}	Diffusion length of electrons in collector region.
L_{ne}	Diffusion length of electrons in emitter region.
L_{pb}	Diffusion length of holes in base region.
L_{pc}	Diffusion length of holes in collector region.
L_{pe}	Diffusion length of holes in emitter region.
m	Electron mass.
m_{eff}	Effective mass of electron or hole.
N_a	Density of acceptor atoms.
N_c	Effective density of states in the conduction band.
N_d	Density of donor atoms.
N_I	Density of scattering centers.
N_v	Effective density of states in the valence-band.
n_1	Electron density defined by (30a).
n_i	Intrinsic carrier density.
n_o	Equilibrium electron density.
n_{ob}	Equilibrium electron density in base region.
n_{oc}	Equilibrium electron density in collector region.
n_{oe}	Equilibrium electron density in emitter region.
p_1	Hole density defined by (30b)
p_o	Equilibrium hole density
p_{ob}	Equilibrium hole density in base region.
p_{oc}	Equilibrium hole density in collector region.
p_{oe}	Equilibrium hole density in emitter region.
q	Electron charge.
r_b'	Base spreading resistance.
T	Temperature.
V_c	DC collector voltage.
V_e	DC emitter voltage (for $I_e = \pm 1$ ma).
V_{eo}	DC emitter voltage for $I_e = 0$.
v_c	AC collector voltage.
v_e	AC emitter voltage.
w_o	Base width of transistor.
$\partial w / \partial V_c$	Space charge widening factor.
y_{11}', y_{12}', y_{21}', y_{22}'	Four-pole parameters defined by (1).
ϵ_o	Permittivity of free space.
κ	Dielectric constant.
μ_{bc}	Base resistance modulation feedback given by (34) and (35).
μ_I	Impurity mobility.
μ_L	Lattice mobility.
μ_{nb}	Electron mobility in base region.
μ_{nc}	Electron mobility in collector region.
μ_{ne}	Electron mobility in emitter region.
μ_{nL}	Lattice mobility for electrons.
μ_{pb}	Hole mobility in base region.
μ_{pc}	Hole mobility in collector region.
μ_{pe}	Hole mobility in emitter region.
μ_{pL}	Lattice mobility for holes.
ω	Circular frequency.
ω_α	Frequency parameter in equivalent circuit (Fig. 5) given by (15).
ρ_b	Resistivity in base region.
ρ_c	Resistivity in collector region.
ρ_e	Resistivity in emitter region.
τ	Carrier lifetime.
τ_{nb}	Lifetime of electrons in base region.
τ_{nc}	Lifetime of electrons in collector region.
τ_{ne}	Lifetime of electrons in emitter region.
τ_{no}	Lifetime of electrons injected into highly p-type material.
τ_{pb}	Lifetime of holes in base region.
τ_{pc}	Lifetime of holes in collector region.
τ_{pe}	Lifetime of holes in emitter region.
τ_{po}	Lifetime of holes injected into highly n-type material.

VII. ACKNOWLEDGMENT

I have to thank my former colleagues at Siemens and Halske, A. G. Halbleiterfabrik, Munich, Germany for many interesting discussions as well as Drs. R. L. Pritchard and R. N. Hall of the General Electric Research Laboratory, and F. A. Brand and W. G. Matthei, Evans Signal Laboratory for corrections and helpful suggestions regarding the manuscript. Particular thanks are due to D. E. Amos of Oregon State College and W. Nakamura of Evans Signal Laboratory for carrying out all the numerical calculations.

Design of Three-Resonator Dissipative Band-Pass Filters Having Minimum Insertion Loss*

J. J. TAUB†, MEMBER, IRE AND B. F. BOGNER†, MEMBER, IRE

Summary—**The purpose of this paper is to present universal design curves for three-resonator band-pass filters having minimum insertion loss. This information is obtained by solving Dishal's equations for a band-pass network uniquely for the condition of minimum insertion loss, the network here consisting of three synchronously tuned resonant circuits (coupled to a resistive generator and a resistive load) having the same finite value of unloaded Q. The general solution for the maximally flat response is presented in detail in the second half of this paper.**

The exact values of the circuit constants for a minimum-insertion-loss response are given both analytically and graphically in terms of the unloaded Q and the fractional bandwidth. Also, the deviation from the exact response shape of a maximally flat filter is discussed for varying values of circuit constants.

INTRODUCTION

PRESENT-DAY design of narrow-band (less than 10 per cent bandwidth) band-pass filters employing synchronously-tuned coupled resonant circuits stems essentially from Dishal's design equations[1] for dissipative band-pass filters. Dishal's equations enable the designer to calculate, for each resonator, the coefficients of coupling and the decrements that will yield the desired amplitude-frequency filter response. These equations were derived by expressing the transfer impedance of an n-coupled synchronously-tuned set of resonant circuits in terms of their coefficients of coupling and decrements. This is equated to the transfer impedance corresponding to the desired relative insertion-loss function (usually a Tchebycheff function[2] with a given pass-band ripple). By equating the n coefficients of each, Dishal obtained sets of design equations for different numbers of resonant circuits. Examination of these relationships reveals n equations containing $n+1$ unknowns ($n-1$ coefficients of coupling and two decrements—the first and the last). For any given problem, the other decrements and the desired bandwidth are known.

The solution of Dishal's equations will yield many sets of circuit constants that would produce the desired response. By imposing the additional condition that the insertion loss—the ratio of the power available from a resistive generator to the power delivered to a resistive load—be minimum, a unique set of circuit constants can be obtained. This principle has been used by the authors to obtain design information for three-resonator filters, with either maximally flat or Tchebycheff-type response. (Only the case of maximally flat response is discussed in detail here.) The only assumption made in this analysis is that the unloaded Q is the same for each of the resonant circuits. In practice, this is usually the case.

The first section presents the curves that give the design information, together with an explanation of their use. An illustrative example is given. The second section describes the derivation and computation of the curves and includes a theoretical evaluation of the criticalness of the design. An expression for midband insertion loss is derived in Appendix I. Appendix II discusses the effect on maximally flat response of small variations in circuit constants.

Symbols are defined below. For clarity, the notation used by Dishal is employed wherever possible, in order to show the logical extension to the optimum design. To obtain universal curves, it was necessary to normalize the circuit constants to the 3-db fractional bandwidth. Fig. 1 shows the relations used in normalizing. (Although Fig. 1 depicts a voltage-fed network, by duality the analysis also holds for a current-fed network.)

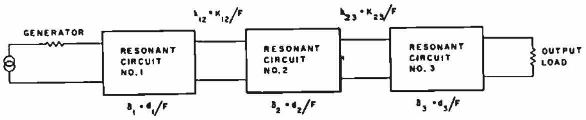


Fig. 1 —Block diagram of three-coupled circuit filter.

The subscripts 1, 2, and 3 denote: 1) resonant circuit 1 loaded only by the generator, 2) resonant circuit 2 in its unloaded condition, and 3) resonant circuit 3 loaded only by the output.

C = equivalent capacitance of resonant circuit
$d=1/Q$ = total resonant circuit decrement
$\delta=d/F$ = normalized decrement
F = total 3-db fractional bandwidth
f_0 = resonant frequency of each resonant circuit
$\omega_0=2\pi f_0$ = angular resonant frequency
g = equivalent conductance of resonant circuit
g_g = equivalent conductance of generator
g_L = equivalent conductance of load
I = magnitude of current from equivalent constant-current generator that drives network

---

* Original manuscript received by the IRE, July 3, 1956; revised manuscript received January 8, 1957.

† Airborne Instruments Lab., Mineola, N. Y.

[1] M. Dishal, "Design of dissipative band-pass filters producing desired exact amplitude-frequency characteristics," PROC. IRE, vol. 37, pp. 1050–1069; September, 1949.

[2] W. R. LePage and S. Seely, "General Network Analysis," McGraw-Hill Book Co., Inc., New York, N. Y., pp. 235–256; 1952.

K = resultant coefficient of coupling between resonant circuits
$k = K/F$ = normalized coefficient of coupling
L = midband insertion loss in db
L_r = relative insertion loss in db
n = number of resonant circuits
P_a = available input power
P_{out} = output power
$Q_1 = Q$ of first resonant circuit loaded only by the input
$Q_2 = Q_u$ = unloaded Q of second resonant circuit
$Q_3 = Q$ of third resonant circuit loaded only by the output
V_p = magnitude of voltage output at frequency of peak response
v = relative voltage response
$\phi = 2(f - f_0)/(Ff_0)$ = normalized frequency variable

Design Procedures

Discussion of Design Curves

By definition, $\delta(=d/F=1/FQ)$ is the decrement for the resonant circuit designated by the subscript, normalized with respect to fractional bandwidth F; δ_2 is the value corresponding to unloaded Q_2. (Since it is assumed that the unloaded Q is the same for all three resonant circuits, Q_2 becomes Q_u.) The normalized coefficients of coupling are k_{12} and k_{23}.

For the sake of completeness, Dishal's minimum-Q curve for three-resonator filters[3] is reproduced here as Fig. 2. In Fig. 3 the loss curve for a particular response shape is plotted against δ_2/δ_{2max}, where δ_{2max} is the value of δ corresponding to Q_{min}, and Q_{min} is defined as the smallest value of unloaded Q that will produce a specified exact response shape with resulting infinite insertion loss. The loss curves shown are for maximally flat response and ½-db and 3-db Tchebycheff response. Those for 1-db and 2-db response fall between the ½-db and 3-db curves, and cannot be shown with clarity.

Fig. 3 therefore shows a useful common property of all three-resonator filters—for all response shapes the curves thus plotted are so close to each other that for engineering purposes they can be approximated by a single "universal" curve. This universal curve is especially important because it tells the designer what unloaded Q his resonators must have in order to satisfy a particular requirement on midband insertion loss.

The universal design charts are given in Fig. 4; they show the required values of δ_1, δ_3, k_{12}, and k_{23} as a function of δ_2 for maximally flat response [Fig. 4(a)] and for Tchebycheff-type response for peak-to-valley values of 0.5 db [Fig. 4(b)], 1 db [Fig. 4(c)], 2 db [Fig.

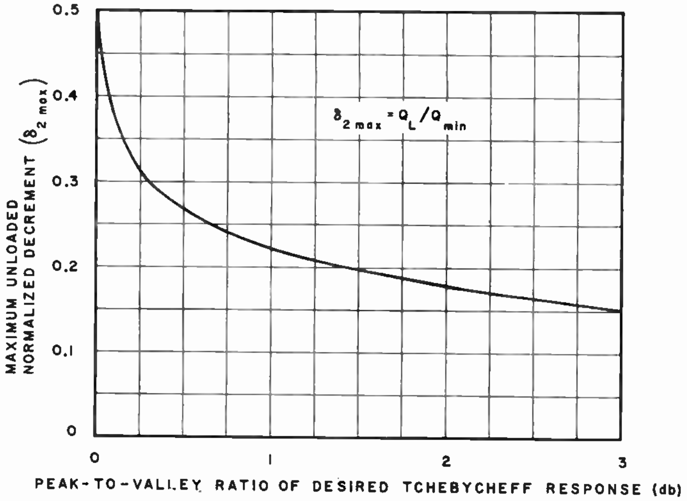


Fig. 2—Ratio of filter loaded Q to minimum unloaded Q required, as a function of peak-to-valley ratio for three resonator-filter.

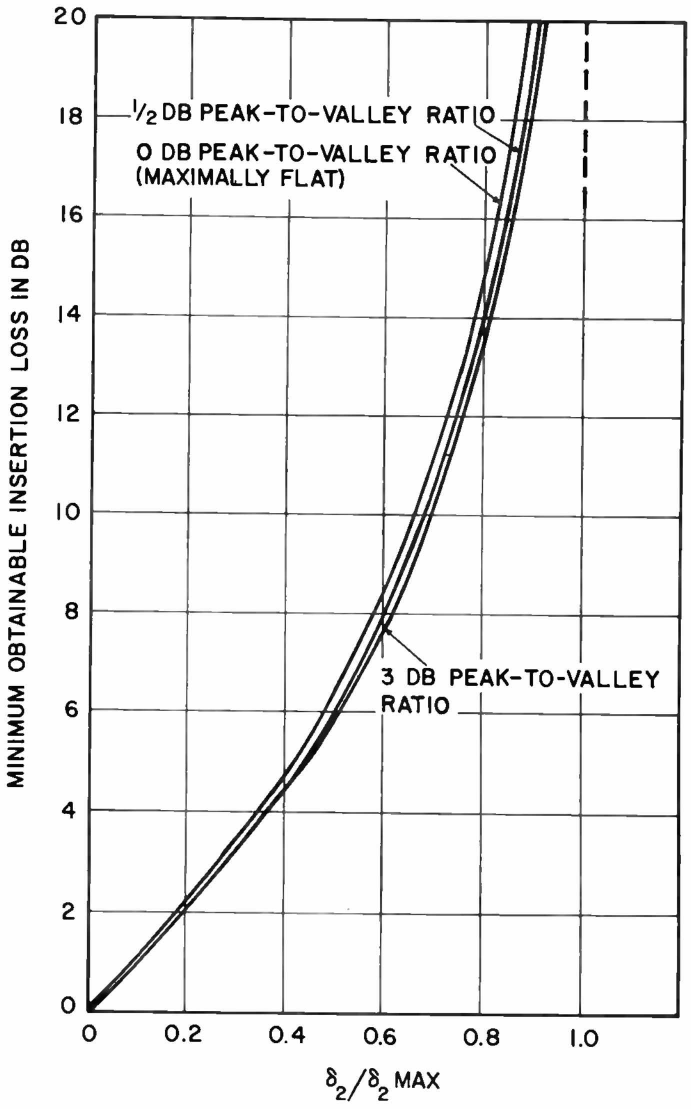
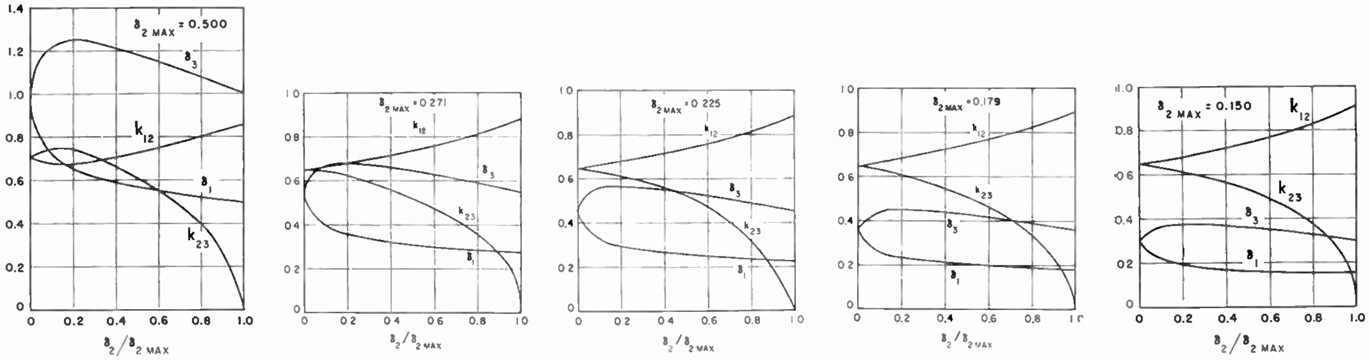


Fig. 3—Minimum insertion loss curves for three-resonator filters. (The curves for 1-db and 2-db response fall between the ½-db and 3-db curves.)

---

[3] M. Dishal, "Concerning the minimum number of resonators and the minimum unloaded-resonator Q in a filter," *Elec. Comm.*, vol. 32; pp. 257–277; December, 1954.



(a) (b) (c) (d) (e)

Fig. 4—Design charts for three-resonator Tchebycheff filters: (a) 0-db ripple (Butterworth), (b) ½-db ripple, (c) 1-db ripple, (d) 2-db ripple, and (e) 3-db ripple, where δ_1 = decrement of resonant circuit No. 1, δ_2 = unloaded decrement of each resonant circuit, δ_3 = decrement of resonant circuit No. 3, k_{12} is coefficient of coupling between resonant circuits No. 1 and No. 2, k_{23} = coefficient of coupling between resonant circuits No. 2 and No. 3—all normalized to 3-db fractional bandwidth.

4(d)], and 3 db [Fig. 4(e)]. From these charts the designer can readily obtain the unique values of circuit constants after the unloaded Q has been determined.

To summarize, Fig. 2 shows the designer the minimum unloaded Q he must have to realize a given response; Fig. 3 indicates the minimum insertion loss that can be attained for the prescribed unloaded Q; and the pertinent design chart of Fig. 4 shows directly the design values of circuit constants that will yield the desired filter.

The following example illustrates the use of these charts. Let the specifications for the filter be:

Center frequency (f_0): 10,000 mc
3-db bandwidth: 10 mc (fractional bandwidth $F = 10^{-3}$)
Maximum midband insertion loss (L): 10 db
Skirt response: 25 db down from peak ±15 mc from f_0.

A three-resonator maximally flat filter is chosen because it meets the response requirements—that is, the skirts are down 28.6 db from peak at ±15 mc.[4] From Fig. 2, for maximally flat response (peak-to-valley ratio 0 db), $\delta_{2\max} = 0.5$. From Fig. 3, for 10-db insertion loss, $\delta_2/\delta_{2\max} = 0.66$; hence $\delta_2 = 0.33$. Then the normalized design values of the circuit constants can be read from Fig. 4a: $\delta_1 = 0.53$, $\delta_3 = 1.13$, $k_{12} = 0.76$, and $k_{23} = 0.52$.

Since F here is 10^{-3}, and by definition $\delta_1 = d_1/F$, etc., the design values are

$$d_1 = 5.3 \times 10^{-4} \qquad K_{12} = 7.6 \times 10^{-4}$$

$$d_3 = 1.13 \times 10^{-3} \qquad K_{23} = 5.2 \times 10^{-4}.$$

These values are then properly set by using the method outlined by Dishal.[5]

Practical Considerations

The design procedure outlined above is based upon the assumption that the required value of Q_u is obtainable, though in many instances this is not the case. It is also conceivable that the Q_u realized in production may be different from that about which the filter was designed. In the second section deviations of response shape for variations in Q_u from an exact design value are considered. Fig. 5 (next page) shows these deviations for a particular value of δ_2. The results indicate that, for Q_u less than that required for a given insertion loss (Fig. 3), the 3-db bandwidth narrows and the skirt response deteriorates. For Q_u greater than the design value, the 3-db bandwidth widens and the skirts become steeper.

THEORETICAL CONSIDERATIONS

The solution for the unique set of constants yielding the required response with minimum midband insertion loss was first obtained by graphical means. This gave insight into the problems of filter design and enabled the authors to present the design procedures outlined previously. With the aid of this work, the analytical expressions for the design values were then derived by E. G. Fubini of Airborne Instruments Laboratory. His results indicate that exact solutions are obtainable for circuits containing three or more resonant coupled circuits. The work he is doing for four or more sections will be presented at a later date.

Solution of Design Equations

The design equations due to Dishal[1] for three coupled resonant circuits having a maximally flat response are

$$d_1 + d_2 + d_3 = 2F \tag{1a}$$

$$K_{12}^2 + K_{23}^2 + d_1d_2 + d_1d_3 + d_2d_3 = 2F^2 \tag{1b}$$

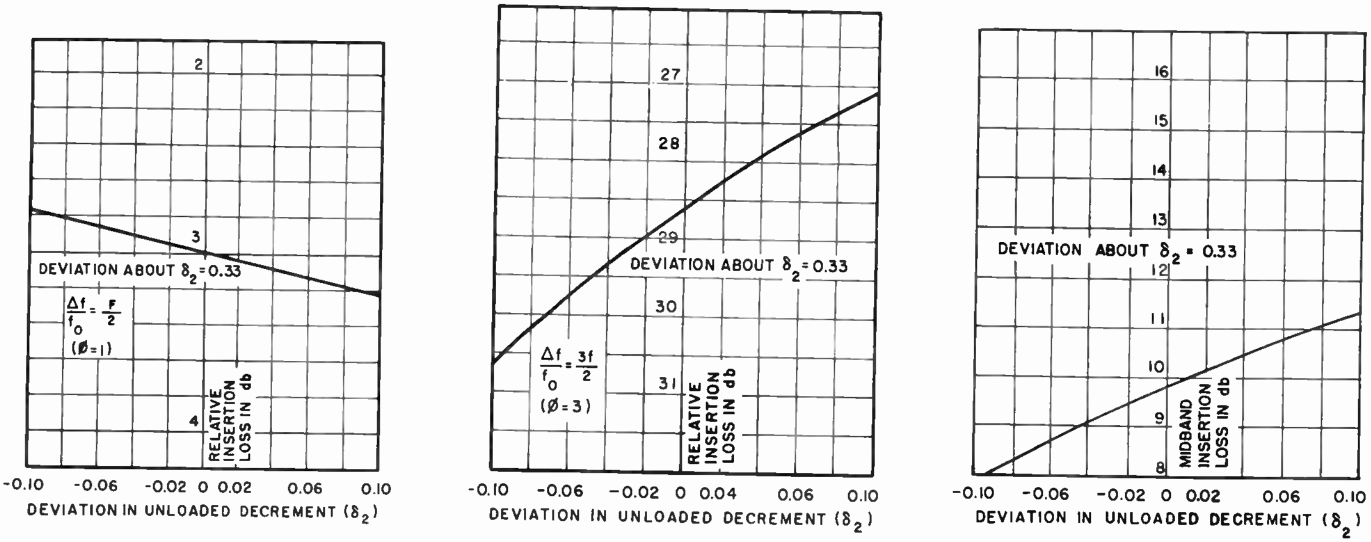
$$K_{12}^2d_3 + K_{23}^2d_1 + d_1d_2d_3 = F^3. \tag{1c}$$

These equations hold for both voltage-fed and current-

---

[4] S. Butterworth, "On the theory of filter amplifiers," *Experimental Wireless and Wireless Eng.* vol. 7, pp. 536–541; October, 1930.

[5] M. Dishal, "Alignment and adjustment of synchronously tuned multiple-resonant-circuit filters," PROC. IRE, vol. 39, pp. 1448–1455; November, 1951.



(a) (b) (c)

Fig. 5—Effect of change in unloaded decrement on (a) 3-db bandwidth, (b) filter response 1.5 bandwidths from center frequency, and (c) midband insertion loss, for three-resonator maximally flat filter.

fed networks. For convenience, they can be rewritten in terms of variables normalized to the fractional bandwidth F:

$$\delta_1 + \delta_2 + \delta_3 = 2 \tag{2a}$$

$$k_{12}^2 + k_{23}^2 + \delta_1\delta_2 + \delta_1\delta_3 + \delta_2\delta_3 = 2 \tag{2b}$$

$$k_{12}^2\delta_3 + k_{23}^2\delta_1 + \delta_1\delta_2\delta_3 = 1. \tag{2c}$$

An expression for midband insertion loss is derived in Appendix I. For maximally flat response it is

$$L = 10 \log \left[4k_{12}^2k_{23}^2(\delta_1 - \delta_2)(\delta_3 - \delta_2)\right]^{-1}. \tag{3}$$

By expressing L as a function of δ_1 and δ_2 and specifying the value of δ_2, a value of δ_1 that will minimize L can be obtained. To determine $L(\delta_1, \delta_2)$ it is necessary to utilize (2a), (2b), and (2c). The choice of δ_1 as the independent variable is arbitrary, since δ_1 and $\delta_3 (\delta_1 \leq \delta_3)$ are interchangeable in (2a), (2b), and (2c). Since δ_2 is known for a given design, the loss function is minimized with respect to δ_1. The factors of (3) expressed in terms of δ_1 and δ_2 are

$$\delta_3 - \delta_2 = 2(1 - \delta_2) - \delta_1 \tag{4a}$$

$$k_{12}^2 = \frac{(1 - \delta_1 + \delta_1^2)(1 - \delta_1)}{2 - 2\delta_1 - \delta_2} \tag{4b}$$

$$k_{23}^2 = \frac{[3 - 3(\delta_1 + \delta_2) + (\delta_1 + \delta_2)^2][1 - (\delta_1 + \delta_2)]}{2 - 2\delta_1 - \delta_2}. \tag{4c}$$

Substitution of (4a), (4b), and (4c) in (3) yields the expression for insertion loss, for which two methods of solution are shown: graphical and analytical.

Graphical Solution: Fig. 6 shows L plotted as a function of δ_1, with δ_2 as a parameter. From this plot the value of δ_1 that, for a given δ_2, produces minimum loss was then used to obtain the design curves of Fig. 4(a). Fig. 6 also shows that, for high-insertion-loss filters, it is important to be able to obtain the correct values of the constants, because the insertion loss rises rapidly from the minimum value obtainable.

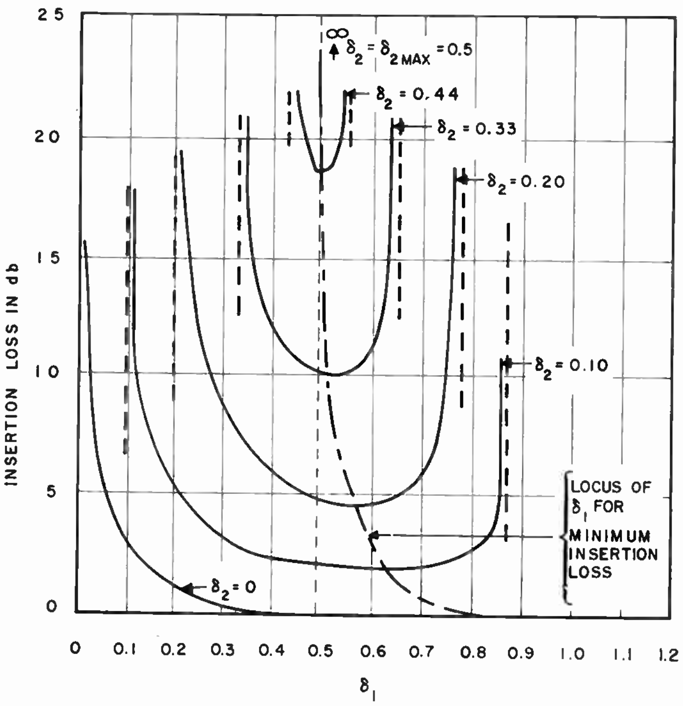


Fig. 6—Insertion loss as a function of δ_1 (input loading) with δ_2 (unloaded decrement) as a parameter, for a three-resonator maximally flat filter.

Analytical Solution: Since a complete presentation of the exact solution for a three-section minimum insertion loss Butterworth filter will be made at a later date, only the results are included. They are as follows.

$$\delta_1 = \delta_2 \frac{\alpha + 2 - \sqrt{\alpha^2 - 4\rho}}{2} \tag{5a}$$

$$\delta_3 = \delta_2 \frac{\alpha + 2 + \sqrt{\alpha^2 - 4\rho}}{2} \tag{5b}$$

$$k_{12}^2 = \delta_2^2 \left[\beta - \rho + \frac{\gamma - \alpha(\beta - \rho)}{\sqrt{\alpha^2 - 4\rho}} \right] \tag{5c}$$

$$k_{23}^2 = \delta_2^2 \frac{-\gamma + \alpha(\beta - \rho)}{\sqrt{\alpha^2 - 4\rho}} \tag{5d}$$

where

$$\alpha = \frac{1}{\delta_2} (2 - 3\delta_2) \tag{6a}$$

$$\beta = \frac{1}{\delta_2^2} (2 - 4\delta_2 + 3\delta_2^2) \tag{6b}$$

$$\gamma = \frac{1}{\delta_2^3} (1 - 2\delta_2 + 2\delta_2^2 - \delta_2^3) \tag{6c}$$

$$\rho = \frac{1}{\delta_2^2} \left[1 - \frac{8\delta_2}{3} + 2\delta_2^2 - \frac{\delta_2}{6} \sqrt{\frac{6 - 8\delta_2}{\delta_2}} \right]. \tag{6d}$$

Deviations from Exact Shape

Knowing the circuit constants of a filter that will give the desired response shape and minimum loss, the designer is often interested in the criticalness of the setting of any given K or d in order to meet a set of specifications. To study this problem, the relative shape equation for triple-tuned maximally flat circuits (Appendix II) was used, and the value of each circuit constant was allowed to vary independently. These variations are shown in (12) through (16), for the specific case of $\delta_2 = 0.33$. This value of δ_2 corresponds to a filter having 10-db insertion loss, and represents a region of difficult design (see illustrative example in first section). The investigation was limited to two regions of general interest: $\phi = 1$ (3-db point of desired Butterworth response), and $\phi = 3$ (28.6-db point of desired Butterworth response).

In an actual design, $\phi = 1$ indicates the crossover point between two adjacent filters; $\phi = 3$ shows the actual off-band rejection 1.5 bandwidths away from f_0. In practice, the quantity that is most likely to vary is the unloaded Q of the individual circuits (the value of Q_u is assumed to be the same for all three circuits). Eq. (17) shows the variation for the case where the normalized decrements all change by the same amount for small changes (less than 25 per cent) in Q_u; it is plotted in Figs. 5(a) and 5(b).

The remaining point to consider is the change in midband insertion loss resulting from variations in value of the circuit constants. This variation was plotted from (7) and is shown in Fig. 5(c).

The proper interpretation of Fig. 5 will aid the designer of filters with high insertion loss to analyze experimentally obtained filter response shapes and determine possible sources of error in the fabrication.

APPENDIX I

MIDBAND INSERTION LOSS

Fig. 7 shows the equivalent circuit of a capacitively coupled three-resonator filter. In terms of the symbols used there, $P_{out} = V_p^2 g_L$; $P_a = I^2/4g_g$. The insertion loss is defined as $L = 10 \log P_a/P_{out}$. Therefore

$$L = 10 \log \frac{I^2}{4g_g g_L V_p^2} = 10 \log \frac{1}{4g_g g_L (V_p/I)^2}.$$

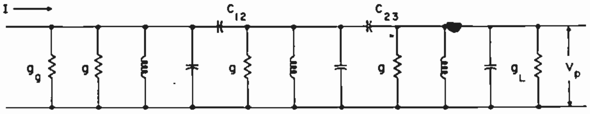


Fig. 7—Equivalent circuit of a capacitively coupled three-resonator filter.

Since the midband insertion loss is of interest, V_p/I is set equal to the filter transfer impedance at midband. For the circuit shown above,

$$\Delta = \begin{vmatrix} Y_{11} & Y_{12} & 0 \\ Y_{21} & Y_{22} & Y_{23} \\ 0 & Y_{32} & Y_{33} \end{vmatrix}$$

$$\frac{V_p}{I} = \frac{\begin{vmatrix} Y_{21} & Y_{22} \\ 0 & Y_{32} \end{vmatrix}}{\Delta}.$$

Since the three resonant circuits are synchronously tuned, the self nodal admittances of the resonant circuits are purely resistive. The admittances are:

$$Y_{11} = g_g + g$$

$$Y_{12} = -j\omega_0 C_{12}$$

$$Y_{22} = g$$

$$Y_{23} = -j\omega_0 C_{23}$$

$$Y_{33} = g_L + g.$$

By definition,

$$d_1 = \frac{g_g + g}{\omega_0 C}$$

$$d_2 = \frac{g}{\omega_0 C}$$

$$d_3 = \frac{g_L + g}{\omega_0 C}$$

$$K_{12} = \frac{C_{12}}{C}$$

$$K_{23} = \frac{C_{23}}{C}.$$

Therefore

$$Y_{11} = \omega_0 C d_1$$

$$Y_{12} = -j\omega_0 C K_{12}$$

$$Y_{22} = \omega_0 C d_2$$

$$Y_{23} = -j\omega_0 C K_{23}$$

$$Y_{33} = \omega_0 C d_3$$

$$\frac{V_p}{I} = \frac{Y_{12}Y_{23}}{Y_{11}Y_{22}Y_{33} - Y_{11}Y_{23}^2 - Y_{33}Y_{12}^2}$$

$$= \frac{-(\omega_0 C)^2 K_{12}K_{23}}{(\omega_0 C)^3[d_1 d_2 d_3 + d_1 K_{23}^2 + d_3 K_{12}^2]}$$

$$\left[\frac{V_p}{I}\right]^2 = \frac{K_{12}^2 K_{23}^2}{(\omega_0 C)^2[d_1 d_2 d_3 + d_1 K_{23}^2 + d_3 K_{12}^2]^2}.$$

Therefore

$$L = 10 \log \frac{[d_1 d_2 d_3 + d_1 K_{23}^2 + d_3 K_{12}^2]^2}{4(d_1 - d_2)(d_3 - d_2)K_{12}^2 K_{23}^2}.$$

Normalizing to fractional bandwidth F gives

$$L = 10 \log \frac{[\delta_1 \delta_2 \delta_3 + \delta_1 k_{23}^2 + \delta_3 k_{12}^2]^2}{4(\delta_1 - \delta_2)(\delta_3 - \delta_2)k_{12}^2 k_{23}^2}. \tag{7}$$

This expression also holds for the general network of Fig. 1.

It is interesting that, by using (2c), the mid-band insertion loss for maximally flat response reduces to

$$L = 10 \log [4(\delta_1 - \delta_2)(\delta_3 - \delta_2)k_{12}^2 k_{23}^2]^{-1}. \tag{8}$$

APPENDIX II

EFFECT OF VARIATIONS IN CIRCUIT CONSTANTS ON AMPLITUDE-FREQUENCY RESPONSE OF THREE-RESONATOR MAXIMALLY FLAT FILTER

The relative voltage response for a triple-tuned circuit is[1]

$$v = \frac{1}{C_0'}[(j\phi)^3 + C_2'(j\phi)^2 + C_1'(j\phi) + C_0'] \tag{9}$$

where

$$C_2' = \delta_1 + \delta_2 + \delta_3$$

$$C_1' = k_{12}^2 + k_{23}^2 + \delta_1\delta_2 + \delta_1\delta_3 + \delta_2\delta_3$$

$$C_0' = k_{12}^2\delta_3 + k_{23}^2\delta_1 + \delta_1\delta_2\delta_3.$$

By equating (9) to the transfer function for a three-resonator filter, the shape equations for a triple-tuned filter can be obtained. The result for the relative insertion loss is

$$L_r = 10 \log \left\{1 + \left[\frac{C_1'^2 - 2C_0'C_2'}{C_0'^2}\right]\phi^2 + \left[\frac{C_2'^2 - 2C_1'}{C_0'^2}\right]\phi^4 + \frac{\phi^6}{C_0'^2}\right\}^{-1}. \tag{10}$$

For a Butterworth response it is

$$L_r = 10 \log [1 + \phi^6]^{-1}. \tag{11}$$

To see deviations in the shape as each circuit value varies, let

$$\delta_2' = \delta_2 + q$$

$$\delta_1' = \delta_1 + r$$

$$\delta_3' = \delta_3 + s$$

$$(k_{12}')^2 = (k_{12})^2 + t$$

$$(k_{23}')^2 = (k_{23})^2 + u.$$

The equations for the case of $\delta_2 = 0.33$ are

$$L_r = 10 \log \left[1 + \frac{(2.22q + 1.51q^2)\phi^2 + (0.66q + q^2)\phi^4 + \phi^6}{1 + 1.23q + 0.38q^2}\right]^{-1} \tag{12}$$

$$L_r = 10 \log \left[1 + \frac{(1.28r + 0.84r^2)\phi^2 + (1.1r + r^2)\phi^4 + \phi^6}{1 + 1.26r + 0.40r^2}\right]^{-1} \tag{13}$$

$$L_r = 10 \log \left[1 + \frac{(-1.52s - 0.735s^2)\phi^2 + (2.24s + s^2)\phi^4 + \phi^6}{1 + 1.52s + 0.58s^2}\right]^{-1} \tag{14}$$

$$L_r = 10 \log \left[1 + \frac{(-0.48t + t^2)\phi^2 - 2t\phi^4 + \phi^6}{1 + 2.24t + 1.25t^2}\right]^{-1} \tag{15}$$

$$L_r = 10 \log \left[1 + \frac{(1.8u + u^2)\phi^2 - 2u\phi^4 + \phi^6}{1 + 1.1u - 0.30u^2}\right]^{-1}. \tag{16}$$

In an actual filter, the factor most subject to error n production is the unloaded Q of each resonant cir-uit. In this case q, r, and s are equal and each can be epresented by p. Then, for $\delta_2 = 0.33$,

$$_{T} = 0 \log \left[1 + \frac{(0.24p + 5.36p^2)\phi^2 + (4p + 3p^2)\phi^4 + \phi^6}{1 + 4.9p + 10p^2} \right]^{-1} \qquad (17)$$

where, since p is less than 0.2, terms containing powers of p higher than the second have been neglected.

There are two general areas of interest: at $\phi = 1$ and at $\phi = 3$. Fig. 5(a) and (b) shows (17) plotted for these areas.

ACKNOWLEDGMENT

The authors wish to thank Dr. E. G. Fubini for his helpful interest and for permission to use his analytical solution for a minimum-insertion-loss three-resonator maximally flat filter.

Correspondence

Oneway Circuit by the Use of Hybrid T for the Reflex Klystron Amplifier*

A reflex klystron amplifier of the metallic internal cavity type has been constructed by the author.[1] In this amplifier, the amplifier tube is mounted on the waveguide between the antenna and load as shown in Fig. 1. The amplified signal is divided into two parts, one of them being carried to the load side while the other is carried back to the antenna side. The latter is a cause of poor efficiency.

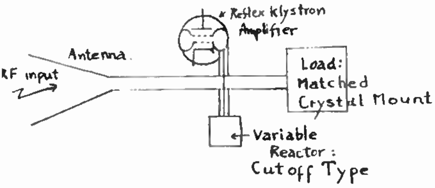


Fig. 1.

To improve the efficiency, a hybrid T was used, and the major part of the amplified backward wave power was sent to the load side.

Figs. 2 and 3 show the construction of the experimental circuit. This circuit consists of the receiving and transmitting horn antennas, hybrid T, twisted waveguide, bends, screw tuners, and reflex klystron amplifier. The amplifier tube is mounted at a position about equal phase distance from the joint of the hybrid tee.

The received signal is divided into three parts, the first part being coupled directly to the colinear arm and reradiated from the transmitting antenna; the second part is coupled to the E-plane arm; and the last part to the H-plane arm of the hybrid T, respectively. If the circuit is adjusted to the equiphase distance from the joint of the hybrid T to the reflex klystron mount, both coupled waves in the H-plane arm and E-plane arm are added together on the antenna of the center conductor of the coaxial cable of the reflex klystron and excite the cavity resonator through the coaxial cable. This signal is amplified by the reflex klystron and comes out from the coaxial cable, being divided into two parts in the waveguide.

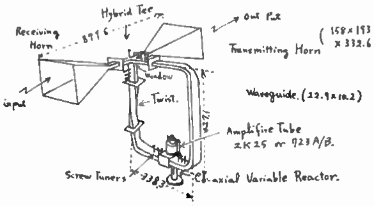


Fig. 2.

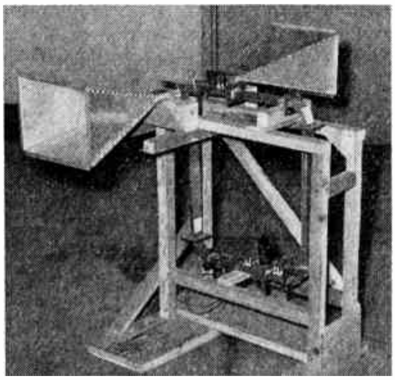


Fig. 3.

The amplified waves go back to the joint of the hybrid T through both E and H arms.

In this case, if the amplitude and phase of the amplified waves are properly adjusted, we may cancel the coupled back wave in the colinear arm of the receiving horn side from both E and H arms and we may add together the coupled wave in the colinear arm of the transmitting horn side by the well-known nature of the hybrid T.

Hence, the efficiency of the reflex klystron amplifier may be improved about 3 db compared with the normally arranged reflex klystron amplifier.

Through the employment of this device, the gain was improved at least 3 db, while the insertion loss and frequency bandwidth were almost equal to the case of the normal arrangement. The apparent gain of this oneway system is 28 db, with 6.8 db of insertion loss at the center frequency of 9370 mc, a 3-db-down frequency bandwidth of 35 mc, and a directivity of 39.82 db.

The author wishes to acknowledge the special assistance of Hiroshi Suzuki, Ikuo Sato, Kaoru Kataishi, and Stanley Repac.

KORYU ISHII
Elec. Eng. Dept.
University of Wisconsin
Madison, Wis.

---

* Received by the IRE, July 10, 1956; revised manuscript received, November, 1956. This work was carried out at the Laboratory of Microwaves, Nihon University, Tokyo, Japan.

[1] K. Ishii, "X-band receiving amplifier," *Electronics*, vol. 28, pp. 202–210; April, 1955.

On the Cotton-Mouton Effect in Ferrites*

Cacheris[1] has constructed a reflection-type ferrite single-sideband microwave modulator (SSM) by placing a shorting plate at the plane of symmetry that exists at the midpoint of a transmission-type SSM. Fox, Miller, and Weiss[2] have pointed out that a stronger birefringence effect could

---

* Received by the IRE, February 28, 1957.

[1] J. Cacheris, "Microwave single-sideband modulator using ferrites," PROC. IRE, vol. 42, pp. 1242–1247; August, 1954.

[2] A. G. Fox, S. E. Miller, and M. T. Weiss, "Behavior and applications of ferrites in microwave region," *Bell Sys. Tech. J.*, vol. 34, pp. 5–103; January, 1955.

be obtained by subjecting a piece of ferrite tubing to a four-pole transverse magnetic field rather than a two-pole field used in the microwave modulators built by Cacheris.

It is interesting to note, however, that a reflection-type SSM (which has the considerable practical advantage of requiring a quarter-wave rather than a half-wave differential phase shift section), using a four-pole applied field, cannot be obtained because a ferrite tubing followed by a shorting plate will show no birefringence when subjected to an applied magnetic field as shown in Fig. 1.

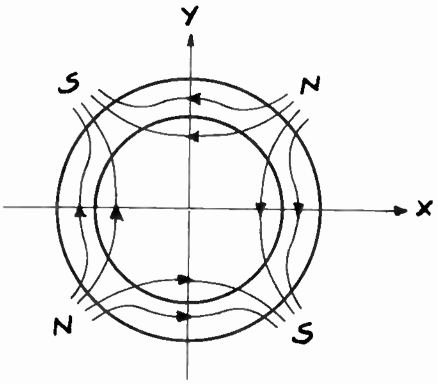


Fig. 1.

A TE_{11} mode, linearly polarized along the x axis while traveling through the ferrite section in the forward direction will receive a phase shift of, say, ϕ^1 radians. Traveling in the reverse direction, the phase shift imparted to this mode will be different, say, ϕ_2 radians. Simple physical reasoning will show that a TE_{11} mode, linearly polarized in the y direction, will receive a phase shift of ϕ_2 radians while traveling in the forward direction, whereas its passage through the ferrite tubing in the reverse direction will result in a phase shift of ϕ_1 radians. Hence for either polarization the round-trip phase shift is $\phi=\phi_1+\phi_2$. No differential phase shift between these two orthogonal modes is obtained, and consequently under these conditions the ferrite tubing is not birefringent.

The advantage of using a quarter-wave rather than a half-wave differential phase-shift section, however, can also be realized in a transmission-type SSM, which makes use of a four-pole magnetic field. In the following, only the differential phase shifts will be considered, and the time factor $\epsilon^{j\omega t}$ will be implied. Assume that a circularly-polarized microwave field, described in an xy-coordinate system by $\vec{e}_i=\vec{a}_x+j\vec{a}_y$ (where $\vec{a}_x$ and $\vec{a}_y$ denote unit vectors), is incident on a quarter-wave differential phase-shift ferrite section. Further assume that a transverse applied magnetic field in an $x'y'$-coordinate system is rotating counterclockwise at a constant angular velocity ω_m. Without any loss of generality assume that the y' component of the microwave field receives a phase shift of $\pi/2$ radians, whereas the x' component receives no phase shift while passing through the ferrite section.

In the $x'y'$-coordinate system, the incident microwave field is described by $\vec{e}_i=(\vec{a}_{x'}+j\vec{a}_{y'})\epsilon^{j\omega_m t}$. After passing through the ferrite the microwave field will be linearly polarized in the $x'y'$-coordinate system: $\vec{c}_0=(\vec{a}_{x'}-\vec{a}_{y'})\epsilon^{j\omega_m t}$. In the stationary xy-coordinate system, however, c_0 will have the form:

$$\vec{c}_0=\left(\frac{1+j}{2}\right)(\vec{a}_x+j\vec{a}_y)$$
$$+\left(\frac{1-j}{2}\right)(\vec{a}_x-j\vec{a}_y)\epsilon^{j2\omega_m t}.$$

The carrier frequency component can be easily rejected because its sense of circulation is opposite to that of the single-sideband component. If we consider that a half-wave differential phase-shift section theoretically completely converts the incident microwave power from the carrier frequency to a single sideband, we see that in the SSM described above we have traded 3 db of microwave power for a 75 per cent reduction in the modulation power (assuming a linear relationship between the differential phase shift and magnet current).

Gunars Kemanis
Hughes Aircraft Co.
Culver City, Calif.

Grid Current in Regulator Tubes*

The series regulator tube in a regulated dc power supply should be capable of passing the desired load current with a minimum of voltage drop. This consideration has led to the design of large low μ triodes such as the 6AS7, since the voltage amplifier driving the grid of the series tube is invariably a high impedance device, incapable of driving the grid positive. This communication reports the substantial improvement made in the case of the 6550 (triode $\mu=8$) tube by introducing a low impedance driver.

The schematic (Fig. 1) shows a fairly conventional regulated power supply, using a two-stage voltage amplifier. The voltage amplifier can drive the 6550 grid directly, or through a 6AQ5 (triode-connected) cathode follower, or through a 6C4 cathode follower in tandem with the 6AQ5 cathode follower. The plates of these cathode followers are connected to the supply B+, since that is the highest potential available. The plate load resistor of the second voltage amplifier stage is also connected to the supply voltage, since the 6550 grid has to be driven above its cathode.

The curves (Fig. 2) show the minimum series tube drop required to maintain regulation, as a function of output current. One cathode follower reduces the required drop about 47 per cent, and tandem cathode followers about 61 per cent. The disadvantage of the single cathode follower is due to the severely-limited plate voltage available for it when it is driving the series tube grid positive. This voltage is simply the series tube drop minus the positive grid swing. The additional (6C4) cathode follower drives the grid of the first positive, which enables it to drive much more grid current into the series tube. This grid current, incidentally, is not wasted, but is part of the output current of the series tube.

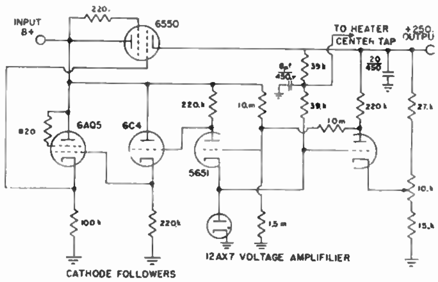


Fig. 1—Regulated power supply. (Shown with both cathode followers connected.)

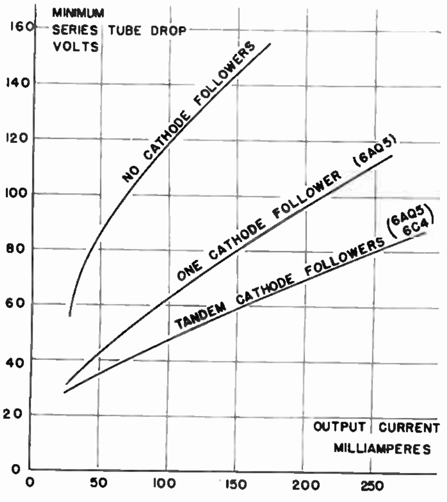


Fig. 2—Minimum series tube drop vs output.

Among the details of the circuit are the 10-megohm resistor, which cancels input hum, and the by-pass at the center of the gas tube series resistor, which circumvents the internal ac impedance of the gas tube, as far as the over-all feedback loop is concerned. This point is also a convenient one for fixing the dc potential of the heaters, and the by-pass prevents the introduction of capacitively-coupled hum from the power transformer.

Joseph M. Diamond
United Transformer Co.
New York 13, N. Y.

An Absolute Microwave Wattmeter*

A new microwave high-power wattmeter (hpw) has been developed which appears to be greatly superior to the conventional water

---

* Received by the IRE, July 23, 1956; revised manuscript received, November 9, 1956.

* Received by the IRE, January 25, 1957.

flow power meter in accuracy, sensitivity, and simplicity of construction and operation. It is apparently suitable for standards and other high-precision work.

The problem of measuring a few watts average or more of microwave power in a few minutes or less, can be reduced to a purely calorimetric problem if the rf energy can be converted to heat in a suitable container.

The field of calorimetry is well developed and accuracies of 1 per cent are commonly attained with the crudest of calorimeters, and 0.03 per cent accuracy is possible by the use of advanced techniques.[1] It therefore seemed sensible to design a microwave hpw around a very simple calorimeter.

Three versions of the calorimetric hpw have been constructed and operated: 1) an x-band version which operates in air and employs a Beckman thermometer; 2) a similar k-band version, and 3) a more refined twin x-band calorimeter with an oil bath for ambient temperature stabilization and a four-junction thermopile for measuring the temperature rise. The last named version which is much less convenient than the first two and which is nonportable, provides much better protection against ambient temperature variations and has a thermometric sensitivity of about 3/10,000 of a degree. Since only a few measurements have been made with this third version, most of what follows will concern the first two versions.

Fig. 1 is a schematic of the calorimeters. Fig. 2 is an exploded view of the x-band loads. Windows are cut in commercial guide and sealed with mica. The microwave energy leaks out of the guide through these windows and is dissipated directly in the water.

The measurement technique depends on the accuracy desired and the nominal power level. For an accuracy of about 2 per cent at a nominal level of 50 watts, heat losses and heating of the water due to the stirring may be ignored.

A single calibration is made by exciting the heater coil with a known dc power and measuring the temperature rise. The calibration will hold for several weeks or until a significant amount of evaporation has taken place and reduced the heat capacity. At 50 watts into the x-band version a 0.5°C temperature rise takes about 3 minutes; in the k-band version a 0.5°C rise takes about one minute.

For higher accuracy, the calorimeter can be calibrated so as to take account of thermal losses and stirring power. For highest accuracy, the calibration is carried out just previous to a measurement. Another high-accuracy method which has proved successful but tedious is as follows. The calorimeter is first heated with rf for a time T_r and the temperature rise θ_r is noted. The calorimeter is then cooled to its original temperature by means of dry ice in a glass tube.

The amount of rf is estimated to within a few per cent from the time and the temperature rise. The calorimeter is then heated with a dc power, P_d, equal to the estimated rf power, for a time, T_r, and the temperature rise, θ_d, is noted. Then since the thermal losses, stirring power and even the range in which the thermometer was used are nearly identical for the rf and dc heating, $P_r = P_d\theta_r/\theta_d$.

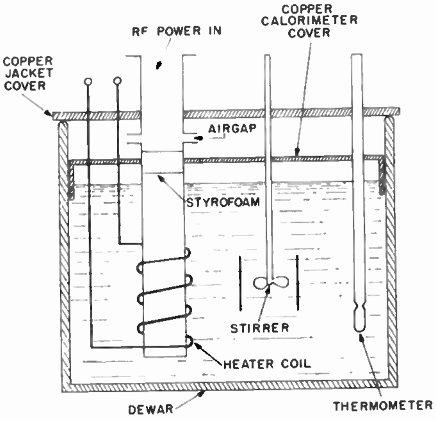


Fig. 1.

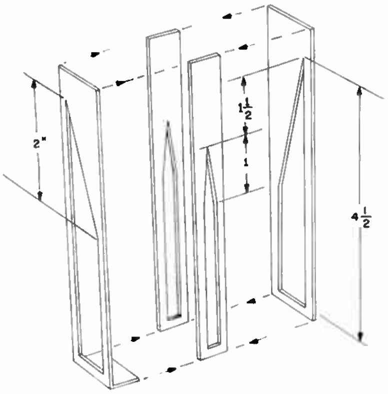


Fig. 2.

The standing-wave ratios looking into the calorimeters were measured only over a limited frequency range. For the x-band version, the swr was less than 1.2 between 8500 and 9400 mc, and for the k-band version the swr was less than 1.1 between 21.7 and 24.8 kmc.

The rf design of the loads can almost certainly be improved. The upper limit of peak power is probably about the same as that for the waveguide itself since there are no projections into the guide. There is no apparent reason why pressurizing could not be employed to increase the upper peak-power limit.

The highest peak powers employed in this work were 40 kw for the x-band version and 60 kw for the k-band version. There was no arcing at these powers. Higher average powers can be handled by faster stirring, larger calorimeters, or possibly by the addition of a known amount of ice.

The least detectable power is probably limited by the erratic leakage of heat into and out of the calorimeter. This will depend on the details of construction of the calorimeter, *i.e.*, whether or not the calorimeter is immersed in an oil bath, the treatment of heat leaks through the top of the calorimeter, etc. In the k-band calorimeter, the estimated least detectable power is about 0.1 watt in the x-band twin calorimeter it is about 0.01 watt. These figures can almost certainly be lowered by equipment improvement and by a statistical treatment of the drift. The simple construction of the loads and the high sensitivity of the hpw would seem to be ideal for millimeter-band work.

A more thorough discussion of the hpw's including a first-order heat-loss theory, a discussion of accuracy, of constructional details, of experimental results, and a comparison with the water-flow powermeter will appear in an NBS report.

Alan Macpherson
Naval Research Lab.
Washington, D.C.

---

[1] W. P. White, "The Modern Calorimeter," The Chemical Catalog Co., Inc., New York, N. Y., pp. 17–19; 1928.

Note on the Analog Computation of Small Quotients*

To the above paper by Bailey[1] may I add this observation. The method given by Bailey is at once a consequence of the relations

$$x \approx \tanh^{-1} x = \frac{1}{2}\log\frac{1+x}{1-x}, \quad |x| < 1.$$

Setting $x = \frac{1}{2}\cdot e_1/e_2$, where e_1/e_2 is the quotient sought, there results

$$\frac{e_1}{e_2} \approx \log\left(e_2 + \frac{e_1}{2}\right) - \log\left(e_2 - \frac{e_1}{2}\right)$$

as deduced by Bailey. That the quotient is obtained directly as a difference of logs with no antilog circuit required is evident from the initial choice of approximating x. Letting 100 ϵ be the per cent error in the computed quotient, then,

$$\epsilon = \frac{\tanh^{-1} x}{x} - 1, \quad x = \frac{1}{2}\cdot\frac{e_1}{e_2}.$$

Clearly, x may be set equal to any $k/2\cdot e_1/e_2$, of magnitude less than unity, with the result (following Bailey's notation) that

$$\frac{e_1}{e_2} \approx \frac{1}{k}\log\frac{ke_1 + \frac{e_2}{2}}{ke_1 - \frac{e_2}{2}},$$

but with an error, increasing with k, given by

$$\epsilon = \frac{\tanh^{-1} x}{x} - 1, \quad x = \frac{k}{2}\cdot\frac{e_1}{e_2}.$$

Martin Masonson
Federal Telecommun. Labs.
Nutley, N. J.

---

* Received by the IRE, December 26, 1956.

[1] A. D. Bailey, Proc. IRE, vol. 44, p. 1874; December, 1956.

Experiments on Noise Reduction in Backward-Wave Amplifiers*

The purpose of this letter is to report some interesting preliminary results of an investigation of noise reduction in backward-wave amplifiers.

Although a generalized one-dimensional noise theory[1] predicts identical ultimate noise figures for both forward and backward-wave amplifiers it does not guarantee that such performance can be realized in practice. The problem of achieving ultimate noise reduction in backward-wave amplifiers differs considerably in character from the corresponding problem in conventional traveling-wave tubes. Beam voltage and plasma wavelength vary rapidly as the pass band is tuned in frequency; the standing wave ratio and phase of the noise convection current in the beam vary in a direction opposite to that which is theoretically required to maintain minimum noise figure. From a fundamental viewpoint, since the parameters encountered in helix-type backward-wave tubes (which we have used in this work) fall in considerably different ranges (hollow beam, large γa, very low impedance) than those used in previous experiments on noise in electron beams, it is expected that, aside from the practical importance of low noise, the experiments will shed further light on the assumptions and validity of the existing one-dimensional noise theory.

The experimental work described here was done at *S* band on tubes which employ single-filar helix circuits operating on the (-1) space-harmonic (skew symmetric). The electron gun structure is unconventional; it features a series of velocity jump electrodes both inside and outside of an annular beam with the internal electrodes supported by a "christmas tree" protruding through the center of the cathode. The high total perveance obtainable with this type of gun furnishes a degree of freedom not obtainable with conventional solid beams; it is an unique feature of this type of gun and permits a high degree of flexibility in transforming the noise waves on the beam.

Some typical data obtained from a single-helix amplifier of this type at a particular midband frequency are shown in Fig. 1. The abscissa is the ratio of operating current I_0 to start-oscillation current Ist. These data were obtained by adjusting the noise figure to an optimum value at about 12 db gain and then taking the measurements as a function of current by varying the potential of the first anode and optimizing the helix voltage for maximum gain at each point. The data shown are terminal noise figures with no corrections for input lead loss. The gain curve of Fig. 1 is typical of the single-helix type of backward-wave amplifier; the use of a cascade amplifier[2] would have the general effect of shifting the gain curve further away from the oscillation threshold.

The noise figure did not vary significantly as the tube was tuned through its sharply peaked response curve (in agreement with theoretical calculations). The general variation of noise figure with beam current of Fig. 1 is typical of curves measured at other midband frequencies. The data showed an interesting variation of noise figure with cathode temperature, a distinct minimum being attained just above the temperature-limited region. This variation agrees qualitatively with some recent calculations by Siegman and Watkins.[3] It is possible, however, that pronounced temperature-dependent barium migration contributed to this effect since the low noise figures were not always highly reproducible and appeared to fade in and out with a long time constant.

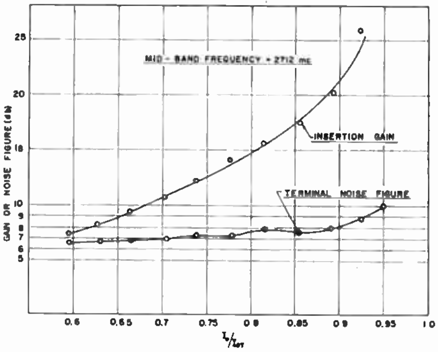


Fig. 1—Gain and noise figure as a function of beam current at a particular midband frequency.

The minimum theoretical noise figure for this tube at 2700 mc and 10 db gain is somewhat greater than 6 db (including factors for circuit loss,[4] shot-noise reduction[5] and finite gain). Thus our best measured results do not differ appreciably from the minimum values predicted by the one-dimensional theory.

In Fig. 2, we have plotted noise figure as a function of midband frequency with the gain held constant at 12 db. The first anode voltage was varied somewhat to maintain constant gain but no other gun potentials were programmed with frequency. It is thus seen that in spite of relatively large variation of tube parameters, tuning ranges of 20 per cent or more with very low noise figures appear to be feasible with backward-wave amplifiers.

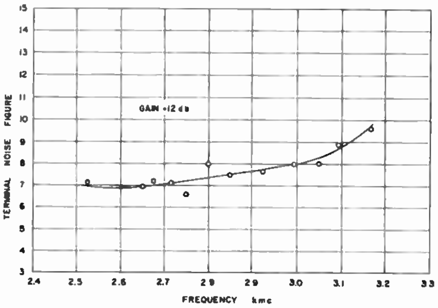


Fig. 2—Noise figure vs midband frequency at a constant level of gain. The potentials of the noise reducing electrodes were not programmed as a function of frequency.

In these experiments no effort was made to produce the smooth uniform type of cathode which has proven essential for very low noise performance in conventional traveling-wave tubes. We believe that the use of hollow beams might well offer some inherently significant advantages even in conventional low noise traveling-wave tubes. An obvious application would be in the higher microwave frequency bands.

Furthermore, we tentatively conclude that the backward-wave type of tube is feasible in receiver applications—it may satisfy the increasingly apparent need for rapidly tunable selective preamplification.

A detailed paper on this research and further applications to the cascade type of backward-wave amplifier will appear at a later time.

M. R. Currie and D. C. Forster
Hughes Aircraft Co.
Culver City, Calif.

---

* Received by the IRE, January 25, 1957.

[1] H. A. Haus and F. N. H. Robinson, "Minimum noise figure of microwave amplifiers," Proc. IRE, vol. 43, pp. 981–991; August, 1955.

[2] M. R. Currie and J. R. Whinnery, "The cascade backward-wave amplifier: a high-gain voltage-tuned filter for microwaves," Proc. IRE, vol. 43, pp. 1617–1632; November, 1955.

[3] A. E. Siegman and D. A. Watkins, "Potential minimum noise in the microwave diode," presented at 14th Annual Conf. on Electron Tube Research, Boulder, Colo.; June, 1956. (To be published.)

[4] M. R. Currie and D. C. Forster, "Noise in backward wave tubes," presented at 14th Annual Conf. on Electron Tube Research, Boulder, Colo.; June, 1956.

[5] D. A. Watkins, "Noise at the potential minimum in the high-frequency diode," *J. Appl. Phys.*, vol. 28, pp. 622–624; May, 1955.

An Extension of the Noise Figure Definition*

In the course of extending our previous general studies[1,2] of noise performance of linear amplifiers, we have been led to generalize the definitions of *available gain G* and *noise figure F* beyond their original meanings.[3] The need arises from situations involving negative resistance, and stems from difficulties in such cases with the usual notion of *available power*. An extension of this concept is required.

Normally, the available power $P_{avl,s}$ of a source is defined as

$$P_{avl,s} \equiv \textit{the greatest power which can be drawn from the source by arbitrary variation of its terminal current (or voltage).} \tag{1}$$

If the Thévenin representation of the source has rms open-circuit voltage E_s and internal impedance Z_s, with $R_s = \text{Re}\,(Z_s) > 0$, (1) leads to

$$P_{avl} = \frac{|E_s|^2}{4R_s} > 0 \text{ for } R_s > 0 \tag{2}$$

which is also a *stationary value* (*extremum*) of the power output regarded as a function of the complex terminal current. Moreover, the available power (2) can actually be delivered to the (passive) load Z_s^*.

---

* Received by the IRE, November 26, 1956. This work was supported in part by the Army (Signal Corps), the Air Force (Office of Scientific Research, Air Res. and Dev. Command), and the Navy (Office of Naval Research).

[1] H. A. Haus and R. B. Adler, "Invariants of linear noisy networks," 1956 IRE Convention Record, Part 2, pp. 53–67.

[2] H. A. Haus and R. B. Adler, "Limitations on Noise Performance of Linear Amplifiers," presented at the Congrès International "Tubes Hyperfréquences," Paris, France; June, 1956 (to be published).

[3] H. T. Friis, "Noise figures of radio receivers," Proc. IRE, vol. 32, pp. 419–422; July, 1944.

When $R_s<0$, however, definition (1) leads to

$$P_{avl}|_s = \infty \text{ for } R_s < 0 \tag{3}$$

since this is indeed the greatest power obtainable from such a source, and is achievable by loading it with the (passive) impedance, $-Z_s$. Observe that (3) is *not* either a stationary value or extremum of the power output as a function of terminal current.

The singular value and failure of the extremal property in (3) make (1) unsatisfactory in the negative resistance case. The following problem of noise figure for a cascade of two amplifiers (Fig. 1) focuses attention clearly upon some of the details which support this statement.

In the neighborhood Δf of some frequency f, the first stage in Fig. 1 has a noise figure F_1 and an available gain G_1, while the second stage has a noise figure F_2 and an available gain G_2. The noise figure of the cascade is then presumably given by the well-known cascading formula

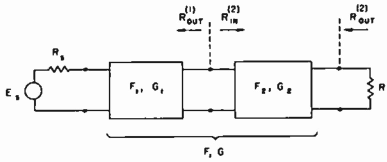


Fig. 1—Two amplifiers in cascade. R_s, R_L, >0.

$$F = F_1 + \frac{F_2 - 1}{G_1}. \tag{4}$$

Suppose, however, that the first amplifier has a negative output resistance $R_{out}^{(1)}$, whereas the second amplifier has positive input and output resistances $R_{in}^{(2)}$ and $R_{out}^{(2)}$. The closer the value of $R_{in}^{(2)}$ to $|R_{out}^{(1)}|$, the higher the transducer gain[4] of the first stage. Indeed, the condition $R_{in}^{(2)}=|R_{out}^{(1)}|$ would lead to infinite gain and instability, and we therefore assume $R_{in}^{(2)}\neq|R_{out}^{(1)}|$ in Fig. 1. Thus the available gain G of the *over-all* amplifier is perfectly well defined in terms of the usual definition (1) of available power.

$$G = \frac{P_{avl}|_{out}}{P_{avl}|_s}. \tag{5}$$

Similarly the noise figure F of the *over-all* amplifier is equally well defined by the general relation

$$F = 1 + \frac{N_{avl}|_{out}}{GkT\Delta f} \tag{6}$$

where $N_{avl}|_{out}$ is the noise power available at the output terminals in the frequency band Δf, when no noise is introduced by the source. It becomes clear, by visualizing the noise voltages (not shown in Fig. 1) which characterize the noise of each amplifier and by noting the condition $R_{in}^{(2)}\neq R_{out}^{(1)}$, that $N_{avl}|_{out}$ is finite. So also is $GkT\Delta f$, which is the power available at the output caused only by the noise power $kT\Delta f$ available from the source resistance at temperature T.

Now, if we try to apply the cascading formula (4) we find that we are in trouble. Indeed, the available gain G_1 of the first stage is infinite by (5), (3), and (2); and thus, according to a cursory inspection of (4), the second stage does not seem to contribute to the over-all noise figure. That this conclusion is incorrect physically follows from a direct consideration of the contributions of the noise generators of the individual amplifiers, in the manner which would be used to obtain the *over-all* system noise figure [(6), etc.]. A more careful examination of (4) in this case reveals the following additional difficulties connected with the fact that $R_{out}^{(1)}<0$:

1) Noise figure F_1 is indeterminate when calculated from (6), because $N_{avl}|_{out}=\infty$ according to (1) and (3), and $G_1=\infty$.

2) Noise figure $F_2=\infty$ by (6). This occurs because $G_2=0$, on the basis of (3), (2), and (5). Thus the term $(F_2-1)/G_1$ in (4) is actually *indeterminate* also, which makes F in (4) *entirely indeterminate*.

3) The use of $kT\Delta f$ in (6) for computing F_2 in this case requires some comment, because $R_{out}^{(1)}<0$ does *not* represent a resistance at thermal equilibrium temperature T, and the "available thermal noise power" $kT\Delta f$ has no clear physical meaning under the circumstances.

We shall now propose a new concept called the *exchangeable power*, of a source, in terms of which an *exchangeable power gain* and a *new noise figure* can be defined. These new definitions remove all of the foregoing difficulties, and always reduce to the familiar ones whenever the latter apply.

The *exchangeable power* P_e of a source is defined as

> $P_e|_s \equiv$ *the stationary value (extremum) of the power output from the source, obtained by arbitrary variation of the terminal current (or voltage).*

In terms of the Thévenin representation of the source (E_s, Z_s),

$$P_e|_s = \frac{|E_s|^2}{4R_s} \text{ for } R_s \neq 0. \tag{7}$$

Observe that $P_e|_s$ reduces to the conventional available power when $R_s>0$. When $R_s<0$ the exchangeable power is negative. As can be confirmed easily, the exchangeable power is in this case the maximum power that can be pushed *into* the "source," achievable by connecting the (nonpassive) impedance Z_s^* to the source terminals. The negative sign of the exchangeable power then conveniently underscores the fact that here we are speaking about a power extremum corresponding to a flow of power *into* rather than *from* the source.

The introduction of exchangeable power suggests the definition of a "ratio of exchangeable powers," the *exchangeable power gain* G_e.

$$G_e = \frac{P_e|_{out}}{P_e|_s}. \tag{8}$$

The exchangeable power gain is the ratio of the exchangeable power at the output terminals of a network to the exchangeable power of the source connected to the input. It reduces to the conventional available power gain if both the output resistance and the source resistance are positive. If either *one* of these resistances is negative, $G_e<0$. If both source and output resistance are negative, $G_e>0$.

We may now extend the definition of the noise figure on the basis of exchangeable power. Let

$$F_e = 1 + \frac{N_e|_{out}}{G_e kT\Delta f} \tag{9}$$

where $N_e|_{out}$ is the exchangeable noise power at the output terminals with no noise from the source, and G_e is the exchangeable power gain of the system. The magnitude of the exchangeable noise power of the source is arbitrarily set equal to the standard $kT\Delta f$, simply for normalization purposes. It should be noted that $(F_e-1)<0$ only when the source resistance is negative; $(F_e-1)>0$ in all other cases.

We may now confirm that the cascading formula (4) has been extended to include all cases, provided F and G are reinterpreted as F_e and G_e. We have

$$N_e|_{out} = N_e|_{out}{}^{(1)}G_{e2} + N_e|_{out}{}^{(2)} \tag{10}$$

$$G_e = G_{e1}G_{e2} \tag{11}$$

and thus

$$\begin{aligned} F_e &= 1 + \frac{N_e|_{out}}{G_e kT\Delta f} \\ &= 1 + \frac{N_e|_{out}{}^{(1)}G_{e2} + N_e|_{out}{}^{(2)}}{G_{e1}G_{e2}kT\Delta f} \end{aligned} \tag{12}$$

or

$$F_e = F_{e1} + \frac{F_{e2} - 1}{G_{e1}}$$

The result (12) differs from (4) only when negative output resistance occurs somewhere in the cascade. Aside from the use of the generalization in such situations, we find it necessary for a careful treatment of the general noise theory of linear amplifiers.

H. A. Haus and R. B. Adler
Dept. Elec. Eng.
Mass. Inst. Tech.
Cambridge, Mass.

---

[4] The transducer gain is defined as the ratio of the *actual* power delivered at the output to the *available power* from the source.

An Accelerated Aging and Coating Procedure for Lowering Current Noise in Carbon Composition Resistors*

The Navy is more or less resigned to noisy carbon composition resistors though they are specifying acceptable noise levels. Cases occur, though, in certain low-signal level guided missile applications, where use of bulky low-noise, wire-wound resistors is required but, due to lack of space, cannot be employed. Also, since experience shows that these resistors occasionally exhibit undesirably high current noise or microphonic properties, an effort was made by the Naval Ordnance Division of the Eastman Kodak

---

* Received by the IRE, February 5, 1957.

Company who were under contract with the Bureau of Ordnance, to investigate reports that noise properties of carbon composition resistors could be improved by suitable treatment. Other disadvantages of wire-wound resistors, in addition to bulkiness, are cost, particularly for larger sizes; radial leads only; and nonavailability in larger values of resistance. The results of Eastman Kodak's investigation are reported below.

Allen-Bradley carbon composition resistors, selected for treatment as laboratory tests on a limited quantity of resistors, seemed to indicate they had generally good low-noise properties as compared to some other makes and types. Some low-noise film type resistors were not found to be as good as wire-wound resistors. The ½-watt size of Allen-Bradley was particularly good for noise.

Allen-Bradley ½-watt carbon composition resistors were baked for 120 hours at 125°C. in an oven. Immediately after being removed from the oven, each resistor was dipped in a thin solution of Tufon No. 58-5 lacquer (made by Brooklyn Varnish Manufacturing Co., Inc.) to prevent absorption of moisture. Resistance and noise measurements were made before and after baking. Resistance was measured on a Shallcross Type 617-F Percent Limit Bridge, except for the highest value resistor, where a General Radio Type 544-B Mehohm Bridge was used. Noise was measured using a component noise tester, a Tekronix Preamplifier Type 122, and a Tekronix Oscilloscope Type 512. (See Fig. 1).

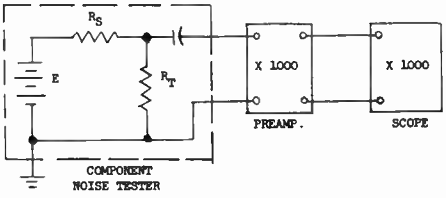


Fig. 1—Noise test circuit.

R_T is the resistor under test. R_S is a low-noise wire-wound resistor of known value. The preamplifier band-pass is 0.2 cps to 40 kc. The voltage source, E, is a well-filtered battery supply with noise output below the 11 microvolts system noise of the measuring equipment. The dc voltage impressed across R_T was equal to that impressed across similar resistors used in a standard production preamplifier application.

After being removed from the oven and dipped in Tufon, the resistors were allowed to cool before any measurements were taken.

The baking process caused no appreciable change in either the noise or resistance of one and two-watt resistors. These resistors were noisier than the equivalent baked ½-watt value before baking, and there was no improvement after baking.

The ½-watt resistors were definitely improved noisewise by the aging process, especially in the lower resistance values, without seriously affecting their resistance. There also was evidence of stabilization of resistance with time and environment.

The following, Table I, summarizes the results of aging these resistors under controlled high temperature. The last two columns refer to the changes brought about by aging process.

TABLE I

Value of resistor in ohms and watts	No. of resistors treated	Average per cent reduction in		Estimated approximate noise microvolts peak-to-peak	
		Resistance	Noise	Before aging	After aging
390, ½w	25	2.5	44	30	16
56k, ½w	24	2.8	49	75	39
120k, ½w	25	3.0	19	52	42
3.3 Meg., ½w	25	3.3	18	75	60
56k, 1w	—	No change	No change	—	—
62k, 2w	—	No change	No change	—	—

Later tests have shown that a similar lacquer, Interchemical Company's Paladin water dip lacquer #3119, is equally as effective as Tufon in sealing the baked resistors; however, the Paladin is much easier to apply than the Tufon. The Paladin lacquer was used subsequently in the production preamplifiers with excellent results.

Satisfactory shelf life of these treated resistors beyond nine months has not yet been fully evaluated though favorable reports of such resistors in use in servo amplifiers since World War II, have been received. These resistors were baked 400 hours. Laboratory tests showed 120 hours to be about as effective however.

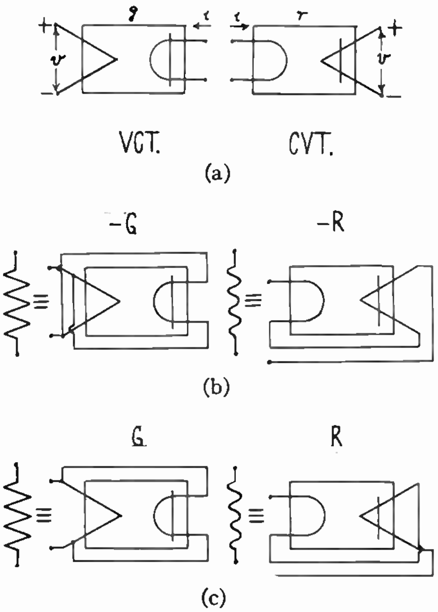
The baking and coating process as described has been found effective in reducing current noise and stabilizing resistance value of some carbon composition resistors. These treated resistors compare favorably with some of the more bulky wire-wound resistors. On the basis of the above findings, baked and coated carbon composition resistors have been used in certain production preamplifier bias circuits with very good results. The improvements obtained could have wider application in other electronic equipment and further investigation is warranted.

William A. Ostaff
U. S. Naval Ord. Experimental Unit
Washington, D. C.

Transactors*

A set of dual ideal active elements has recently been proposed.[1] These elements were called the "transactor" elements and a symbolism was introduced. This is shown in Fig. 1(a). The voltage-current transactor (vct) is defined by its admittance matrix.

$$Y = \begin{bmatrix} 0 & 0 \\ g & 0 \end{bmatrix}. \tag{1}$$



(a)

(b)

(c)

Fig. 1—(a) The ideal transactors. (b) Negative resistance. (c) The ideal dissipators.

The current-voltage transactor (cvt) is defined by its impedance matrix.

$$Z = \begin{bmatrix} 0 & 0 \\ r & 0 \end{bmatrix}. \tag{2}$$

The causal equations for these elements are

$$\begin{aligned} g\cdot v &\to i \\ r\cdot i &\to v \end{aligned} \tag{3}$$

g and r are real and the arrow implies that the process is not reversible. These active elements are physically distinct, and their method of operation is characterized by an irreversible electric to magnetic (or magnetic to electric) transfer action. They have therefore been called the *transactor* elements.

In these elements complete separation of voltage and current branches is obtained. A current branch is therefore denoted by the letter C (or C turned through 180°) and a voltage branch by the letter V laid on its side (or turned through 180°). The bar across a branch indicates that transmission is unilateral from the closed to the open end of the branch.

The above results may be stated as follows.

Hypothesis on Activity

When a change from voltage to current (or vice versa) is accompanied by an energy gain to the system it can be considered to have been caused by one of a dual pair of ideal active elements (or by their derivatives).

One dual pair of active derivatives of the transactor elements is represented by the

---

* Received by the IRE, December 17, 1956.

[1] G. E. Sharpe, "Ideal active elements," *J. IEE*, vol. 3, pp. 33–34; January, 1957.

negative conductor (voltage-transacting) and negative resistor (current-transacting) shown in Fig. 1(b). The terminal pairs are now identified by means of parallel and series connection, but these devices remain, by hypothesis, physically distinct.

For all voltages, except zero voltage, the negative conductor is active but unstable. It is, therefore, short-circuit stable. For all currents, except zero current, the negative resistor is active but unstable. It is, therefore, open-circuit stable. The phenomenon of open and short circuit stability of "negative resistance" can, therefore, be predicted and explained by the introduction of the transactor elements.

A distinct symbolism for these elements is now introduced. The voltage transacting conductor is depicted by a saw-tooth line (Letters V laid on side, end to end). The current transacting resistor is depicted by a wavy line (Letters C end to end).

A slight change in the identification of terminals, leads to the dissipative connection shown in Fig. 1(c). In order to remain consistent, one is led to the general view that dissipators must also be of dual nature and therefore physically distinct.

HYPOTHESIS ON DISSIPATION

When a change from voltage to current (or vice versa) is accompanied by a loss of energy to the system it can be considered to have been caused by one of a dual pair of ideal dissipating elements.

The same distinct symbolism as used for negative resistance has been retained. The ideal dissipators are defined as follows: 1) The "conductor" is voltage-transacting. It dissipates energy while changing voltage to current. 2) The "resistor" is current-transacting. It dissipates energy while changing current to voltage.

Moreover, an ideal dissipator remains an open (or a short) circuit unless brought into conductance (or resistance) by an impressed voltage or current.

This generalization of Ohm's law appears necessary, if activity and dissipation are to be mutually compatible.

Details of these researches will be published elsewhere.

GERALD E. SHARPE
British Telecommun. Res. Ltd.
Taplow Court, Taplow
Bucks., England

An Exact Solution for a Cylindrical Cavity Containing a Gyromagnetic Material*

This communication gives exact expressions for the fields and resonant frequencies of a circular cylindrical cavity oscillating in any TM_{nq0}-mode[1] and containing a centered circular rod of gyromagnetic material. The merit of selecting these modes is their great simplicity. The equations are sufficiently simple to be practicable for use with experimental measurements. The general solution for a cavity given by Epstein[2] will yield our results, but it is more convenient to obtain them directly for the modes specified above.

It is assumed that the medium has a magnetic susceptibility (for sinusoidal fields) such that

$$(\mu) = \begin{pmatrix} \mu_1 & i\alpha & 0 \\ -i\alpha & \mu_1 & 0 \\ 0 & 0 & \mu_3 \end{pmatrix}. \tag{1}$$

μ_1, α, and μ_3 may be complex. A ferrite material magnetized by a dc field along the z direction may exhibit the property (1).

We use Maxwell's curl equations for such a medium as given by Epstein, assuming no free charge and exp $(-i\omega t)$ time dependence:

$$(\mu)^{-1}\nabla \times \bar{E} = i\omega\bar{H} \tag{2}$$

$$\nabla \times \bar{H} = -i\omega\epsilon\bar{E}. \tag{3}$$

$(\mu)^{-1}$, the inverse of (μ) is

$$(\mu)^{-1} = \begin{pmatrix} M & iK & 0 \\ -iK & M & 0 \\ 0 & 0 & M_3 \end{pmatrix}, \tag{4}$$

in which

$$M = \frac{\mu_1}{\mu_1^2 - \alpha^2}, \quad K = \frac{-\alpha}{\mu_1^2 - \alpha^2}, \quad M_3 = \frac{1}{\mu_3}. \tag{5}$$

We consider the special case where the fields are independent of the z coordinate, which yields the two independent wave equations (as was first shown by Kales)[3]

$$(M\nabla_p^2 + \epsilon\omega^2)E_z = 0 \tag{6}$$

$$(M_3\nabla_p^2 + \epsilon\omega^2)E_p = 0, \tag{7}$$

where ∇_p^2 is the Laplacian in the transverse (r, ϕ) space and E_p is a certain transverse electric field. Eq. (6) corresponds to a TM-wave and (7) to a TE-wave.

We now consider the solutions of (6) and (7), independent of the coordinate z, fitting the boundary conditions in a closed cylindrical cavity (Fig. 1). In this case a nontrivial solution involving E_p cannot exist because a transverse electric field cannot exist on the end plates of the cavity. Therefore, only (6) has a solution and only a TM-mode can exist under the conditions imposed.

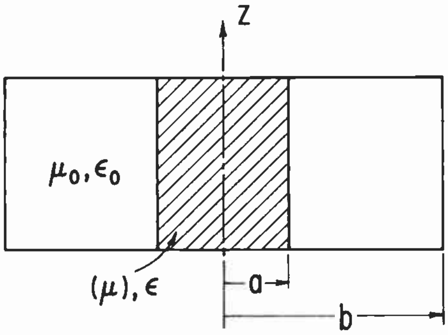


Fig. 1—Circular cylindrical cavity with centered post.

Using a right-handed circular cylindrical coordinate system and the method of separation of variables, one obtains $E_z = AJ_n(\beta' r)e^{\pm in\phi}$ as the solution for the electric field in the rod, where A is the amplitude. The cylinder function $J_n(\beta' r)$ is chosen here because it is appropriate to the region from $r=0$ to $r=a$, β' is $(\omega^2\epsilon/M)^{1/2}$, and n is an integer. Similarly, in the unfilled annulus the solution of (6) with M replaced by $M_0 \equiv 1/\mu_0$ and ϵ by ϵ_0 gives $E_z = C_n(\beta r)e^{\pm in\phi}$ where $\beta = (\omega^2\epsilon_0\mu_0)^{1/2}$, and $C_n(\beta r) = BJ_n(\beta r) + DY_n(\beta r)$. The ratio D/B of the amplitudes must be chosen so that E_z vanishes at the metal wall $(r=b)$. This gives

$$C_n(\beta r) = B[J_n(\beta r) - Y_n(\beta r)(J_n\beta b)/Y_n(\beta b)]. \tag{8}$$

For brevity the indices n and q have been omitted from ω, β', and β. They are, however, implied as subscripts everywhere in this letter.

Eq. (2) is used to obtain H from E. The fields in the post are then $H_z = E_r = E_\phi = 0$, and

$$E_z = AJ_n(\beta' r)e^{\pm in\phi}$$

$$H_r = \frac{A}{\omega}\left[\pm\frac{nM}{r}J_n(\beta' r) - \beta' KJ_n'(\beta' r)\right]e^{\pm in\phi}$$

$$H_\phi = \frac{A}{i\omega}\left[\pm\frac{nK}{r}J_n(\beta' r) - \beta' MJ_n'(\beta' r)\right]e^{\pm in\phi}. \tag{9}$$

Likewise, in the annular space the fields are $H_z = E_r = E_\phi = 0$, and

$$E_z = C_n(\beta r)e^{\pm in\phi}$$

$$H_r = \pm\frac{nM_0}{\omega r}C_n(\beta r)e^{\pm in\phi}$$

$$H_\phi = \frac{i\beta M_0}{\omega}C_n'(\beta r)e^{\pm in\phi}. \tag{10}$$

M_0 is $1/\mu_0$. $J_n'(x)$ and $C_n'(x)$ are the derivatives with respect to x.

By equating the tangential components E_z and H_ϕ from (9) and (10) at the boundary $r=a$, we obtain two homogeneous equations in the amplitudes A and B [B is the amplitude attached to $C_n(\beta r)$]. Setting the determinant of the coefficients of A and B equal to zero, we obtain the transcendental equations in β'

$$\frac{\beta' aMJ_n'(\beta' a)}{J_n(\beta' a)} \mp nK = \frac{\beta aM_0C_n'(\beta a)}{C_n(\beta a)}. \tag{11}$$

Eq. (11) represents two equations, the upper sign pertaining to $e^{+in\phi}$ and the lower sign to $e^{-in\phi}$. With (11) the unknowns M and K may be obtained from the two resonant frequencies ω_+ and ω_- for the positively and negatively rotating waves, respectively, and vice versa.

After setting $M=1/\mu$ and $K=0$ (case of a post with scalar permeability) β' becomes $(\omega^2\mu\epsilon)^{1/2}$, and with $n=0$, (11) reduces to

$$\frac{(\epsilon/\epsilon_0)^{1/2}J_0'(\beta' a)}{(\mu/\mu_0)^{1/2}J_0(\beta' a)} = \frac{C_0'(\beta a)}{C_0(\beta a)}. \tag{12}$$

This formula (12) obtained from (11) is identical with one that we have previously obtained directly for a TM_{010}-mode cavity containing a rod with scalar electrical constants μ and ϵ (unpublished notes).

---

* Received by the IRE, December 20, 1956. This work was partially supported by Order No. Buships /1700R-564.

[1] TM_{nqp} refers to a transverse magnetic mode with ϕ, r, z indices of n, q, and p respectively.

[2] P. S. Epstein, "Theory of wave propagation in a gyromagnetic medium," *Rev. Mod. Phys.*, vol. 28, pp. 3–17; January, 1956.

[3] M. L. Kales, "Modes in waveguides containing ferrites," *J. Appl. Phys.*, vol. 24, pp. 604–608; May, 1953.

With considerable algebra, $C_n'(\beta a)/C_n(\beta a)$ reduces to

$$\frac{J_{n-1}(\beta a)}{J_n(\beta a)} + \frac{2J_n(\beta b)}{\pi\beta a J_n(\beta a)[J_n(\beta b)Y_n(\beta a) - J_n(\beta a)Y_n(\beta b)]} - \frac{n}{\beta a}, \tag{13}$$

which is convenient for computations.

When the sample radius a is very small (11) may be approximated and compared with an available TM_{110}-mode cavity perturbation formula.[4] Using the fact that as $x \to 0$, $xJ_1'(x) \doteqdot J_1(x)$, the left side of (11) becomes $M \mp K = (\mu_1 \mp \alpha)^{-1}$, for $n=1$. We use one-term expansions of the function on the right-hand side, in the form (13). $J_1(\beta b)$ is nearly zero, since βb is nearly r_{11}, the first root of J_1. Therefore we use for its argument $\beta b = r_{11}(1 - \Delta\omega/\omega)$, where $\Delta\omega/\omega = (\omega_0 - \omega_1)/\omega_0$ is the fractional change in the resonant frequency of the cavity due to the magnetic perturbation. Elsewhere use $\beta b = r_{11}$. Eq. (11) then becomes

$$\frac{\Delta\omega_\pm}{\omega} = \frac{\mu_1 \mp \alpha - \mu_0}{\mu_1 \mp \alpha + \mu_0} \frac{\pi r_{11} Y_1(r_{11})}{4J_0(r_{11})} \frac{a^2}{b^2}, \tag{14}$$

which is equivalent to the perturbation formula given in (21) of Le Craw and Spencer,[4] although the signs differ because our off-diagonal signs in (1) are different.

Exact calculations may start with M and K estimated from (14) followed by an iterative procedure in (11). In the usual case ϵ is unknown too, but (11) can also furnish ϵ if M and K are known, so an iterative calculation using two different cavity modes, say the TM_{010} and the TM_{110}, can yield ϵ, M, and K. Complex frequencies may be used to obtain losses.

H. E. Bussey and L. A. Steinert
National Bureau of Standards
Boulder, Colo.

---

[4] R. C. LeCraw and E. G. Spencer, "Tensor permeabilities of ferrites below magnetic saturation," 1956 IRE Convention Record, Part 5, pp. 66–74.

Effects of Evaporated Electrodes on Quartz Resonator Vibrating in a Contour Mode*

It is well-known that evaporated electrodes, deposited on the surface of quartz resonator vibrating in a *thickness mode*, always lower the resonant frequency of the resonator and have little effect on its Q. But this is not the case of a resonator vibrating in a *contour mode*. Both the frequency and the Q are remarkably influenced by the presence of electrodes. In certain cases the frequency increases with the thickness of electrodes.

The metallic deposits on crystal surface, which make up evaporated electrodes, are usually quite different from ordinary metal in their nature. It is found, however, that values of elastic constants can be assumed to be equal to those of ordinary metal, and the internal loss follows the Voight's model[1] after appropriate heat treatments.

From a consideration of the energy relation in a vibrating elastic body, the change of the resonant frequency f due to electrodes, can be expressed by the form:

$$\frac{\Delta f}{f} \doteqdot \frac{1}{2}\left(\frac{P'}{P} - \frac{K'}{K}\right). \tag{1}$$

While, as shown below, the over-all Q consists of Q_i and Q' which depend on internal loss of the resonator itself and the electrodes, respectively. As the Q' is usually of the order of $10^5 \sim 10^6$, it takes a considerable part of the Q for the recent high-Q quartz resonator whose Q_i is better than 10^6.

$$\frac{1}{Q} = \frac{1}{Q_i} + \frac{1}{Q'} \tag{2}$$

$$Q' \doteqdot \frac{F'}{P}. \tag{3}$$

The K, P, and F in (1) and (3) are, respectively, the time averages of kinetic energy, potential energy, and internal energy loss in the resonator itself, and the primes indicate the corresponding quantities in the electrodes. They can be expressed by the following tensor forms neglecting a certain numerical coefficient.

$$K = (2\pi f)^2 \iiint \rho u_i u_i dv \tag{4}$$

$$P + jF = \iiint T_{ij} S_{ij} dv \tag{5}$$

where ρ, u, S, and T are density, displacement, strain, and stress, respectively. According to the Voigt's model the stress-strain relationship takes the form:

$$T_{ij} = (c_{ijkl} + j2\pi f b_{ijkl}) S_{kl}. \tag{6}$$

The thickness of electrodes is usually thin enough to assume that the displacement in the electrodes is equal to the displacement at the crystal surface. This makes the evaluation of these integrals fairly easy, if we know the solution of free vibration of the resonator.

It is not always necessary, however, to perform the integrations. If we use *full electrodes* and if one and only one strain component predominates for the mode under consideration, then both integrals in numerator and denominator of (1) and (3) can be canceled out except certain numerical constants. The latter condition is the case of most contour modes for practical use.

For example, for the longitudinal mode (1) and (3) reduce to:

$$\frac{\Delta f}{f} = \frac{1}{2}\left(\frac{E'}{E} - \frac{\rho'}{\rho}\right)\frac{t}{} \tag{7}$$

$$Q' = \frac{Et}{2\pi f b_l' t'} \tag{8}$$

while for the face shear mode:

$$\frac{\Delta f}{f} = \frac{1}{2}\left(\frac{E'}{2(1-\sigma')s_\theta} - \frac{\rho'}{\rho}\right)\frac{t'}{t} \tag{9}$$

$$Q' = \frac{}{2\pi f b_f' s_\theta t'} \tag{10}$$

where E is Young's modulus, σ Poisson's ratio, t thickness and s_θ elastic (shear) compliance. The first term in the brackets of (7) and (9) is characteristic of contour modes in contrast with thickness modes. In Table I the calculated values of $(\Delta f/f)/(t'/t)$, for several cuts and metals, are compared with experimental values.

TABLE I

Cut	Metal of electrodes	$-(\Delta f/f)/(t'/t)$	
		Calculated	Measured
18.5° X	silver	1.41	1.5_9
CT	silver	1.51	1.4_7
CT	gold	3.14	3.0_2

Details concerned with the loss factors, b_l' and b_f', will appear elsewhere, as they are highly dependent on evaporation procedure and heat treatments. It might be interesting, however, to point out, as a direct conclusion of (10), that the Q' of CT-cut is 2.3 times higher than the Q' of DT-cut, when the frequency, the thickness of resonator, and the thickness of electrodes are equal for both cuts.

For partial electrodes, effects of electrodes on the frequency and the Q' depend not only on its thickness but also on its shape and its location on the crystal surface. This is because P' and F' become large at the portion of high strain, while K' becomes large at the portion of large displacement.

For the longitudinal mode the displacement is maximum and the strain is minimum at the very end of the plate, while the displacement is minimum and the strain is maximum at the center of the plate. Therefore, a small electrode at the end of the plate considerably lowers the frequency, but has little effect on the Q'. An electrode at the center of the plate, however, increases the frequency and considerably lowers the Q'. Quantitative experiments done by Mr. Takahara at Electrical Communication Laboratories, Japan Telephone and Telegram Corporation, using a 18.5° X cut with electrodes divided into 12 segments along its length have shown good agreement with this theory.

The author wishes to acknowledge the advice by Prof. N. Takagi and the information kindly sent by Mr. Takahara.

Morio Onoe
Institute of Industrial Science
University of Tokyo
Chiba City, Japan

---

* Received by the IRE. January 10, 1957.

[1] W. Voigt, "Lehrbuch der Kristallphysik," B. G. Teubner, Leipzig, 1910, s.792.

Amplification-Bandwidth Exchange in Transistor Video Amplifiers*

Bruun[1] has described several ways of efficiently trading amplification for band-

---

* Received by the IRE. January 24, 1957.

[1] G. Bruun, "Common-emitter transistor video amplifiers," Proc. IRE, vol. 44, pp. 1561–1572; November, 1956.

width in an RC coupled transistor video amplifier. One technique involves the choice of emitter current bias to provide the desired exchange. The external interstage load is kept a constant optimum value no matter what low frequency stage amplification is used.

As it is not always desirable from a practical point of view to vary emitter current bias over a wide range, it is interesting to inquire what penalty is paid by maintaining the bias constant and varying the interstage load as is done in the vacuum tube video amplifier.

Some specific data on this question are available from work done at our Laboratories on RC coupled common emitter transistor video amplifiers. The performance of representative transistors in amplifiers was calculated by means of the NBS SEAC digital computer. The results of interest here are shown in Fig. 1. The amplification-bandwidth product as a function of stage voltage amplification (one stage of an iterative amplifier) is shown for four transistor types. The 2N104 (audio) and 2N139 (IF) are alloy germanium transistors. The SB-100 is a surface barrier type; the TA-E 1579 is a drift transistor, the predecessor of the 2N247.

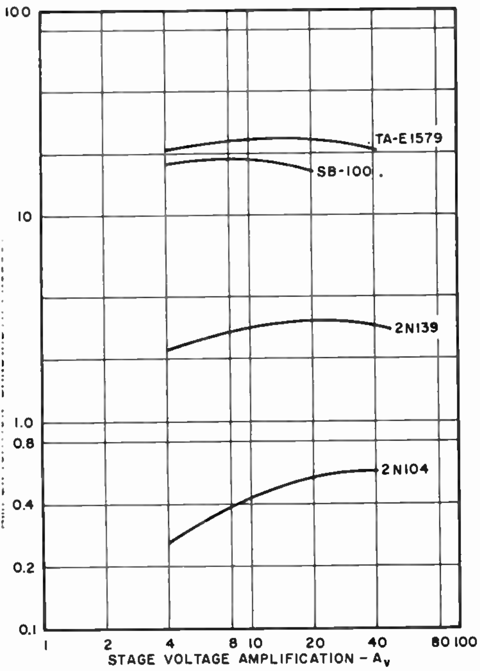


Fig. 1—Video amplification-bandwidth products of various transistors.

The point of interest to this discussion is the fact that the amplification-bandwidth products of the two high-frequency transistors (SB-100 and TA-E 1579) very only slightly over the useful range of stage voltage amplification.

For most applications the loss from the optimum value of amplification-bandwidth product would be unimportant.

THOMAS A. PRUGH
Diamond Ordnance Fuze Labs.
Washington 25, D. C.

A Precise New System of FM Radar*

Presumably voicing a question that has arisen in the minds of others working in the radar altimeter field, I would like to ask Mr. Ismail to expand upon his excellent presentation,[1] to describe the effect of direct signal leakage between antennas of his altimeter. The mixing process expressed by (17) of his paper presumes that only the local oscillator signal u_{F1} and the signal u_r received from the ground are present. It would appear that there is also a third signal which I shall call u_i, which is a direct leakage signal between transmitter and receiver. This signal, even though suppressed by isolation, does not seem to be negligible by comparison with the reflected signal u_r, and, since it produces a spectrum also centered at the intermediate frequency F_{s01}, it should be at least accounted for in the analysis.

The leakage signal u_i has the same form as (12) of the paper, except that the time delay T is replaced by T_a, the transit time between antennas, and the Doppler shift w_v is absent. When this signal is applied to the mixer along with signals u_r and u_{F1}, there results sums and differences of the possible argument combinations. The sums, of course, are removed by filtering, as is the component centered at "zero" frequency. The two differences of interest are the ones expressed by (18) of Ismail and another one like it given by, if the approximations of Ismail are applied:

$$u_{Zi}=U_{Zi}\cos\left[\Omega_{s01}t-\Delta\Omega T_a\cos\omega_m t+\phi_i\right],\quad (1)$$

which is of the form

$$B\cos(\alpha+\gamma)\quad (2)$$

where $\alpha=\Omega_{s01}t$, and the nomenclature is seen by comparison. Similarly, (18) of Ismail is of the form

$$A\cos(\alpha+\beta).\quad (3)$$

The sum of (2) and (3) may be expressed as

$$B\cos(\alpha+\gamma)+A\cos(\alpha+\beta)$$
$$=R\cos(\alpha+\psi)\quad (4)$$

where

$$R=\sqrt{A^2+B^2+2AB\cos(\beta-\gamma)}\quad (5)$$

$$\psi=\mathrm{Tan}^{-1}\frac{A\sin\beta+B\sin\gamma}{A\cos\beta+B\cos\gamma}.\quad (6)$$

Now as long as $A\neq B$, which would cause R to swing through zero at intervals, we may assume that R can be made constant by limiting, so that only the derivative of the argument of (4) is of interest. This can be shown to be

$$\omega_{s1}=(\dot\alpha+\dot\psi)=\dot\alpha$$
$$+\frac{A^2\dot\beta+B^2\dot\gamma+AB\cos(\beta-\gamma)(\dot\beta+\dot\gamma)}{A^2+B^2+2AB\cos(\beta-\gamma)}\quad (7)$$
$$=\dot\alpha+\dot\beta-(\dot\beta-\dot\gamma)$$
$$\cdot\frac{B}{A}\,\frac{\dfrac{B}{A}+\cos(\beta-\gamma)}{1+\left(\dfrac{B}{A}\right)^2+2\dfrac{B}{A}\cos(\beta-\gamma)},\quad (8)$$

wherein, from (1) above and (18) of Ismail,

$$\dot\alpha+\dot\beta=\Omega_{s01}+\omega_v+\omega_m\,\Delta\,\Omega T\sin\omega_m t$$
$$\dot\beta-\dot\gamma=\omega_m\Delta\Omega(T-T_a)\sin\omega_m t+\omega_v$$
$$\beta-\gamma=\omega_v t-\Delta\Omega(T-T_a)\cos\omega_m t+\phi'-\phi_i$$
$$\frac{B}{A}=\frac{U_{si}}{U_{s1}}.$$

Since from the mixing process

$$U_{si}\propto U_{F1}U_i,$$

and

$$U_{s1}\propto U_{F1}U_r$$

then

$$\frac{B}{A}=\frac{U_i}{U_r},$$

which might be termed the "spillover ratio" for the system. For the case where $U_i=0$, (8) reduces to the result of Ismail, since the last term becomes zero. To the extent that the spillover ratio is finite, it would appear that the last term of (8) introduces a time-varying distortion into the frequency measurement, periodic in ω_m, irrespective of the fact that subsequent mixing processes translate the center frequency to a new and lower value. The distortion is similar to that due to multipath propagation in fm communication and distance-measuring systems, which has been studied in considerable detail by Argimbau[2] and others,[3] and, at least in these systems, has been shown to produce serious effects under certain circumstances.

It would be preposterous to imply that an unworkable or inaccurate altimeter results because of this leakage, since Ismail has obviously built one and tried it. However, the effect would not have appeared in his reported bench tests except by accident, since there was but one delay path via a cable, and not two as exist when antennas are present. Therefore, I believe some more data should be supplied by him relating to tests with an actual altimeter, particularly as regards the accuracy thereof, in the interests of a complete discussion. Alternatively, bench tests with two propagation paths of greatly differing lengths might prove informative.

RODNEY W. JOHNSON
Interstate Electronics Corp.
Anaheim, Calif.

Author's Comment[4]

The effect of direct signal leakage between the transmitting and the receiving antennas, which Mr. Johnson has brought out in his discussion on my paper, has always been a serious problem that has accompanied all fm radar systems from the beginning of their use in practice. Hence, utmost care has to be taken when designing and locating the antennas to attain a very high degree of isolation between them. In spite of this, there always exist some weak signal that succeeds in reaching the receiving antenna directly from the transmitting one

---

* Received by the IRE, November 26, 1956.

[1] M. A. W. Ismail, PROC. IRE, vol. 44, pp. 1140–1145; September, 1956.

[2] See quarterly reports of Res. Lab. Electronics, Mass. Inst. Tech., Cambridge, Mass., for the past several years.

[3] T. E. Sollenberger, "Multipath phase errors in cw-fm tracking systems," IRE TRANS., vol. AP-3, pp. 185–192; October, 1955.

[4] Received by the IRE, January 8, 1957.

Direct signal leakage is one of the main causes that confined the use of fm radar systems to the cases where its troublesome results could be kept at an acceptable minimum. One of the cases in which fm radar is used almost exclusively, is as a low range airplane altimeter. For altimeters working at 440 mc, a 70 db or more signal attenuation from one antenna to another could be attained. As the reflecting surface here is unlimited, since it is that of ground or sea water, the reflected signal strength in the 0–400 feet range will, undoubtedly, be so strong that U_i will be negligibly small with respect to U_r. In such a case, the precision of the new system still holds, and very low altitudes can be measured accurately. This is actually the most important advantage of this system, since its main object is to measure accurately and without a fixed error very low altitudes, to help in the blind landing of airplanes. In the higher altitude range from 400–4000 feet, the direct feedthrough becomes more troublesome as the altitude increases, especially when flying over very poor conducting ground, because the reflected signal becomes very weak. However, a proper flight test on the altimeter which I had built should be carried out, to see actually what the effect of direct signal leakage at different altitudes will be. Unfortunately, I did not have the opportunity to carry out the flight test myself in Switzerland. Moreover, as I have been in Egypt since October, 1955, after developing the prototype for Hasler Laboratories in Bern, Switzerland, it is materially impossible to carry out further bench tests.

In the interest of further investigating the effect of direct signal leakage at high altitudes, let us consider the case where

$$U_i = 0.1\ U_r. \qquad (1)$$

If we substitute this in Johnson's (8) we get,

$$\omega_{z1} = \dot{\alpha} + \dot{\beta} - (\dot{\beta} - \dot{\gamma}) \cdot \frac{0.01 + 0.1 \cos(\beta - \gamma)}{1 + 0.01 + 0.2\cos(\beta - \gamma)}. \qquad (2)$$

Also, at high altitudes $T \gg T_a$, so that we may substitute T for $T - T_a$ in both $\dot{\beta} - \dot{\gamma}$ and $\beta - \gamma$ which, therefore, will be:

$$\dot{\beta} - \dot{\gamma} \cong \omega_m \Delta\Omega T \sin \omega_m t + \omega_v$$

$$\beta - \gamma \cong \omega_v t - \Delta\Omega T \cos \omega_m t + \phi' - \phi_i.$$

The difference between the two values of ω_{z1} as given by (18)[5] and (2) above, will be, in this case, the error caused by direct signal leakage and is given by

$$\Delta\omega_{z1} \cong -(\omega_m \Delta\Omega T \sin \omega_m t + \omega_v) \cdot \frac{0.01 + 0.1 \cos(\omega_v t - \Delta\Omega T \cos \omega_m t + \mathring{\phi})}{1 + 0.2 \cos(\omega_v t - \Delta\Omega T \cos \omega_m t + \mathring{\phi})} \qquad (3)$$

where

$$\mathring{\phi} = \phi' - \phi_i.$$

The magnitude of the denominator here can vary between maximum and minimum values of 1.2 and 0.8, respectively. The numerator of (3) can be expanded as follows:

$$\begin{aligned}
&-(\omega_m \Delta\Omega T \sin \omega_m t + \omega_v) \\
&\cdot [0.01 + 0.1 \cos(\omega_v t - \Delta\Omega T \cos \omega_m t + \mathring{\phi})] \\
&\cong -(\omega_m \Delta\Omega T \sin \omega_m t + \omega_v) \\
&\quad \{0.01 + 0.1 [I_0(\Delta\Omega T) \cos(\omega_v t + \mathring{\phi}) \\
&\quad + I_1(\Delta\Omega T)[\sin(\omega_m t + \omega_v t + \mathring{\phi}) \\
&\quad - \sin(\omega_m t - \omega_v t - \mathring{\phi})] \\
&\quad - I_2(\Delta\Omega T)[\cos(2\omega_m t + \omega_v t + \mathring{\phi}) \\
&\quad + \cos(2\omega_m t - \omega_v t - \mathring{\phi})] \\
&\quad + I_3(\Delta\Omega T)(\cdots\cdots\cdots\cdots) \\
&\quad + \cdots\cdots\cdots\cdots\cdots\cdots \text{etc.}]\}
\end{aligned} \qquad (4)$$

where $I_n(\Delta\Omega T)$ is the Bessel function of the first kind with argument $\Delta\Omega T$ and nth order.

Since the If amplifier that precedes the altitude indicator is selective at frequency f_m, then only components of (4) at a frequency f_m approximately can cause errors in altitude. This can only occur at $f_v \cong 0$, f_m, $2f_m$, $3f_m$, $\cdots$, etc. Considering the case where $f_v = 0$, we get

$$\Delta\omega_{z1(\omega_v=0)} \cong -\frac{\omega_m \Delta\Omega T [0.01 \sin \omega_m t + 0.1 \sin \omega_m t \cos \mathring{\phi} (I_0(\Delta\Omega T) - I_2(\Delta\Omega T))]}{1.2 > \text{denominator} > 0.8}, \qquad (5)$$

showing that the relative error $\Delta\omega_{z1(\omega_v=0)} / \omega_m \Delta\Omega T \sin \omega_m +$changes with range and will only be 1 per cent at such a range where $I_0(\Delta\Omega T) = I_2(\Delta\Omega T)$. Eq. (4) also shows that at $\omega_v \cong 0$, the mean value of (4) $=0$; *i.e.*, no false indication of speed of a target of a fixed range exists.

In my book "A Study of the Double Modulated FM Radar," I have already proposed a method to minimize the effect of direct signal leakage at high altitudes. A summary of this method is given below:

Analogous to (22),[6] the output signal from the last IF amplifier, resulting from the direct signal leakage alone is

$$u_{zi}''' = U_{zi}''' \cos(\Omega_{z03} t - \Delta\Omega T_a \cos \omega_m t + \phi_i'''). \qquad (6)$$

The expansion of (6) gives

$$\begin{aligned}
u_{zi}''' = U_{zi}''' \{ & I_0(\Delta\Omega T_a) \cos(\Omega_{z03} t + \phi_i''') \\
& + I_1(\Delta\Omega T_a)[\sin(\Omega_{z03} t + \omega_m t + \phi_i''') \\
& - \sin(\Omega_{z03} t - \omega_m t + \phi_i''')] \\
& + I_2(\Delta\Omega T_a)[\cos(\Omega_{z03} t + 2\omega_m t + \phi_i''') \\
& + \cos(\Omega_{z03} t - 2\omega_m t + \phi_i''')] \\
& + I_3(\Delta\Omega T_a) \cdots\cdots\cdots\cdots \text{etc.} \}
\end{aligned} \qquad (7)$$

As the transit time between the antennas T_a usually is very small, $\Delta\Omega T_a$ will also be very small, especially when ΔF is made small, which is always true when measuring long ranges. In this case, the only component of significant amplitude in (7) is the first with $I_0(\Delta\Omega T_a) \cong 1$, while all other components are negligibly very small.

For example:

$$\Delta F \cong 150 \text{ kc for 0–4000 feet range}$$

$$\text{direct signal leakage path} = 5 \text{ meters}$$

$$\Delta\Omega T_a \cong 0.0157$$

$$\therefore I_0(\Delta\Omega T_a) \cong 1, \quad I_1(\Delta\Omega T_a) \cong 0.0075 \quad \text{and } I_2(\Delta\Omega T_a) \cong 0.$$

If, therefore, the first component, namely at frequency F_{z03}, is balanced out, signal u_{zi}''' will be almost completely suppressed, giving a remainder of only 1 or 2 per cent of its normal amplitude. This can easily be accomplished in pratice by adding to the output of the last IF amplifier a local signal at frequency F_{z03} that is made equal in amplitude and opposite in phase to the fundamental component of u_{zi}'''.

MOHAMED A. W. ISMAIL
.Faculty of Eng.
Ein Shams University
Cairo, Egypt

Ismail, *op. cit.*, p. 1143.

[6] *Ibid.*, p. 1143.

On the Tail in the Transient Behavior of Point-Contact Diodes*

Several recent discussions of the transient behavior of small hemispherical p-n junctions,[1,2] to which point-contact diodes are at least an approximation, agree that the transient is determined largely by the radius of the junction, and little affected by the carrier lifetime. This is in contrast to the behavior of large area junctions where the lifetime is an important factor.

Although the main part of the transient in the point-contact diodes is almost independent of lifetime, it is interesting to notice that there is a "tail" on the transient which is almost exponential, and is determined by the lifetime. This tail may or may not be important, or even noticeable, in a given situation, according to the circumstances.

This is probably most easily shown for the open circuit transient after the diode has passed a pulse of forward current. It has been shown[2] that p_n, the minority carrier concentration at the junction (the discussion here assumes that holes are injected into n-type material; with necessary changes, it would, of course, apply to the opposite case) is given by:

$$p_n = p_{ni} - (p_{ni} - p_{no}) \left(\frac{L}{L - r_o} \right) \cdot \left\{ 1 - \frac{r_0}{L} \operatorname{erf} \left(\frac{t}{\tau} \right)^{1/2} - e^{((L^2/r^2) - 1)t/\tau} \operatorname{erfc} \frac{(Dt)^{1/2}}{r_0} \right\}. \qquad (1)$$

p_{ni} is the value of p_n at time $t=0$, p_{no} the equilibrium value, D the diffusion constant, τ the lifetime, $L = (D\tau)^{1/2}$ the diffusion length, and r_o the radius of the junction.

Ordinarily $L \gg r_o$. Then, for not too small values of t the erfc term may be represented by the first term in its asymptotic representation.[3] This, along with some rearranging, makes (1) become

---

* Received by the IRE, November 21, 1956.

[1] B. R. Gossick, "On the transient behavior of semiconductor rectifiers," *J. Appl. Phys.*, vol. 27, pp. 905–911; August, 1956.

[2] H. L. Armstrong, "On open circuit transient effects in point contact rectifiers," *J. Appl. Phys.*, vol. 27, pp. 420–421; April, 1956.

[3] B. O. Pierce, "A Short Table of Integrals," Ginn and Co., Boston, Mass., 3rd ed., p. 120; 1929.

$$p_n = p_{no} + \frac{r_o(p_{ni} - p_{no})}{L - r_o}\left\{\left(\frac{\tau}{\pi t}\right)^{1/2} e^{-t/\tau} - \operatorname{erfc}\left(\frac{t}{\tau}\right)^{1/2}\right\}. \quad (2)$$

Over a range $t \sim \tau$, the erfc term does not depart too far from exponential behavior; thus under these circumstances the excess charge may decay almost exponentially.

For $t \gg \tau$, the asymptotic representation of the erfc term may again be used; then (2) gives

$$p_n \sim p_{no} + \frac{r_o(p_{ni} - p_{no})}{2(L - r_o)(\pi)^{1/2}}\left(\frac{\tau}{t}\right)^{3/2} e^{-t/\tau} \quad (3)$$

which is the eventual behavior of p_n as $t \rightarrow \infty$. Thus it is seen that the lifetime does control a part of the transient, but only that part which follows the initial change due to diffusion effects.

Harold L. Armstrong
National Res. Council
Ottawa, Ont., Can.

The Influence of Threshold Action on the RMS Value of Input Gaussian Noise*

Threshold action is often present in many communication systems containing pulse shapers and coding equipment, either as an inherent feature of the system or as a parameter designed into the system for a definite purpose. When noise is present at the input, either in place of or in addition to some desired signal, the threshold action changes the probability distribution of the noise input. In treating both military and commercial problems which involve signal-to-noise statistics, such an alteration can be significant.

This discussion shows how the presence of a threshold reduces the rms value of the input voltage when the input voltage is Gaussian noise. In particular, an expression is derived which relates S, the rms value of noise voltage after threshold action, to σ, the rms value of noise voltage before threshold action.

Before threshold action, if the input noise is Gaussian the probability density $\phi(y)$ is as shown in Fig. 1 and is given by

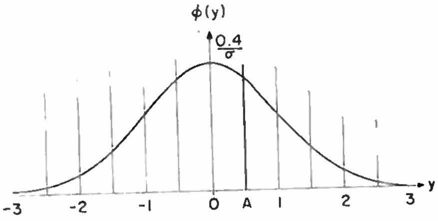


Fig. 1—Probability density before threshold action.

$$\phi(y) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(\frac{-y^2}{2\sigma^2}\right).$$

After threshold action the probability density $p(x)$ will be that shown by Fig. 2.

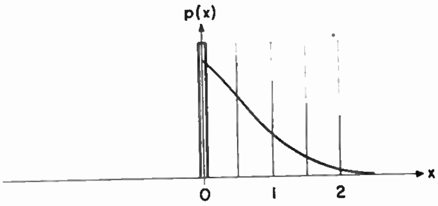


Fig. 2—Probability density following threshold action.

For positive x, $p(x)$ is given by

$$p(x) = B\delta(0) + p'(x)$$

$$p(x) = B\delta(0) + \frac{1}{\sqrt{2\pi\sigma^2}} \exp \frac{-(x + A)^2}{2\sigma^2} \qquad (x \geq 0) \quad (1)$$

where B is the probability that a noise amplitude lies between $-\infty$ and A

$\delta(0)$ is the Dirac delta function at $x=0$
A is the threshold level, and
$x = y - A$.

By definition the mean square value (the variance) S^2 of $p(x)$ is given by

$$S^2 = m_2 - m_1^2 \quad (2)$$

where m_2 is the second moment and m_1 is the first moment (mean) of the distribution after threshold action. These moments are defined by (3) and (7).

By definition

$$m_1 = \frac{1}{N}\int_0^\infty xp(x)dx = \int_0^\infty xp'(x)dx \quad (3)$$

where N, the normalizing factor, is given by

$$N = \int_0^\infty p(x)dx = 1.$$

Substitution of (1) into (3) and integration yield

$$m_1 = \frac{\sigma}{\sqrt{2\pi}} \exp\left(\frac{-g^2}{2}\right) - \frac{A}{2} \operatorname{cerf}\left(\frac{g}{\sqrt{2}}\right) \quad (4)$$

where

$$g = \frac{A}{\sigma}, \text{ a convenient dimensionless ratio,} \quad (5)$$

and cerf denotes the complementary error function defined by

$$\operatorname{cerf} U = \frac{2}{\sqrt{\pi}} \int_u^\infty e^{-z^2} dz. \quad (6)$$

In a similar fashion

$$m_2 = \frac{1}{N}\int_0^\infty x^2 p(x)dx = \int_0^\infty x^2 p'(x)dx. \quad (7)$$

Substitution of (1) into (7) and integration yield

$$m_2 = \frac{-A\sigma}{\sqrt{2\pi}} \exp\left(\frac{-g^2}{2}\right) + \left(\frac{\sigma^2 + A^2}{2}\right) \operatorname{cerf}\left(\frac{g}{\sqrt{2}}\right). \quad (8)$$

Substitution of (4) and (8) into (2) and normalization to σ^2 yield

$$\left(\frac{S}{\sigma}\right)^2 = \frac{-g}{\sqrt{2\pi}} \exp\left(\frac{-g^2}{2}\right) + \left(\frac{1 + g^2}{2}\right) \operatorname{cerf}\left(\frac{g}{\sqrt{2}}\right) - \left\{\frac{\exp\left(\frac{-g^2}{2}\right)}{\sqrt{2\pi}} \frac{-g}{2} \operatorname{cerf}\left(\frac{g}{\sqrt{2}}\right)\right\}. \quad (9)$$

Eq. (9) is the desired expression. It is used to obtain Fig. 3 where S/σ is plotted as a function of $g = A/\sigma$. Fig. 3 shows how S, the rms value after threshold action, depends upon σ, the rms value before threshold action, and upon the threshold level, A. For example, if the threshold level A is set equal to σ, then the rms value of the output voltage is approximately one-quarter of the rms value of the input Gaussian voltage.

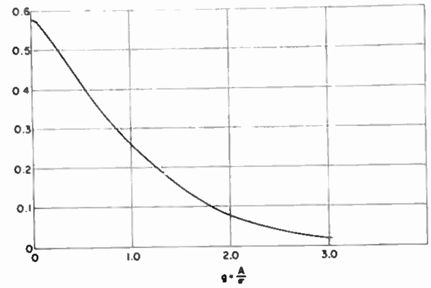


Fig. 3—RMS value S following threshold action.

By using the curve of Fig. 3, a designer can predict how much a specified threshold level A will decrease the rms value of the input noise voltage. Or, he can determine where the threshold level must be set to reduce the rms value of noise below some specified value which can be tolerated. These features should be of particular interest, for example, when a receiver must operate in the presence of considerable interference due to noise originating outside the receiver.

R. D. Teasdale
General Electric Co.
Philadelphia, Pa.
A. H. Benner
RCA Victor
Camden, N. J.

Radar Horizon and Propagation Loss*

If a radar is at a height h_1 above the surface of the earth, the distance R_1 to the point of tangency is given by

$$R_1 = \sqrt{2kah_1} \quad (1)$$

---

* Received by the IRE, March 11, 1957.

* Received by the IRE, February 15, 1956. The research reported here was supported jointly by the U. S. Army, Navy, and Air Force under contract with Massachusetts Institute of Technology.

where a is the radius of the earth (3960 statute miles) and ka is the effective earth's radius, Fig. 1. A smooth earth is assumed. The factor k allows for the effects of atmospheric refraction and under normal conditions in most of the United States, it is taken to be equal to 4/3. This fortunate choice of k allows (1) to be written as

$$R_1 \text{ (statute miles)} = \sqrt{2h_1 \text{ (feet)}} \qquad (2)$$

The point of tangency in Fig. 1 has been called by some the optical horizon,[1] and by others, the radio,[2] or radar horizon.[3]

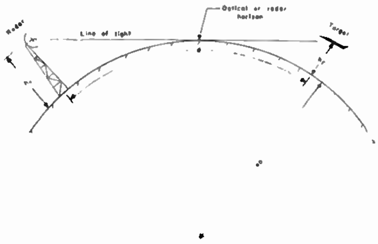


Fig. 1—Geometry for radar propagation over curved earth.

If the target is at a height h_2 above the earth's surface, its distance to the point of tangency is also given by an expression similar to (1). Hence, the length of the "line of sight" joining the radar at height h_1 and the target at height h_2 and which is tangent to the surface of the earth is

$$d = \sqrt{2kah_1} + \sqrt{2kah_2}. \qquad (3)$$

The line of sight as shown in Fig. 1 and given by (3) has sometimes been used to indicate the limits of the low altitude coverage of a radar.[3] That is, a target at distance d from the radar was said to be within the view of a radar at height h_1 if the target were at a height of h_2 or greater. This implies that the simple radar range equation[4] can be used when the target is on the radar line of sight without taking account of propagation losses. It is the purpose of this note to show that neglecting propagation losses along the line of sight can lead to overly optimistic results and that the use of (3) to predict the low altitude coverage of a radar is not justified. The radar signal received from a target located along the line of sight is usually many decibels below the signal which would have been received at the same range in free space. Although this fact is well known to propagation workers, it may not be as familiar to the radar systems engineer.

Some examples of the radar propagation losses experienced when the radar and target are both on the line of sight are shown in Fig. 2. The losses are for two-way (radar) propagation. The losses encountered by the radar system at the line of sight are of sufficient magnitude to rule out simple geometrical considerations for predicting radar coverage.

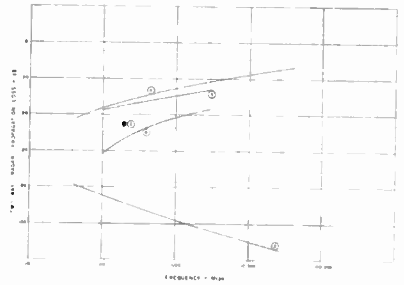


Fig. 2—Radar propagation losses (two-way) when target and radar are both on the optical line of sight.
Curve 1—$h_1 = h_2 = 100$ m, vertical polarization, $k=1$, dry soil; from Burrows and Attwood.[5]
Curve 2—Same as (1) but with $h_1 = 100$ m, $h_2 = 0$; from Burrows and Attwood.[6]
Curve 3—$h_1 = 110$ feet, $h_2 = 2100$ feet, horizontal polarization, $k = 4/3$, sea water; from Kerr.[7]
Curve 4—$h_1 = 9$ m, $h_2 = 282$ m, horizontal polarization, $k = 4/3$, sea water; from Burrows and Attwood.[8]
Curve 5—$h_1 \approx 0$, $h_2 = 30{,}000$ ft., AFCRC experimental measurements.[9]

The so-called radar coverage obtained with (3) is shown by the dashed curve 1 of Fig. 3 for a radar at a height of 200 feet. A more realistic indication of the low altitude capabilities of a radar would be that contour which corresponded to the minimum detectable radar signal. The calculation of the contours of constant signal strength is tedious and much more complicated than merely taking a square root as in (3), but it can be found by using well-known techniques.[10,11] Examples of such contours are indicated in Fig. 3 by curves 2–5. These were drawn assuming that the radar minimum detectable signal occurred at free space ranges of 32, 64, 128, and 256 miles. Also shown in Fig. 3, curve 6, is the boundary between the diffraction region and free space region. Below this curve, propagation losses must be taken into account. The assumptions used in obtaining curves 2–6 are shown in the figure caption. Figs. 2 and 3 illustrate that targets on the optical or radar line of sight lie within the diffraction zone of the radar and radar signals received from such targets are subject to considerable losses beyond that obtained with normal free space propagation.

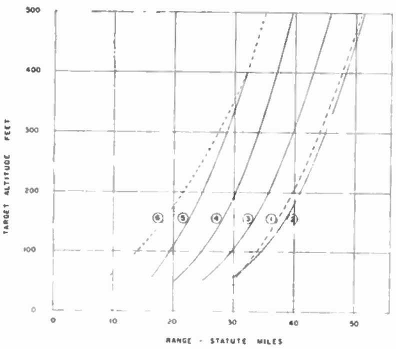


Fig. 3—Contours of "radar coverage" for radar height of 200 feet above curved earth.
Curve 1—Optical or radar line of sight contour from (3) with $k = 4/3$.
Curve 2—Constant radar signal contour in the diffraction zone for a signal strength equal to the free space signal at 256 miles, vertical polarization, sea water, $k = 4/3$, $f = 500$ mc.
Curve 3—Same as 2, but for 128-mile free space signal.
Curve 4—Same as 2, but for 64-mile free space signal.
Curve 5—Same as 2, but for 32-mile free space signal.
Curve 6—Zero transmission loss contour, same conditions as curves 2–5.

Although a radar was used as the example in this note, the same arguments apply to a radio communications system located within the diffraction region except that only one-way propagation losses need be considered. In Fig. 3, the curves apply directly to the communications case if radar height and target are interpreted as transmitter height and receiver height.

MERRILL I. SKOLNIK
Lincoln Lab.
Mass. Inst. Tech.
Lexington, Mass.

---

[1] C. R. Burrows and S. S. Attwood, "Radio Wave Propagation," Academic Press, New York, N. Y., p. 379; 1949.

[2] H. R. Reed and C. M. Russell, "Ultra-High Frequency Propagation," John Wiley and Sons, New York, N. Y., p. 3; 1953.

[3] J. F. Reintjes and G. T. Coate, "Principles of Radar," McGraw-Hill Book Co., Inc., New York, N. Y., p. 970; 1952.

[4] L. N. Ridenour, "Radar System Engineering," McGraw-Hill Book Co., Inc., New York, N. Y., p. 21; 1947.

[5] Burrows and Attwood, *op. cit.*, p. 382, Fig. 6.

[6] *Ibid.*, p. 382. Fig. 5.

[7] D. E. Kerr, "Propagation of Short Radio Waves," McGraw-Hill Book Co., Inc., New York, N. Y., p. 408, Fig. 6; 1951.

[8] Burrows and Attwood, *op. cit.*, p. 9, Fig. 13.

[9] P. J. Klass, "Discovery may triple uhf-vhf range," *Aviation Week*, vol. 65, p. 87; November 5, 1956.

[10] Burrows and Attwood, *op. cit.*, pp. 377–453.

[11] K. A. Norton, "The calculation of ground-wave field intensity over a finitely conducting spherical earth," PROC. IRE, vol. 29, pp. 623–639; December, 1941.

Contributors

W. P. Ayres

Wesley P. Ayres (M'56) was born on September 26, 1924, at Los Angeles, Calif. He served as an electronic technician aboard a destroyer during World War II, returned to college in 1948, and received the B.S. degree in physics from Fresno State College in 1951. He then entered Stanford University where he received the M.S. degree in 1953 and the Ph.D. degree in 1954 in physics.

In 1954, he joined the Electronic Defense Laboratory of Sylvania Electric Products, Inc., Mountain View, Calif., where he engaged in ferrite research at microwave frequencies. In 1956, Dr. Ayres joined the staff of the Microwave Engineering Laboratories, Inc., Palo Alto, Calif., where he is presently doing research on microwave components. Dr. Ayres is a member of RESA and the American Physical Society.

❖

B. F. Bogner

Bruce F. Bogner (M'56) was born in New York, N. Y. on June 22, 1931. He received the B.E.E. degree from City College of New York in 1953 and is currently pursuing studies leading to a degree of Master of electrical engineering at the Polytechnic Institute of Brooklyn.

In June, 1953, he joined Airborne Instruments Laboratory, Mineola, N. Y. and did work on stripline components before entering the armed forces in August, 1953. From 1953 to 1955, he was in the Signal Corps attached to the radar division at Evans Signal corps Laboratory, Fort Monmouth, N. J. While in the army, he did research and development work on antennas and made echo area measurements on missiles. In 1955, he returned to Airborne Instruments Laboratory and has been working on countermeasures systems and the development of strip transmission lines.

Mr. Bogner is a member of Eta Kappa Nu.

❖

F. E. Bond

Frederick E. Bond (M'47–SM'55) was born in Philadelphia, Pa, on January 10, 1920. He received the B.S. degree in electrical engineering from Drexel Institute of Technology in 1941. During World War II, he served with the U. S. Army Signal Corps in Europe where his assignments included research and development on British fire control radar for coastal artillery, and staff planning for the use of electronic countermeasures.

Since 1946 he has been with the Communications Department of the Signal Corps Engineering Laboratories engaged in research and development of ground radio and wire transmission equipments and communications systems engineering. At present he is Director of the Radio Communication Division.

He received the M.S. E.E. degree from Rutgers University in 1950, and the D.E.E. from Polytechnic Institute of Brooklyn in 1956.

Dr. Bond is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu. He is also a Major in the U. S. Army Reserve.

❖

M. L. Doelz

Melvin L. Doelz (M'45–SM'54) was born in Minneapolis, Minn., on December 30, 1918. He received the B.S. degree in electrical engineering from the University of Minnesota in 1941 and the M.S. degree in physics from the State University of Iowa in 1946. In 1941 he joined the Collins Radio Company where he has been engaged in the development of binary signaling systems, voice multiplex equipment, mechanical filters, magnetostriction resonators, hf airborne communications equipment, and hf mobile equipment.

In 1951 Mr. Doelz became director of the Burbank Research and Development Division of Collins Radio Company. He was promoted to resident manager of the Burbank plant in 1955 while retaining his capacity of director of engineering.

Mr. Doelz is a member of Eta Kappa Nu and Tau Beta Pi, and an associate member of Sigma Xi.

❖

For a photograph and biography of Bobby J. Duncan, see page 544 of the April, 1957 issue of Proceedings.

❖

W. W. Gärtner

Wolfgang W. Gärtner (M'54) was born in Vienna, Austria on July 5, 1929. He received the Ph.D. degree in physics from the University of Vienna and the Dipl.-Ing. degree from the Technische Hochschule, Vienna, in 1951 and 1955 respectively. He has been engaged in electron tube and semiconductor research with Siemens and Halske A.G. in Vienna, Austria and Munich, Germany. He became associated with the Signal Corps Engineering Laboratories, Fort Monmouth, N. J. in 1953.

Dr. Gärtner is the author of papers on semiconductor properties, transistor design, circuit theory, and ultrasonics. He is a member of the American Physical Society.

❖

E. T. Heald

Earl T. Heald was born in Tipton, Iowa, on March 29, 1919. He attended William Penn College in 1936, and the University or Iowa (extension study) in 1942. He joined Collins Radio Company in 1941 and served in the United States Navy during World War II.

In 1946, he assumed the responsibilities of development engineer with the special products department, Collins Radio Company, Burbank, Calif. In 1950 he became project engineer, Western Division, and was promoted to Head of Development Group B, Department II, Western Division, in 1952. He has developed data systems and predicted wave signaling systems.

❖

D. L. Martin

Donald L. Martin (S'50–A'52) was born in Terra Bella, Calif., on September 5, 1925. He received the B.S. degree in electrical engineering from Stanford University in 1950 and the M.S. degree from Stanford in 1951. He joined Collins Radio Company, Burbank, Calif., in 1951 as a research and development engineer in the Western Division. In 1955, he became assistant director of research and development, Western Division. He has since been engaged in the development of AFCRC data system receiver, Signal Corps baud sync signaling system, TE-101 signaling system (Dewline), and Kineplex system.

Mr. Martin is a member of the AIEE.

❖

Jack L. Melchor (SM'56) was born on July 6, 1925, in Mooresville, N. C. He received the B.S. degree and the M.S. degree in physics from the University of North Carolina. His undergraduate studies were interrupted by military service in the U. S. Navy. In 1949 he worked as a civilian physicist with the U. S. Navy Mine Countermeasures Station.


J. L. MELCHOR

While attending the University of Notre Dame in 1950, he was a U. S. Rubber Co. Fellow in high polymer physics, In 1952 and 1953, he worked with the Missile Division of Bendix Aviation Corp. and received the Ph.D. degree from Notre Dame in 1953. In 1953, Dr. Melchor joined the Electronic Defense Laboratory of Sylvania Electric Products, Inc., Mountain View, Calif., where he was engaged in ferrite research at microwave frequencies.

In 1956, he left Sylvania to form Microwave Engineering Laboratories, Inc., Palo Alto, Calif. where he is president of the new organization, doing research and development in microwave components and systems. He is a member of Sigma Xi and RESA.

❖

For a photograph and biography of Harold F. Meyer, see page 1885 of the December, 1956 issue of PROCEEDINGS.

❖

For a photograph and biography of Leonard Swern, see page 546 of the April 1957 issue of PROCEEDINGS.

Jesse J. Taub (S'48–A'50–M'55) received the B.E.E. degree from City College of New York in 1948. After obtaining the M.E.E. degree from Polytechnic Institute of Brooklyn in 1949, he joined the microwave tube section of the Naval Material Laboratory as a project engineer. In 1951, he assumed the position of supervisor of the klystron and microwave semiconductor unit at the Naval Material Laboratory. In June, 1955, Mr. Taub joined the special systems and components department of Airborne Instruments Laboratory where he is presently engaged in the development of special microwave receiving and transmitting systems.


J. J. TAUB

He is currently pursuing studies leading toward the D.E.E. degree at Polytechnic Institute of Brooklyn.

Mr. Taub is a member of Sigma Xi.

❖

Perry H. Vartanian (S'52–M'56–SM'56) was born in Rochester, N. Y. on June 14, 1931. He received the B.S. degree in electrical engineering in 1953 from the California Institute of Technology and the M.S. and Ph.D. degrees from Stanford University in 1954 and 1956.


P. H. VARTANIAN

At Stanford, he was a Tau Beta Pi Fellow and later a research assistant at the Electronics Research Laboratory. In 1951 and 1952, he worked part time at the U. S. Naval Radiological Defense Laboratory on radiation detectors.

In 1954, Dr. Vartanian joined the Electronic Defense Laboratory of Sylvania Electric Products, Inc., Mountain View, Calif., where as a senior project leader he is engaged in research in microwave applications of ferrites. Dr. Vartanian is a member of Tau Beta and RESA.

❖

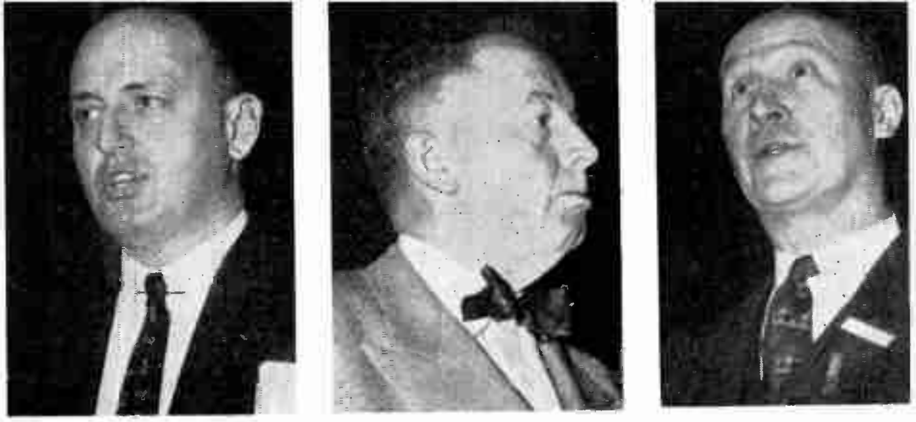
Laurens E. Whittemore (A'16–M'25–F'27) was born in Topeka, Kan. on August 20, 1892. He graduated from Washburn College in Topeka in 1914 and received the M.A. degree from the University of Kansas in 1915 where his major work was in physics. After three years of graduate study and teaching at the University of Kansas he went to Washington, D. C. where he was employed in the Radio Laboratory of the National Bureau of Standards from 1917 to 1923. In 1924 he was a member of the staff of the U. S. Department of Commerce and served as Secretary of the Interdepartment Radio Advisory Committee. He was Assistant Secretary or Secretary of the four annual National Radio Conferences called by the Secretary of Commerce, Herbert Hoover, 1922–1925.


L. E. WHITTEMORE

From 1925 to date Mr. Whittemore has been a member of the headquarters staff of the American Telephone and Telegraph Company in New York where he has been concerned, among other things, with relations with Federal regulatory agencies. He has attended a number of International Radio and Communication Conferences either on behalf of the U. S. Government or the American Telephone and Telegraph Company. He was Secretary of the International Radio Conference at Washington in 1927.

Mr. Whittemore was Vice-President of the IRE in 1928 and was a member of the Board of Directors from 1926 to 1929 and from 1935 to 1937. He has held assignments on a number of IRE Committees, including the Standardization Committee of which he was Chairman from 1926 to 1929, and the Annual Review Committee of which he was Chairman from 1940 to 1949. He served on the Board of Editors from 1929 to 1953. He is also a member of the American Institute of Electrical Engineers and Sigma Xi.

THE 1957 IRE NATIONAL CONVENTION IN PICTURES



The Annual Meeting of IRE on opening day heard Editor D. G. Fink (*left*) speak on "Electronics and the IRE—1967" and saw outgoing President A. V. Loughren turn over the gavel of office to J. T. Henderson (*right*).

54,000 Attendance Shatters All Records

On March 18–21, New York City was the scene of the largest gathering of technical manpower and equipment ever witnessed anywhere, as the IRE held what was unquestionably the most successful national convention in its forty-five year history.

Although numbers do not alone spell success, they do give some idea of the tremendous mass-interchange of technical information that is made possible by the convention. This year 54,074 engineers had the opportunity to hear 284 technical papers and see some 17,000 of the latest products produced by 756 firms.

The record-breaking attendance, larger than any previous professional meeting of any kind, was 32 per cent ahead of last year's snow-laden 41,017. The previous high was 42,133 in 1955. New York's top-coat weather, a marked change from last year's 18-inch blizzard, was an important factor in the large turnout.

An even greater factor was the new and much-improved location of the Radio Engineering Show. The recently-opened Coliseum offered superior facilities, more exhibit space, a location convenient to midtown Manhattan and to the Waldorf-Astoria Hotel, and room for 22 of the 55 technical sessions.

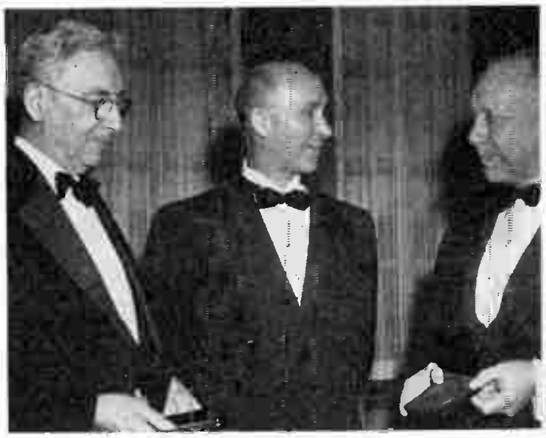
The outstanding program of technical papers (see March issue) drew larger audiences than ever before, with the 5300-seat capacity of the eight session halls filled almost continuously during the four days. One session, on high fidelity, overflowed into another room which, appropriately, was equipped with loudspeakers of lesser, but adequate, fidelity.

Highlighting the program were two special symposiums on "Applications of Electronics to Air Traffic Control" and on "Microminiaturization—The Ultimate Technique," held Tuesday evening at the Waldorf-Astoria and the Coliseum, respectively.

All available papers will be published shortly in the *IRE National Convention Record* (see p. 563, April issue).

A picture record of the annual meeting, banquet and other convention highlights appears on these pages.

HIGHLIGHTS AND EVENTS



Left to right: R. A. Heising, winner of the Founders Award; J. T. Henderson, 1957 IRE President; and J. A. Stratton, winner of the Medal of Honor. Dr. Heising, a consulting engineer and patent agent, won his award "for his leadership in IRE affairs, for his contributions to the establishment of the permanent IRE Headquarters, and for originating the PG system." Dr. Stratton, Chancellor of M.I.T., won his award "for his inspiring leadership and outstanding contributions to the development of radio engineering as a teacher, physicist, engineer, author and administrator."

Above—1957 award winners were (*left to right*): D. A. Buck, Browder J. Thompson Memorial Prize; O. G. Villard, Jr., Morris Liebmann Memorial Prize; Georg Goubau, Harry Diamond Memorial Award; and Donald Richman, Vladimir K. Zworykin Television Prize. Below—W. R. G. Baker (*right*) congratulates the joint winners of the new W. R. G. Baker Award, R. J. Kircher, D. R. Fewer and R. L. Trent, authors of papers published in TRANSACTIONS on Audio.

ACTIVITIES OF IRE SECTIONS AND PROFESSIONAL GROUPS

J. L. Barnes (*left*), chairman of the recent Western Joint Computer Conference, examines a computer component as A. L. Samuel (*center*), research advisor to IBM, and J. M. Bridges, Director of Electronics at the Office of the Assistant Secretary of Defense, look on. Highlight of the conference was a session devoted to discussion of the TX-2 transistorized computer system

Keith Kinsey (*left*), speaker at the February meeting of the San Fernando Valley Subsection, explains target drones to Subsection Chairman J. C. Van Groos.

H. L. Richardson, a Sylvania vice-president (*left*), talks over engineering management problems with L. G. Clarke, president of the San Francisco Chapter of PGEM. Mr. Richardson was the speaker before a recent joint PGEM-San Francisco Section dinner meeting. This was only one in a series of meetings in which electronics firms' engineering management problems were discussed.

At the annual banquet of the IRE Washington, D. C. Section, six Fellow awards were presented by J. T. Henderson, 1957 IRE President, and five distinguished service citations were awarded by Section Chairman R. I. Cole to Section members. J. M. Bridges of the Office of the Secretary of Defense made the student awards. Shown left to right are: J. M. Bridges; Donald Carruth, Univ. of Maryland; E. E. Reber, Geo. Washington Univ.; J. T. Henderson; J. R. Manning, Geo. Washington Univ.; J. A. Reyes, Univ. of Maryland; and R. I. Cole. Among the four hundred present were also IRE national officers A. V. Loughren, J. G. Brainerd, and G. W. Bailey.

IRE MEMBERS INVITED TO AID FCC IN INTERFERENCE PROGRAM

The IRE has been asked by the Joint Technical Advisory Committee to assist the Federal Communications Commission in organizing local Cooperative Interference Committees (CIC) throughout the United States to help the FCC in the huge task of investigating and eliminating sources of radio communication interference.

Under the CIC Plan, which is already operating with conspicuous success in a few localities, individuals in a given area who have a common interest in radio communication services—manufacturers, engineers, service organizations and users—are encouraged to form a self-governing committee to consider and resolve interference problems with which the members are mutually concerned. Each CIC is an autonomous organization whose sphere of operation is determined entirely by the wishes of the participating members.

The IRE has distributed full details of the CIC Plan to the Chairman of each IRE Section. IRE members who are interested in participating in this important work are urged to contact their Section Chairmen. Their names and addresses appear on page 713 of this issue.

MAY MARS SCHEDULE RELEASED

The Air Force MARS Eastern Technical Net which broadcasts over the air every Sunday afternoon from 2:00 until 4:00 p.m. (EST) on 7635 or 7540 kc announces the following guest speakers for the month of May:

May 5—Raymond Chapman, Chief Airborne Equipment Engineer, General Precision Laboratories. Topic: Doppler applications for aircraft.

May 12—C. J. Hirsch, Chief Engineer, Research Div., Hazeltine Corp. Topic: color TV.

May 19—J. N. Dyer, Vice-Pres., Airborne Instruments Laboratory. Topic: antenna theory.

May 26—J. V. Bernardo, Aviation Development Advisor, N.E. Regional HQ, C.A.A. Topic: electronics in air traffic control.

News of interest to all members of the IRE residing in states east of the Mississippi River is broadcast on the Eastern Technical Net each Sunday at 3:30 p.m.

IRE ADDS ANOTHER SUBSECTION

The IRE Executive Committee, at its meeting of March 5, approved the formation of the Kitchener-Waterloo Subsection of the Hamilton Section.

IRE ADDS NEW PG CHAPTERS

The following Professional Group Chapters were approved by the IRE Executive Committee at its meeting March 5: PG on Circuit Theory, San Antonio Section; and PG on Antennas & Propagation, Boston Section.

The following Professional Group Chapters were approved by the Executive Committee on April 10: PG on Microwave Theory & Techniques and PG on Broadcast Transmission Systems, Washington, D. C., Section; PG on Communications Systems, Hawaii Section.

PROGRAM AND SPEAKERS OF FIRST PGPT NATIONAL MEETING SET FOR JUNE 6–7 AT CAPITOL

The first National Symposium on Production Techniques, sponsored by the Washington Chapter of the IRE Professional Group on Production Techniques, will be held at the Hotel Willard, Washington, D. C., June 6–7. Registration at the door will start at 8 A.M., June 6. Advance registration is $3.00; registration at the door is $4.00.

The first session, scheduled for 9:30 A.M.–12:00 P.M., will contain talks by D. D. Israel, Emerson Radio & Phonograph Corp.; Mel Parkes, Admiral Corp.; J. A. Cadwallader, G. E. Co.; A. H. Postle, Sprague Electric; Edgar Weinberg, Bureau of Labor Statistics, Dept. of Labor; R. W. Daniels, United Shoe Co.; and Jacob Rabinow, Rabinow Engineering Co., on how management prepares for and implements automation. Mr. Israel will preside.

Annual awards going to IRE-PGPT members for outstanding contributions to the field of production techniques will be a feature of the luncheon on June 6.

E. R. Gamson, North American Aviation, will be chairman of the Thursday afternoon session, which runs from 2:00 to 5:00 P.M. Production design and production engineers will present papers on automation techniques covering experiences, approaches materials handling, bottle-necks, automatic testing and quality control.

The session scheduled from 9:00 A.M. to noontime June 7 will be headed by J. M. Bridges, Director of Electronics, Office of the Assistant Secretary of Defense. Speakers will be J. M. Bridges; Capt. W. I. Bull, Assistant Chief of Bureau of Ships for Electronics, Department of the Navy; A. W. Rogers, Director, Electronic Parts & Materiel Division of Signal Corps; D. E. Noble, Motorola, Inc.; William Schneider, Stavid Engineering; and William Bainbridge, Aerovox Corp. They will discuss military problems in implementing automation.

A. A. Lawson is general chairman of the symposium. Helping him are: J. M. Lee, vice-chairman; S. Levine, technical program; J. P. Nigro, local arrangements, exhibits and finance; H. S. Wolf, publicity and publications; and P. Zukauska. The steering committee consists of R. E. Bauer, J. W. Brush, R. L. Henry, F. Israel, A. A. Lawson, J. H. Lee, S. Levine, J. P. Nigro, G. Shapiro, Mrs. H. S. Wolf and R. I. Cole. The advisory board consists of R. R. Batcher, J. M. Bridges, L. M. Clement, R. I. Cole, A. R. Gray, and R. L. Henry.

It is hoped that papers presented at this symposium will later be made available in TRANSACTIONS. Specific information can be obtained from each speaker.

Books

Basic Electrical Engineering, 2nd ed. by A. E. Fitzgerald and D. E. Higginbotham

Published (1956) by McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y. 36, N. Y. 523 pages+3 appendix pages+11 index pages+xi pages. Illus. 9¼×6¼. $6.50.

Those who know the first edition of this book will be well pleased with the current edition. The new edition contains revisions, reorganization, and additions which are the result of technical progress and the experience of the authors and others in the use of the earlier edition of the book.

This second edition is an extremely well organized complete modern text and basic reference work recognizing the scientific, analytical, and physical basis of modern electrical engineering. Particular emphasis has been placed on electronics, measurements, and control in addition to adequate coverage of the machinery and power fields.

The introductory chapters cover electrical circuits, magnetic circuits, machinery, and electronics. Feedback control theory is introduced in the chapters on circuit theory, machinery, and electronics so that the student is familiar with this concept when the chapter on feedback control is reached. The revised edition now includes such subjects as magnetic amplifiers, transistors, self-balancing recorders and controllers, phase sensitive modulators and demodulators, control amplifiers, dc and ac control motors, and transfer-function and frequency-control analysis.

This text has been written primarily for the undergraduate and provides a thoroughly up-to-date treatment of the field of basic electrical engineering. However it also is an excellent source of reference and refresher material for the electrical or electronic engineer who by specialization or for some other reason may have lost contact with the subjects covered by the text. Careful selection of examples at the end of each section has contributed to this edition's understandability. A number of well chosen problems are given at the end of each chapter.

The second edition is an outstanding contribution to the material available for training future engineers.

J. L. HEINS
Garden City, N. Y.

Statistical Analysis of Stationary Times Series by Ulf Grenander and Murray Rosenblatt

Published (1957) by John Wiley & Sons, Inc., 440 Fourth Ave., N. Y. 16, N. Y. 287 pages+6 appendix pages+5 pages of bibliography+2 index pages. 9¼ × 6¼. $11.00.

It is encouraging to note the growing trend toward unification of the several approaches to the problems which engineers classify under "noise," the statisticians call "time series," and the mathematicians define as "stochastic processes." Convergence of these various points of view should lead to a greatly improved understanding of many natural phenomena. Communication between investigators in the different schools of thought has been hampered by lack of a common language. Different motivations have also obstructed mutual interchange of ideas and results. The mathematician pursued abstract ideas and was content to prove theorems from hypotheses without regard to physical meaning. The statistician lived in a world of his own constructed of parametric models about which he computed confidence intervals. The engineer relied on his measuring equipment and his mastery of the laboratory environment to make his work meaningful.

Now it is becoming apparent that the three schools are working in a common field and each could benefit from the discoveries and techniques of the others. Unfortunately the engineer is likely to be frustrated in his attempts to understand what the mathematicians and statisticians have to say about his problem because of the unfamiliar concepts upon which their arguments are based. Whether the representatives of the other fields have found the engineering literature equally opaque is not certain, but there is evidence that in spite of semantic difficulties the basic engineering concepts have begun to diffuse through the mathematical and statistical fields.

This preamble introduces a book which should advance the general understanding of what is now known about noise from the three different points of view. It is not a royal road to knowledge and in fact it is tough going most of the way. But the development is honest and there are adequate references given to what is not included. As a reward for effort, many of the now classical formulations of basic noise problems are interspersed in remarkably neat and concise form. The economy of presentation is deceptive for it depends on an essential framework of advanced mathematical thinking. It appears likely that once the principles are mastered, one could go on to solve new and more difficult problems, but this cannot be guaranteed. The best reward would probably come to one willing to go through the material for its own sake.

Specifically the book deals almost entirely with "weakly stationary processes," that is, ensembles in which first and second order statistics, including, for example, first and second moments, spectral density, and covariance, do not change with time. Emphasis is placed on the spectral density as a basic analytical tool and respects are paid to the physical sciences which have been pioneers in the exploitation of the spectral method. To the statisticians, spectral density represents an example of a non-parametric model. There is only one chapter of the book dealing with parametric models. One favorite type would be described by the engineer as consisting of oscillators, tapped delay lines, and feedback connections. With a sufficiently complicated arrangement one should be able to fit almost data. Physical reality of the model is not a necessary adjunct. It is amusing to read that in former times some statisticians ran their data through what the engineer would call transversal filters in order to remove random fluctuations and expose the hidden periodicities. A damper was put on this practice by Slutzky's theorem, which when translated into engineering terms, warns the unwary that transmission of noise through a long chain of identically tuned resonant circuits produces an output with spectral density function approaching that for a sine wave at the resonant frequency. No doubt parallel cases could be found where engineers have been equally obtuse about situations which would be clear to statisticians.

The book includes chapters about what can be done if the spectrum is known, how to estimate the spectrum from a finite number of observations, and how to find distribution functions for spectral estimates. Applications are given to electrical noise, turbulence, optics, and ocean waves. Sundry other topics touched upon include detection of signals in noise, confidence intervals and tests, zeros and maxima, prefiltering, tests of normality, and various species of prediction. In short, the book appears to be a gold mine for the reader who is not afraid to dig below the surface.

W. R. BENNETT
Bell Tel. Labs., Inc.
Murray Hill, N. J.

Advances in Electronics and Electron Physics, Vol. VIII, ed. by L. Marton

Published (1956) by Academic Press, Inc., 111 Fifth Ave., N. Y. 3, N. Y. 539 pages+22 index pages +xi pages. Illus. 9¼×6¼. $13.00.

This volume contains reviews of the following subjects: new applications and techniques of molecular beams; field emission; mass spectroscopy; amplitude and time measurement in nuclear physics; pulse amplitude analysis; electron guns and focusing in high-density electron beams; the electrical life of an oxide-cathode receiving tube; storage tubes; magnetron mode transitions.

"Some New Applications and Techniques of Molecular Beams," by V. G. King and J. R. Zacharias starts with a brief review of the applications of molecular beams to masers, frequency standards, and the measurement of magnetic fields, acceleration, and length standards. The rest of the article consists of descriptions of more or less conventional molecular-beam components with suggestions for future development, with the purpose of assisting new users of molecular beams. Under a description of sources and associated equipment are considered gas sources, source slits, canals, gas-flow control, ovens, ion sources, and recirculating sources. Types of detectors received are Pirani gauges, deposition and ionizing detectors, mass spectrometers, and equipment for measuring small currents. This is followed by some practical notes on the design of deflecting and uniform magnetic fields, and radio-frequency equipment.

"Field Emission," by W. P. Dyke and W. W. Dolan is an able historical summary of field emission theory and observation, with special attention to the crystal structure of the emitter. The recent work at Linfield College is described, with emphasis on pulsed emission microscopy and the practical applications of field emission as a pulsed source. The description of the effects on cathode stability of helium diffusion through the glass envelope is especially interesting, as is also a critical review of the evidence supporting the view that some of the peculiar dynamic phenomena seen in a field emission microscope in the presence of contaminants are actually due to single molecule adsorbed on the emitting surface.

The work of Dyke and his colleagues has gone a long way towards the achievement of stable practical field emission sources, and the concluding description of their techniques will interest new people in this field.

"Mass Spectroscopy," by L. Kerwin, Laval University, covers the high points of this rapidly developing field since 1947. It includes sources, analyzers, detecting and recording systems, data processing, and descriptions of individual instruments, including first- and second-order, single and double focusing, high-order double focusing, pulsed, time-of-flight, single and double focusing, and radio frequency time-of-flight, single and double focusing. Applications are treated only lightly, since the field is so large. Recent significant work in isotope existence and abundance, atomic masses, nuclear studies, chemical analysis, and ionization and dissociation phenomena is reviewed.

"Amplitude and Time Measurement in Nuclear Physics," by E. Baldinger and W. Franzen, is an exposition of their own circuit design methods in these two fields. The concept of "ballistic deficit" is employed in amplitude measurement, this being defined as the difference between the voltage amplitude resulting from a current pulse of finite duration and the amplitude resulting from an infinitely short current pulse carrying the same total charge. Input, amplifier, and output circuits are then designed to minimize this quantity. The section on time measurement discusses the problem of coincidence, and the effect of time dispersion on the information from the ionizing particle before it reaches the coincidence stage.

"Pulse Amplitude Analysis," by J. L. W. Churchill and S. C. Curran is a review of gas, liquid, and solid counters in which the energy of the primary particle is measured, so that the devices act both as detectors and spectrometers. Subjects discussed are proportional counters, scintillation spectrometers, voltage discrimination, voltage-to-length conversion analysis, voltage-to-time conversion analysis, and alternative methods of data presentation in amplitude-to-time conversion analyzers.

"Electron Guns and Focusing for High-Density Electron Beams," by C. Susskind is a critical review of present gun design, including the Pierce, Heil and Muller guns, with a discussion of focusing methods, such as the immersed gun, the shielded gun, and periodic focusing. New cathode materials are treated briefly.

"On the Electrical Life of an Oxide-Cathode Receiving Tube," by G. H. Metson is a tube industry and there, also, I became deeply impressed by the need for further knowledge.

I am keenly interested in reliability and its vital implications to our national defense. This concern, rather than any desire to display such knowledge as I may have, was the motivating factor in my remarks. Since the book under discussion bears directly on the reliability problem and national defense, it is not an ordinary book, but one which, in my opinion, can have far-reaching effects on our military establishment. Because of this belief, I felt that I had no choice but to point out what appeared to me erroneous or misleading. In speaking emphatically on the issues, I had no desire or intention of doing injustice to Mr. Henney or his publisher. I regret any words which may have seemed caustic—they were intended only to be forceful.

Of the nine examples given in the review, only two, I believe, require further discussion. These are concerned with the mathematical approach to reliability, and ionic grid currents in vacuum tubes.

(1) *Mathematical Approach to Reliability*

The original review stated:

> "The author fails to distinguish between the 'population' and the 'sample,' defining probability relations and concepts only in terms of the sample. This is dangerous, for it infers to the uninitiated that one failure in two observations has precisely the same meaning as ten failures in twenty observations."

This statement, as I read it now, is easily misinterpreted and does not unambiguously convey my original intent. For this, I apologize to Mr. Miles. My objection was that reliability was defined in terms of the sample and not in terms of a true probability. Defining reliability in terms of the sample tends to obscure the necessity for computing the effects of sample size on the result. But defining it in terms of probabilities forces attention to the sample size and encourages recognition of the fact that the *sample results are only an estimate of the probability.* The difference between these viewpoints may seem esoteric, but I sincerely believe that a clear understanding of this distinction is of fundamental importance to sound progress in reliability. Mr. Miles did include statements on the importance of sample size, but the nature of his definition seems to preclude consideration of this important factor in the mathematical approach to reliability.

(2) *Ionic Grid Currents in Vacuum Tubes*

The original review stated:

> "Figure 8-20 shows ionic grid current increasing to a maximum and then decreasing as plate current in the electron tube is increased. That ionic grid current is directly proportional to plate current has been an established fact of physical electronics for many decades."

In the interests of brevity, the review did not mention several other points of variance between Figure 8-20 and other published information on grid currents. Those readers interested in resolving this issue in their minds may wish to refer to:

(1) *Fundamentals of Engineering Electronics*, William G. Dow; p. 177, fig. 6.4.
(2) IRE Standards on Electron Tubes; p. 931, fig. 27.

A study of the references and some reflection on the probable voltage scale of the figure should help to clarify my criticisms. Also, since the figure represents "high vacuum" tube characteristics, I believe it is reasonable to disregard plasma effects.

C. R. KNIGHT
Aeronautical Radio, Inc.
Washington, D. C.

CORRECTION

In the February, 1957 issue on page 252 of the PROCEEDINGS OF THE IRE, there was a review of the book, "Handbook of Basic Circuits" by Matthew Mandl, published by The Macmillan Co., 60 Fifth Ave., N. Y. 11, N. Y. It was erroneously stated that the book had 110 pages of text. Actually, there are 309 pages of text.

RECENT BOOKS

Czech, J., *The Cathode Ray Oscilloscope*, Interscience Pub., 250 Fifth Ave., N. Y. 1, N. Y. $8.50.

Electronic Computers, ed. by T. E. Ivall. Philosophical Library, Inc., 15 E. 40 St., N. Y. 16, N. Y. $10.00.

Martin, T. L., Jr., *Physical Basis for Electrical Engineering*. Prentice-Hall, Inc., 70 Fifth Ave., N. Y. 11, N. Y. $10.00.

Most-Often-Needed 1957 Radio Diagrams and Servicing Information, Vol. 17. Compiled by M. N. Beitman. Supreme Publications, 1760 Balsam Road, Highland Park, Ill. $2.50.

Proceedings of the Symposium for Management on the Industrial Applications of Analog Computers. Midwest Research Institute, 425 Volker Blvd., Kansas City 10, Mo. $5.00.

Solid State Physics, Volume Three—Advances in Research and Applications, ed. by Frederick Seitz and David Turnbull. Academic Press, Inc., 111 Fifth Ave., N. Y. 3, N. Y. $12.00.

Stibitz, G. R. and Larrivee, J. A., *Mathematics and Computers.* McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y. 36, N. Y. $5.00.

The Radio Amateur's Handbook, 34th ed., 1957. American Radio Relay League, West Hartford 7, Conn. $3.50 in the United States; $4.00, U. S. Possessions; $4.50, elsewhere.

Tubes for Computers. Elsevier Press Inc., 2330 Holcombe Blvd., Houston 25, Tex. $1.50.

Tube Selection Guide 1956–1957. Compiled by T. J. Kroes. Elsevier Press Inc., 2330 Holcombe Blvd., Houston 25, Tex. $1.50.

Tuska, C. D., *Patent Notes for Engineers*, 7th ed. McGraw-Hill Book Co., Inc., 330 W. 42 St., N. Y. 36, N. Y. $4.00.

UHF Tubes for Communication and Measuring Equipment. Elsevier Press Inc., 2330 Holcombe Blvd., Houston 25, Tex. $1.50.

Wayland, Harold, *Differential Equations Applied in Science and Engineering.* D. Van Nostrand Co., Inc., 257 Fourth Ave., N. Y. 10, N. Y. $7.50.

First National Convention on Military Electronics

SHERATON PARK HOTEL, WASHINGTON, D. C., JUNE 17–19, 1957

SPONSORED BY THE IRE PROFESSIONAL GROUP ON MILITARY ELECTRONICS

The theme of the first National Convention on Military Electronics will be "Missiles and Electronics." With a large attendance expected, advance registration fees will be $1.00 for IRE members, $3.00 for non-IRE members; registration at the convention will be $2.00 for IRE members, $4.00 for non-IRE members.

Convention committee chairmen are: L. D. Whitelock, Exhibits; J. W. Klotz, Arrangements and Registration; R. E. Frazier, Technical Program; Henry Randall, Finance and George Rappaport, Public Relations.

MONDAY, JUNE 17
2—5 P.M.

Design goals for future missile system electronics

Invited papers to be announced.

Instrumentation and telemetry

Automatic Tracking Digitherodolite, A. B. White, W. I. Frank and E. Jamgochian, Electronic Corp. of America.

Visual Surveillance System, J. F. Clevenger, Glenn L. Martin Co.

Recovering Experimental Missile Data, M. W. DeMerit, Jr., General Electric Company.

Telemetering Equipments Utilizing Transistor-Magnetic Circuitry and High-Density Packaging, W. D. Murray and R. M. Tillman, Burroughs Corp.

Rugged, Wide-Band Magnetic Tape Recorder, J. D. Rosenberg, Diamond Ordnance Fuze Lab.

Optical and Electromagnetic Range Instrumentation, E. Kullman, Rome Air Development Center.

Mechanical design for reliability

A Working Procedure for Evaluating the Thermal Effects on Airborne Equipment Reliability, T. C. Reeves, RCA.

Approximation of Heat Transfer Within a Closed System, R. J. Spotz, G. E. Co.

Evaporative-Gravity Cooling for Electronic Equipment, M. Mark, Mark Stephenson, Costas Goltsos, Raytheon Mfg. Co.

Investigation of Temperature Distribution and Thermal Stresses in a Supersonic Radome, R. D. Sutherland, Convair.

Electronic Packaging in the Terrier Missile, H. Chrystie, Convair.

Electronics Packaging for a Tactical Guided Missile Weapons System, M. G. Comuntzis and G. F. Ervin, Jet Propulsion Lab.

Circuitry and subsystems I

Keyed Local Oscillator as Microwave Receiver Range Gate, Harry Beazell, Bendix.

The Ultrasonic Light Modulator, Adolph Rosenthal, Fairchild Corp.

High Frequency Transistor Circuit Design, A. E. Hayes, Jr., General Mills, Inc.

Interval Timing with Transistor Switching Elements, J. W. Higginbotham, Glenn L. Martin Co.

Signal Enhanced Delay Line, T. I. Humphreys, Packard-Bell Co.

A Stable and Reliable Direct Current Transistor Amplifier for Missile Applications, A. R. DeRuyck, Bendix.

TUESDAY, JUNE 18

9 A.M.—NOON

Precision ranging and tracking I (Confidential)

The Effect of Automatic Gain Control on Radar Tracking Performance, D. D. Howard, U. S. Naval Research Lab.

Short Pulse Radar, C. D. Hardin and J. Salerno, Diamond Ordnance Fuze Lab.

A High Accuracy Ground to Ground Optical Radar, J. G. Lawton and R. F. Schneeberger, Cornell Aeronautical Lab., Inc.

Delay Stabilized Transponder, G. Rabow and A. Nashman, Fed. Telecommunication Labs.

The AN/APN-81 Doppler Navigation System, F. A. McMahon, General Precision Lab., Inc.

The AN/APN-81 Frequency Tracker, W. B. Lurie and J. W. Gray, General Precision Lab., Inc.

Component parts I

Component Part Reliability Studies for Complex Military Equipments, J. W. Gruol, Signal Corps Engineering Lab.

Precise Frequency Control Devices for Missiles, E. A. Gerber, Signal Corps Engineering Lab.

Reliability of Electron Tubes for Guided Missiles, L. L. Kaplan, Signal Corps Engineering Lab.

Radiation Effects on Semiconductor Diodes, J. W. Clark and H. L. Wiser, Hughes Aircraft Co.

The Application of Transistors to Ordnance Electronics, S. H. Gordon, Diamond Ordnance Fuze Lab.

The Application of Auto-Sembly (Printed Wiring and Automatic Assembly) to the Missile Field, S. G. Bassler, Signal Corps Engineering Lab.

Electrical interference avoidance

RF Interference Design Techniques in Radar Systems, E. R. Radford, G. E. Co.

Radio Interference Testing of Airborne Electronic Equipment, C. F. W. Anderson, C. W. North and F. W. Snow, Glenn L. Martin Co.

Evaluation of Radar and Communications Interference Existing at Air Force Bases, J. W. Worthington, RADC, USAF, and C. L. Frederick, Frederick Research Corp.

Electronically Controllable IF Bandpass Varies Symmetrically Around Center Frequency, G. W. Clevenger, Bendix.

Reduction of Spurious Signal Radiation from Microwave Radars, P. L. Hammann, Bell Tel. Labs.

A Program for Reducing Electronic Interference in a Guided Missile System, G. P. Allison and R. V. Danner, Glenn L. Martin Co.

Test equipment and maintenance

A Precise Electro-Pneumatic Altitude Simulator, H. H. Chanowitz and B. B. Cunningham, Associated Missile Products Corp.

Introduction of Automation in Military Maintenance, Arthur Morrow, Sperry Gyroscope Co.

Guided Missile Test Set AN/DSM-18, speaker from Bendix.

Considerations in the Development of Checkout and Maintenance Equipment to Meet Army Ordnance Requirements, Alvin Steinberg, Redstone Arsenal.

British and American Maintenance Techniques from the Maintainability and Equipment Design Viewpoint, M. V. Ratynski, Rome Air Development Center.

2—5 P.M.

Simulation equipment I (Confidential)

Stacked Beam Radar Signal Simulator, R. J. Hansen, G. E. Co.

Aero 21B Aircraft Tail Turret System Operator's Trainer, Irwin Friedland, U. S. Naval Training Center.

Simulated Air-to-Air Firing Technique, Thomas Mongello, U. S. Naval Training Center.

Altitude Effects on Absorption of Radio Signals by Rocket Exhausts, J. M. Headrick and J. L. Ahearn, Jr., U. S. Naval Research Lab.

A Realistic Radar and Target Simulator, N. V. O'Neal, U. S. Naval Research Lab.

Component parts II

High Rate Batteries for Guided Missile Applications, A. Fischbach, Signal Corps Engineering Lab.

Design Data for Silicon Infrared Optical Systems, Harry Letaw, Jr., Raytheon Mfg. Co.

Radiation Properties of a VHF Ferrite Antenna, O. R. Cruzan, Diamond Ordnance Fuze Lab.

Pencil-Tube, S-Band, Pulsed Oscillator Units for Military Beacon Use, D. W. Power, D. K. Wilde and H. G. Parish, RCA.

Application of Mechanical Filters to Military Electronic Equipment, J. W. Bunce, Collins Radio Co.

A Fast Response, Full Wave Magnetic Amplifier, G. E. Lynn, Westinghouse Electric Co.

Operations analysis

Coordinated Weapon Assignment in Missile Systems with Overlapping Coverage, J. K. Carlyle, RCA.

The Value of Range and Overlapping Coverage in Air Defense Missile Systems, S. N. Mille, D. A. Cole, A. D. Davies, and M. E. Hawley, RCA.

The Application of Game Theory to Tactical Problems, Walter Biernat, Admiral Corp.

Reliability of a Radar System, F. D. Mason, Operations Analysis Group, USAF.

Operational Study of a Ballistic Camera System, Ernest Stern, Ramo-Wooldridge Corp.

An Example of Operations Analysis of the Matador Tactical Missile, R. M. Wood, Jr., Headquarters Tactical Air Command.

Computers and data links

High Speed, High Accuracy Computers for Military Electronic Control Systems, C. T. Leondes, Univ. of Calif.

An Airborne Digital Computer for System Control, R. E. Slack, IBM.

Instrument Thermo-Elements as Nonlinear Elements in Analog Computers, J. R. Boykin, Westinghouse Corp.

A Wideband Data Link Incorporated Video Channelling and Angle Data Equipment, W. L. Wright and R. P. Shipway, Marconi's Wireless Telegraph Co., Ltd.

A Data Transmission System Using Pulse Phase Modulation, R. R. Mosier, Collins Radio Co.

A Magnetized, Digital Data Link, Lyle Thompson and C. A. Taylor, Burroughs Corp.

WEDNESDAY, JUNE 19

9 A.M.—NOON

Miscellaneous (Confidential)

Planning the Instrumentation to Support an Integrated Weapon System Development, J. N. James, Jet Propulsion Lab.

Determination of Velocity and Position, J. R. White, Army Ballistic Missile Agency.

Cooling Infrared Detectors, Ernest Zahn, Perkin-Elmer Corp.

System Human Engineering for Guided Missiles, J. H. Hill, U. S. Naval Research Lab.

A New Approach to Antenna Feeds for Precision Tracking Radars, P. J. Allen, U. S. Naval Research Lab.

Recent Developments in Inertial Instrumentation Bell Aircraft Corporation Accelerometer-Integrator, D. D. Lenhard, Bell Aircraft Corp.

Reliability, performance and methods

Predicting Performance Reliability for Electronic Equipments of High Unit Cost, B. J. Wilson, U. S. Naval Research Lab.

Reliable Operation of Electron Tubes in the SAGE System, N. E. Nitachke, IBM.

A Reliability Test Program, TACAN AN/ARN-21, R. A. Simendinger, U. S. Naval Air Development Center.

Programmed Marginal Checking of the SAGE Computer, R. J. Brennan, IBM.

Weapon Systems Reliability, M. M. Tall, RCA.

Reliability, Methods and Performance,

R. C. Gillis and J. W. Tarzwell, Autonetics of North American.

Simulation equipment II

Resolver Synchros as Ballistic Function Generators, Anthony Bruno, Frankford Arsenal.

Search Radar Track and Noise Simulator, L. Packer and M. Raphael, Gruen Applied Science Labs.

Determination of Loop Performance of Sampled Data Systems with Nonlinear Elements Using Digital Simulation Techniques, J. O. Clark and W. E. Shepard, Westinghouse Electric Corp.

Radar Simulation Techniques, J. I. Leskinen, U. S. Naval Training Device Center.

Standardizing Flight Simulation Circuits, H. L. Ehlers, Autonetics, North American.

Target Simulation for Closed Loop Testing of Fire Control Systems, John Russell and George Barton, Sperry Gyroscope.

Inertial systems

Principles of Inertial Navigation, C. F. O'Donnell, Autonetics, North American.

Use of a "Strapped-Down" Hermetic Integrating Gyroscope System as an Inertial Reference for Guidance and Control of the Vanguard Satellite Launching Vehicle, R. A. Delp, Minneapolis-Honeywell Regulator Co.

Comparison of Acceleration Feedback and Sensitivity Feedback in Missile Guidance Servos, R. B. Schaaf, Bendix.

Effects of Errors in External Damping Reference for Inertial Guidance Systems, J. P. Martino, Wright Air Development Center.

Platform Stabilization, D. P. Chandler and R. H. Cannon, Autonetics, North American.

2—5 P.M.

Guidance systems (Confidential)

Problems in Infrared Guidance, L. W. Sieck, Air Force.

Guidance System Used on the Dart Antitank Missile, B. M. Cole, H. A. Wagner Co.

Automatic Astro Compass, Type MD-1, D. F. Garman and D. B. Nichinson, WADC and Kollsman Instrument.

Airborne Guidance Employing Television Displays, L. Brotman, J. Minker, and S. W. Spaulding, RCA.

A Transistorized Guidance Equipment for NIKE, J. R. Logie, Jr., Bell Tel. Labs.

Experience with the LACROSSE Precision CW Ranging System, A. R. Tanguay and R. E. Frazier, Cornell Aeronautical Lab.

Circuitry and subsystems II

Comparison of Shunt and Series Feedback in Precision Transistor Amplifiers, R. J. Patch, G. E. Co.

An Automatic Gain Control for an Acceleration Command Autopilot, L. J. Schipper, Bendix.

A Laboratory Standard AC Power Supply, D. A. Rosenfield, Bell Aircraft Corp.

Problems Presented by the Integrating Capacitor in a Missile-Borne DC Analog Integrator, Paul Jones, Jet Propulsion Lab.

Variable Bandwidth Servo to Optimize Slewing and Noise Rejection, V. F. Raque, G. E. Co.

Hydraulic Drive Applied to Tracking Radar, Harold Perkel, RCA.

Component assemblies

DC to DC Power Converter, D. L. Cronin, Minneapolis-Honeywell Regulator Co.

Antenna Miniaturization, A. W. Walters, U. S. Naval Ordnance Lab.

High Powered Doppler Transponder, M. H. Murphy, Packard-Bell Electronics Co.

A Stripling Microwave Mixer System for a Missile Application, R. E. Stone, Convair.

Variations in Magnetic Modulator Design, H. E. Thomas, Fed. Telecommunication Labs.

Operating Time Indicator, W. T. Eriksen, Raytheon Mfg. Co.

Ranging and tracking

Bearing Memory for Direction Finders, R. E. Anderson, G. E. Co.

Monopulse Automatic Tracking and the Thermal Bound, H. T. Budenbom, Stavid Engineering, Inc.

A Precision Multi-Purpose Radio Navigational System, W. P. Frantz, Sperry Gyroscope.

A Precision Ranging System, A. G. Chressanthis and A. J. Lisicky, RCA.

Center of Gravity Beam Splitting, J. Kirshner, E. Ramos and C. Ravilious, Diamond Ordnance Fuze Lab.

Application of Frequency Following to DME Systems, P. F. Panter and R. C. Davis, Fed. Telecommunication Labs.

Professional Groups†

Aeronautical & Navigational Electronics—Joseph General, 6019 Highgate Dr., Baltimore 15, Md.

Antennas & Propagation—H. G. Booker, School of Physics and Elec. Engrg., Cornell Univ., Ithaca, N. Y.

Audio—Dr. H. F. Olson, RCA Labs., Princeton, N. J.

Automatic Control—J. C. Lozier, Bell Tel. Labs., Whippany, N. J.

Broadcast & Television Receivers—L. R. Fink, Research Lab., General Electric Company, Schenectady, N. Y.

Broadcast Transmission Systems—O. W. B. Reed, Jr., Jansky & Bailey, 1735 DeSales St., N.W., Washington, D. C.

Circuit Theory—H. J. Carlin, Microwave Res. Inst., Polytechnic Inst. of Brooklyn, 55 Johnson St., Brooklyn 1, N. Y.

Communications Systems—F. M. Ryan, American Telephone and Telegraph Co., 195 Broadway, New York 7, N. Y.

Component Parts—R. M. Soria, American Phenolic Corp., 1830 S. 54 Ave., Chicago 50, Ill.

Electron Devices—R. R. Law, CBS-Hytron, Danvers, Mass.

Electronic Computers—J. D. Noe, Div. of Engineering Research, Stanford Research Institute, Stanford, Calif.

Engineering Management—Rear Adm. C. F. Horne, Jr., Convair, Pomona, Calif.

Industrial Electronics—C. E. Smith, Consulting Engineer, 4900 Euclid Ave., Cleveland 3, Ohio.

Information Theory—M. J. Di Toro, Polytech. Research & Dev. Corp., 200 Tillary St., Brooklyn, N. Y.

Instrumentation—F. G. Marble, Boonton Radio Corporation, Intervale Road, Boonton, N. J.

Medical Electronics—V. K. Zworykin, RCA Labs., Princeton, N. J.

Microwave Theory and Techniques—H. F Englemann, Federal Telecommunication Labs., Nutley, N. J.

Military Electronics—C. L. Engleman, 2480 16 St., N.W., Washington 9, D. C.

Nuclear Science—W. E. Shoupp, Westinghouse Elec. Corp., Commercial Atomic Power Activities, P.O. Box 355, Pittsburgh 30, Pa.

Production Techniques—R. R. Batcher, 240-02—42nd Ave., Douglaston, L. I., N. Y.

Reliability and Quality Control—Victor Wouk, Beta Electric Corp., 333 E. 103rd St., New York 29, N. Y.

Telemetry and Remote Control—C. H. Hoeppner, Radiation, Inc., Melbourne Fla.

Ultrasonics Engineering—J. F. Herrick, Mayo Foundation, Univ. of Minnesota, Rochester, Minn.

Vehicular Communications—Newton Monk, Bell Labs., 463 West St., N. Y., N. Y.

---

† Names listed are group Chairmen.

Sections*

Akron (4)—C. O. Lambert, 1144 Roslyn Ave., Akron 20, Ohio; M. L. Kult, 1006 Sackett Ave., Cuhahoga Falls, Ohio.

Alamagordo-Holloman (6)—O. W. Fix, Box 915, Holloman AFB, N. M.; T. F. Hall, Box 824, Holloman AFB, N. M.

Albuquerque-Los Alamos (7)—G. A. Fowler, 3333—49 Loop, Sandia Base, Albuquerque, N. M.; S. H. Dike, Sandia Corp., Dept., 5120, Albuquerque, N. M.

Atlanta (3)—W. B. Miller, 1369 Holly Lane, N.E., Atlanta 6, Ga.; W. H. White, 1454 S. Gordon St., S.W., Atlanta 10, Ga.

Baltimore (3)—M. I. Jacob, 1505 Tredegar Ave., Catonsville 28, Md.; P. A. Hoffman, 514 Piccadilly Rd., Baltimore 4, Md.

Bay of Quinte (8)—R. L. Smith, Northern Electric Co., Ltd., Box 400, Belleville, Ont., Canada; M. J. Waller, R.R.1, Foxboro, Ont., Canada.

Beaumont-Port Arthur (6)—J. G. Morgan, 508 Garland St., Beaumont, Tex.; B. J. Ballard, Box 2831, Rm. 608, Beaumont, Tex.

Binghamton (1)—Arthur Hamburgen, 926 Glendale Drive, Endicott, N. Y.; Y. M. Hill, 2621 Smith Dr., Endicott, N. Y.

Boston (1)—R. A. Waters, Box 368, S. Sudbury, Mass.; T. F. Jones, Jr., 62 Bay St., Squantum, Mass.

Buenos Aires—A. H. Cassiet, Zavalia 2090 1 "B," Buenos Aires, Argentina; O. C. Fernandez, Transradio Internacional, 379 San Martin, Buenos Aires, Argentina.

Buffalo-Niagara (1)—G. F. Buranich, Route 1, Lewiston, N. Y.; Earl Whyman, 375 Mt. Vernon Rd., Snyder 21, N. Y.

Cedar Rapids (5)—J. L. Dalton, 2900 E. Ave., N.E., Cedar Rapids, Iowa; S. M. Morrison, 2034 Fourth Ave., S.E., Cedar Rapids, Iowa.

Central Florida (3)—G. F. Anderson, Dynatronics, Inc., 717 W. Amelia Ave., Orlando, Fla.; J. W. Downs, 1020 Highland Ave., Eau Gallie, Fla.

Central Pennsylvania (4)—R. E. Skipper, 276 Ellen Ave., State College, Pa.; S. A. Bowhill, Dept. of Elec. Eng., Penn. State Univ., University Park, Pa.

Chicago (5)—R. M. Soria, 1830 S. 54th Ave., Chicago 50, Ill.; G. H. Brittain, 3150 Summit Ave., Highland Park, Ill.

China Lake (7)—C. F. Freeman, 100-B Halsey St., China Lake, Calif.; P. K. S. Kim, 200-A Byrnes St., China Lake, Calif.

Cincinnati (4)—F. L. Weidig, Jr., 3819 Davenant Ave., Cincinnati 13, Ohio; H. E. Hancock, R.R. 4, Branch Hill Box 52, Loveland, Ohio.

Cleveland (4)—J. F. Keithley, 22775 Douglas Rd., Shaker Heights 22, Ohio; C. F. Schunemann, 2021 Sagamore Dr., Euclid 17, Ohio.

Columbus (4)—T. E. Tice, 2214 Jervis Rd., Columbus 21, Ohio; G. R. Jacoby, 78 N. James Rd., Columbus 13, Ohio.

Connecticut Valley (1)—B. R. Kamens, 94 Admiral Dr., New London, Conn.; J. D. Lebel, Benedict Hill Rd., New Canaan, Conn.

Dallas (6)—G. K. Teal, Texas Instruments Inc., 6000 Lemmon Ave., Dallas, Texas; John Albano, 4134 Park Lane, Dallas, Texas.

Dayton (4)—R. W. Ittelson, 724 Golfview Dr., Dayton 6, Ohio; Yale Jacobs, 310 Ryburn Ave., Dayton 5, Ohio.

Denver (6)—R. C. Webb, 2440 S. Dahlia St., Denver 22, Colo.; S. B. Peterson, 1295 S. Jackson, Denver 10, Colo.

Detroit (4)—E. C. Johnson, 4417 Crooks Rd., Royal Oak, Mich.; G. E. Ryan, 5296 Devonshire Rd., Detroit 24, Mich.

Egypt—H. M. Mahmoud, Faculty of Engineering, Fouad I University, Giza, Cairo, Egypt; El Garhi I El Kashlan, Egyptian Broadcasting, 4, Shari Sherifein, Cairo, Egypt.

Elmira-Corning (1)—J. P. Hocker, Pilot Plant No. 2, Corning Glass Works, Corning, N. Y.; J. H. Fink, 26 Hudson St., Bath, N. Y.

El Paso (6)—J. H. Maury, 328 Olivia Circle, El Paso, Tex.; W. A. Toland, 912 Brazil St., El Paso, Tex.

Emporium (4)—H. S. Hench, Jr., Sylvan Heights, Emporium, Pa.; H. J. Fromell, Sylvania Elec. Prod. Inc., Emporium, Pa.

Evansville-Owensboro (5)—D. D. Mickey, Jr., Engineering Department, General Electric Co., Owensboro, Ky.; C. L. Taylor, 2613 Cherokee Dr., Owensboro, Ky.

Florida West Coast (3)—E. L. White, 460 Coffee Pot Riviera, St. Petersburg, Fla.; R. Murphy, 12112 N. Edison Ave., Tampa 4, Fla.

Fort Huachuca (7)—J. H. Homsy, Box 123 San Jose Branch, Bisbee, Ariz.; R. E. Campbell, Box 553, Benson, Ariz.

Fort Wayne (5)—T. L. Slater, 1916 Eileen Dr., Waynedale, Ind.; F. P. Smith, Windsor Rd., R.R. 15, Fort Wayne, Ind.

Fort Worth (6)—G. C. Sumner, 3900 Spurgeon, Fort Worth, Texas; C. W. Macune, 3132 Forest Park Blvd., Fort Worth, Texas.

Hamilton (8)—C. N. Chapman, 40 Dundas St., Waterdown, Ont., Can.; C. J. Smith, Gilbert Ave., Dancaster Courts, Sub. Serv. 2, Ancaster, Ont., Canada.

Hawaii (7)—R. R. Hill, 219 Uilma St., Lanikai, T. H.; L. R. Dawson, 432 A Kalama St., Lanikai, T. H.

Houston (6)—R. L. Ransome, 1705 Huge Oaks, Houston 24, Tex.; T. N. Whitaker, 3801 Cullen Blvd., Houston 4, Tex.

Huntsville (3)—T. L. Greenwood, 1709 La Grande St., Huntsville, Ala.; W. J. Robinson, 20 Polk Dr., Huntsville, Ala.

Indianapolis (5)—V. V. K. French, 1636 Pennsylvania St., Indianapolis, Ind.; N. Drilling, 3002 Ashland Ave., Indianapolis 26, Ind.

Israel—Franz Ollendorf, Box 910, Hebrew Inst. of Technology, Haifa, Israel; A. A. Wulkan, P.O.B. 1, Kiryat Motzkin, Haifa, Israel.

Ithaca (1)—H. S. McGaughan, Dept. of Elec. Eng., Cornell Univ., Ithaca, N. Y.; W. H. Murray, General Electric Co., Ithaca, N. Y.

Kansas City (6)—R. W. Butler, Bendix Aviation Corp., Kansas City Division, Kansas City 10, Mo.; Mrs. G. L. Curtis, 6005 El Monte, Mission, Kan.

Little Rock (6)—D. L. Winn, 10th and Spring Sts., Little Rock, Ark.; F. J. Wilson, Rt. 7, Box 500-J, Little Rock, Ark.

London (8)—E. R. Jarmain, 13 King St., London, Ont., Canada; W. A. Nunn, Radio Station CFPL-TV, London, Ont., Canada.

Long Island (2)—David Dettinger, Wheeler Laboratories, Inc., Great Neck, Long Island, N. Y.; T. C. Hana, 59–25 Little Neck Parkway, Little Neck, Long Island, N. Y.

Los Angeles (7)—V. J. Braun, 2673 N. Raymond Ave., Altadena, Calif.; J. N. Whitaker, 323—15th St., Santa Monica, Calif.

Louisville (5)—O. W. Towner, WHAS Inc., 525 W. Broadway, Louisville 2, Ky.; F. M. Sweets, 114 S. First St., Louisville 2, Ky.

Lubbock (6)—J. B. Joiner, 2621—30th St., Lubbock, Texas; E. W. Jenkins, Jr., Shell Oil Co., Admin. Dept., Box 1509, Midland, Tex.

Miami (3)—W. H. Epperson, Aeronautical Communications Equipment Co., 3090 Douglas Rd., Coral Gables, Fla.; R. S. Rich, 7513 S.W. 54 Ct., S. Miami, Fla.

Milwaukee (5)—J. E. Jacobs, 6230 Hale Park Dr., Hales Corners, Wis.; L. C. Geiger, 2734 N. Farwell Ave., Milwaukee 11, Wis.

Montreal (8)—F. H. Margolick, Canadian Marconi Co., 2442 Trenton Ave., Montreal, Quebec, Canada; A. H. Gregory, 170 Fieldcrest Ave., Point Claire, P. Q., Canada.

Newfoundland (8)—J. A. McDavid, Hqtrs. Dir. Comm., Northeast Air Command APO 862, N. Y., N. Y.; J. A. Willis, Canadian Marconi Co., Ltd., Pinetree-NEAC Depot, Pepperrill AFB, St. John's Newfoundland, Canada.

New Orleans (6)—M. F. Chapin, General Electric Co., 236 Lee Circle Bldg., New Orleans 12, La.; G. A. Hero, 1102 Lowerline St., New Orleans 18, La.

New York (2)—H. S. Renne, Bell Telephone Laboratories, Inc., Publication Department, 463 West St., New York 14, N. Y.; O. J. Murphy, 410 Central Park W., New York 25, N. Y.

North Carolina-Virginia (3)—M. J. Minor, Route 3, York Rd., Charlotte, N. C.; E. G. Manning, Elec. Engr. Dept., North Carolina State College, Raleigh, N. C.

Northern Alberta (8)—J. E. Sacker, 10235—103rd St., Edmonton, Alberta, Canada; Frank Hollingworth, 9619—85th St., Edmonton, Alberta, Canada.

Northern New Jersey (2)—A. M. Skellett, 10 Midwood Terr., Madison, N. J.; G. D. Hulst, 37 College Ave., Upper Montclair, N. J.

Northwest Florida (3)—F. E. Howard, Jr., 573 E. Gardner Dr., Fort Walton, Fla.; W. W. Gamel, Canoga Corp., P.O. Box 188, Shalimar, Fla.

Oklahoma City (6)—C. M. Easum, 3020 N.W. 14th St., Oklahoma City, Okla.;

---

* Numerals in parentheses following Section designate region number. First name designates Chairman, second name, Secretary.

Nicholas Battenburg, 2004 N.W. 30th St., Oklahoma City 6, Okla.

Omaha-Lincoln (5)—J. S. Petrik, 760 S. 70 St., Omaha, Neb.; H. W. Becker, 1214 N. 34 St., Omaha 3, Neb.

Ottawa (8)—C. F. Pattenson, 3, Braemar, Ottawa 2, Ont., Canada; J. P. Gilmore, 1458 Kilborn Ave., Ottawa, Ont., Canada.

Philadelphia (3)—M. S. Corrington, RCA Victor TV Division, Cherry Hill, 204-2, Camden 8, N. J.; I. L. Auerbach, 1243—65th Ave., Philadelphia 26, Pa.

Phoenix (7)—Everett Eberhard, 30 E. Colter St., Phoenix, Ariz.; R. V. Baum, 1718 East Rancho Dr., Phoenix, Ariz.

Pittsburgh (4)—Gary Muffly, 715 Hulton Rd., Oakmont, Pa.; H. R. Kaiser, WHC-WWSW, Sherwyn Hotel, Pittsburgh 22, Pa.

Portland (7)—R. R. Pooley, 3153 N.E. 83 Ave., Portland 20, Ore; R. C. Raupach, 135 N.E. 18 Ave., Apt. 4, Portland, Ore.

Princeton (2)—L. L. Burns, Jr., RCA, Princeton, N. J.; Sylvan Fitch, Coll. of Eng., Rutgers Univ., New Brunswick, N. J.

Regina (8)—William McKay, 2856 Retallack St., Regina, Saskatchewan, Canada; J. A. Funk, 138 Leopold Crescent, Regina, Saskatchewan, Canada.

Rio de Janeiro—W. W. L. Heininger, Rua Anchieta 5, Apt. 1001—LEME, Rio de Janeiro, Brazil; J. C. B. Frederico, AV Atlantica 586, Apt. 1101—LEME, Rio de Janeiro, Brazil.

Rochester (1)—W. F. Bellor, 186 Dorsey Rd., Rochester 16, N. Y.; R. E. Vosteen, 473 Badkus Rd., Webster, N. Y.

Rome-Utica (1)—M. V. Ratynski, 205 W. Cedar St., Rome, N. Y.; Sidney Rosenberg, 907 Valentine Ave., Rome, N. Y.

Sacramento (7)—E. W. Berger, 3421—58 St., Sacramento 20, Calif.; P. K. Onnigian, 4003 Parkside Ct., Sacramento, Calif.

St. Louis (6)—F. W. Swantz, 16 S. 23rd St., Belleville, Ill.; Gilbert Pauls, R.R. 1—Box 294-B, Imperial, Mo.

Salt Lake City (7)—V. E. Clayton, 1525 Browning Ave., Salt Lake City, Utah; A. L. Gunderson, 3906 Parkview Dr., Salt Lake City 17, Utah.

San Antonio (6)—W. H. Hartwig, Dept. of Elec. Eng., University of Texas, Austin 12, Tex.; E. L. Hixson, Dept. of Elec. Eng., University of Texas, Austin 12, Tex.

San Diego (7)—E. J. Moore, 3601 Eighth St., San Diego 3, Calif.; R. J. Cary, Jr., 4561 Normandie Place, La Mesa, Calif.

San Francisco (7)—J. S. McCullough, 1781 Willow St., San Jose 25, Calif.; E. G. Goddard, Stanford Research Institute, Menlo Park, Calif.

Schenectady (1)—J. S. Hickey, Jr., General Electric Co., Box 1088, Schenectady, N. Y.; C. V. Jakowatz, 10 Cornelius Ave., Schenectady 9, N. Y.

Seattle (7)—K. R. Willson, 1100—17th Ave. 206, Seattle 22, Wash.; W. J. Siddons, 6539—39th N.E., Seattle 15, Wash.

South Bend-Mishawaka (5)—J. L. Colten, 149 E. Tasher, South Bend, Ind.; P. G. Cox, R.R. 2, Box 441, Osceola, Ind.

Southern Alberta (8)—W. Partin, 448—22nd Ave., N.W., Calgary, Alberta, Canada; R. W. H. Lamb, Radio Station CFCN, 12th Ave. and Sixth St. E., Calgary, Alberta, Canada.

Syracuse (1)—P. W. Howells, General Electric Co., H.M.E.E. Dept., Bldg. 3, Industrial Park, Syracuse, N. Y.; G. M. Glasford Elec. Eng. Dept., Syracuse University, Syracuse 10, N. Y.

Tokyo—Hidetsugu Yagi, Musashi Kogyo Daigaku, 2334 Tamagawa Todoroki 1, Setagayaku, Tokyo, Japan; Fumio Minozuma, 16 Ohara-Machi, Meguro-Ku, Tokyo, Japan.

Toledo (4)—M. E. Rosencrantz, 4744 Overland Parkway, Apt. 204, Toledo, Ohio; L. B. Chapman, 2459 Parkview Ave., Toledo 6, Ohio.

Toronto (8)—H. W. Jackson, 352 Laird Dr., Toronto 17, Ont., Can.; R. J. A. Turner, Philips Industries, Ltd., 10 Eglinton Ave., E., Toronto, Ont., Can.

Tucson (7)—R. C. Bundy, Department 15, Hughes Aircraft Co., Tucson, Ariz.; Daniel Hochman, 2917 E. Malvern St., Tucson, Ariz.

Tulsa (6)—J. D. Eisler, Box 591, Tulsa 2, Okla; J. M. Deming, 5734 E. 25th St., Tulsa, Okla.

Twin Cities (5)—J. L. Hill, 25—17 Ave., N.E., North St. Paul 9, Minn.; F. C. Wagner, 16219 Tonkaway Rd., Wayzata, Minn.

Vancouver (8)—J. S. Gray, 4069 W. 13th Ave., Vancouver, B. C., Canada; L. R. Kersey, Department of Electrical Engineering, Univ. of British Columbia, Vancouver 8, B. C., Canada.

Washington (3)—R. I. Cole, 2208 Valley Circle, Alexandria, Va.; R. M. Page, 5400 Branch Ave., Washington 23, D. C.

Wichita (6)—J. W. Patterson, 300 N. Broadway, Wichita 2, Kan.; H. C. Davis, 1908 S. Parkwood Lane, Wichita 18, Kan.

Williamsport (4)—F. T. Henry, 1345 Pennsylvania Ave., Williamsport, Pa.; W. H. Bresee, 818 Park Ave., Williamsport, Pa.

Winnipeg (8)—H. T. Wormell, 419 Notre Dame Ave., Winnipeg, Manitoba, Canada; T. J. White, 923 Waterford Ave., Fort Garry, Winnipeg 9, Manitoba, Canada.

Subsections

Berkshire (1)—A. H. Forman, jr., O.P. 1-203, N.O.D., General Electric Co., 100 Plastics Ave., Pittsfield, Mass.; E. L. Pack, 62 Cole Ave., Pittsfield, Mass.

Buenaventure (7)—O. La Plant, 325 N. "J," St. Oxnard, Calif.; W. L. MacDonald Naval Air Missile Test Center, Code MT-4, Point Mugu, Calif.

Charleston (3)—A. Jonas, 105 Lancaster St., N. Charleston, S. C.; F. A. Smith, Route 4, Melrose Box 572, Charleston, S. C.

East Bay (7)—H. F. Gray, Jr., 2019 Mira Vista Dr., El Cerrito, Calif.; D. R. Cone, 6017 Chabolyn Terr., Oakland 18, Calif.

Erie (1)—J. D. Heibel, 310 W. Grandview, Erie, Pa.; D. H. Smith, 3025 State St., Erie, Pa.

Gainesville (3)—W. E. Lear, Dept. of Elec. Eng., Univ. of Fla., Gainesville, Fla. (Chairman)

Hampton Roads (3)—R. L. Lindell, 2731 Jason Ave., Norfolk 9, Va.; J. E. Eller, Waterview Apts., Apt. E-3, Portsmouth, Va.

Kitchener-Waterloo (8)—Officers to be elected.

Lancaster (3)—W. T. Dyall, 1415 Hillcrest Rd., Lancaster, Pa.; P. W. Kaseman, 405 S. School Lane, Lancaster, Pa.

Las Cruces-White Sands Proving Grounds (6)—Officers to be elected.

Lehigh Valley (3)—J. J. Karakash, Dept. of Elec. Eng., Lehigh Univ., Bethlehem, Pa.; L. G. McCracken, Dept. of Elec. Eng., Lehigh Univ., Bethlehem, Pa.

Memphis (3)—R. N. Clark, Box 227, Memphis State College, Memphis, Tenn. (Chairman)

Mid-Hudson (2)—J. C. Logue, IBM Eng. Lab. Annex, Poughkeepsie, N. Y.; R. R. Blessing, IBM South Rd., Poughkeepsie, N. Y.

Monmouth (2)—W. M. Sharpless, Box 107, Bell Tel. Labs., Red Bank, N. J.; A. P. King, Bell Tel. Labs., Box 107, Red Bank, N. J.

Nashville (3)—Officers to be elected.

New Hampshire (1)—M. R. Richmond, 55 Raymond St., Nashua, N. H.; R. O. Goodwin, 86 Broad St., Nashua, N. H.

Orange Belt (7)—J. Tampico. 2709 N. Garey Ave., Pomona, Calif.; R. E. Beekman, 113 N. Lillie, Fullerton, Calif.

Palo Alto (7)—W. B. Wholey, 25044 La Loma Dr., Los Altos, Calif.; A. M. Peterson, 14846 Manuella Ave., Los Altos, Calif.

Panama City (3)—Officers to be elected.

Pasadena (7)—R. M. Ashby, 3600 Fairmeade Rd., Pasadena, Calif.; J. L. Stewart, Department of Electrical Engineering, California Institute of Technology, Pasadena, Calif.

Piedmont (3)—H. H. Arnold, 548 S. West view Dr., Winston-Salem, N. C.; C. A Norwood, 830 Gales Ave., Winston-Salem N. C.

Quebec (8)—R. E. Collin, 590 Avenue Mon Repos, Ste. Foy, Quebec, Can.; R. M. Vaillancourt, 638 Avenue Mon Repos, Ste. Foy, Quebec, Canada.

Richland (7)—W. G. Spear, 1503 Birch, Richland, Wash.; P. C. Althoff, 1800 Thompson, Richland, Wash.

San Fernando (7)—J. C. Van Groos, 14515 Dickens St., Sherman Oaks, Calif.; F. E. La Fetra, 22700 Erwin St., Woodland Hills, Calif.

Shreveport (6)—E. D. Nuttall, Box 1407, Shreveport, La.; R. W. Bains, 827 Martha Lane, Shreveport, La.

USAFIT (5)—L. D. Williams, USAF Institute of Technology, MCLI, Box 3039, Wright-Patterson AFB, Ohio; G. P. Gould, Box 3274, USAFIT, Wright-Patterson AFB, Ohio.

Westchester County (2)—F. S. Preston, Norden Laboratories, 121 Westmoreland Ave., White Plains, N. Y.; R. A. La Plante, Philips Laboratories, Inc., S. Broadway, Irvington, N. Y.

Western North Carolina (3)—J. G. Carey, 1429 Lilac Rd., Charlotte, N. C.; R. W. Ramsey, Sr., 614 Clement Ave., Charlotte 4, N. C.

this standardization activity will be described and outlined in detail.

Production Testing in the Automatic Factory—H. S. Dordick (p. 59)

Progress in the mechanization of production testing of electronic products is reviewed. Several test equipments are described and evaluated. The necessity for considering the quality monitoring function of production as a continuous and integrated system is emphasized. This approach enables the test process planner to utilize the powerful tools of operations research in determining the nature of the test equipment and procedures required for optimum operation. A test system for the automatic factory is described. This system calls for the more efficient use of statistical sampling techniques as well as the more efficient feedback of test data. Within the framework of this system, new requirements on test equipment have been developed. The activities of an industry-wide RETMA Task Group on Standards for Product Testing in Mechanized Production is described.

The Xatron—A Variable Speed Electronic Drive for Process Control—A. J. Humphrey (p. 68)

The trend today is the use of electronic variable speed drives in applications which normally would have been filled by rotating conversion units. Physically, electronic drives have a space and weight advantage over rotating equipment. Electrically, they lend themselves to precise control and rapid response to error signals.

Small drives using thyratrons to supply and control d-c motors are quite common. Large Ignitron and Excitron drives have been in successful use for many years. An electronic drive, the Xatron, using a grid controlled rectifier has been marketed in the 30 to 100 horsepower range. It is believed that this drive will capture the mass market for packaged drives within five to ten years. Chief use will be in the machine tool industry and for process control.

Many varieties of electric variable-speed drives have been built and used in the past seventy-five years. The common feature in most of them has been the prime mover itself, the d-c motor. Compared to the induction motor, the d-c motor is an expensive device to produce, chiefly due to necessity for a commutator and brushes. In spite of this factor the d-c motor today remains the foundation upon which the commercial wide range variable speed drive is based.

Today between 80 and 90% of the electric drives built consist of a motor driven d-c generator providing a variable armature voltage for a d-c motor. Until 10 years ago an additional d-c generator was used to supply excitation for the motor field. This rotating member has been largely replaced either with a hot cathode rectifier or with a dry plate rectifier. The ease with which a thyratron field supply could be regulated pointed the way to completely static conversion for both armature and field. The increasing cost of copper and iron has tended to give the static converter an economic advantage over the older combination.

Several factors which have led to increasing use of electronic drives are listed.

1. *Space and weight:* The electronic drive today is much lighter and is furnished in smaller cabinets than are comparable rotating drives. If progress in electronic drives continues, we may expect a complete drive in a cabinet scarcely larger than that of a reduced voltage starter for an induction motor.
2. *Efficiency:* Rotating drives can be made with high efficiencies but at the expense of using extra material. Electronic drives of today are more efficient than their rotating counterparts. Electronic drives of the future will approach 96 to 98% conversion efficiency, and present drives are as high as 92%.
3. *Starting surges:* An a-c motor when started with a contactor across an a-c line usually causes considerable voltage dip which affects other equipment. Starting transients in an electronic drive are related only to output torque and can be easily controlled.
4. *Swift response:* Electronic drives have opened a new era of control with the speed of response that is available through their use. Both the physical inertia and the electrical time constant of larger d-c generators have made it difficult to control motors for rapid variation in speed or load. Rapid changes in power level are inherently easy to obtain with an electronic drive.
5. *Maintenance:* Electronic drives eliminate a good deal of the bearing and brush maintenance problems. Breakdowns are repaired by part replacement rather than by rewinding. Maintenance is usually no more than keeping the electronic unit clean.

Automatic Process Control with Radiation Gauges—W. H. Faulkner, Jr., G. F. Ziffer, and Gilbert Corwin (p. 76)

The optimum automatic process control system requires a continuous flow of information relating to the process variations. Radiation gauges utilizing absorption or scattering of radiation produced by a radioisotope source as a means of measuring thickness, weight per unit area, or density of a product offer a means for obtaining this information. Process control utilizing these gauges differs from the usual control system in that large delays exist between the measuring point and the control point. The existence of such delays requires the use of specialized control systems, usually utilizing interrupted control. A typical control system of this type is described and the safety precautions required to prevent malfunction or damage are discussed.

Measurement and Control in a Large Steam Turbine-Generator Department—R. G. Goldman (p. 82)

Rapidly rising steam temperatures and pressures in addition to new design techniques have vastly increased both the quantity and quality of x-ray and ultrasonic testing required. Consequently, the development pressure, particularly in ultrasonics, which in its modern form is of postwar birth, has been heavy. Some of the techniques, equipment and circuitry of present day inspection are described and the characteristics and operation of ultrasonic transducers noted.

Sodium iodide, the linear accelerator and industrial television have brought the promise of mechanization to the examination of large castings, while the promulgation of acceptance standards and the use of ABC scan representation and recording gives equal promise of speeding up the inspection and quality control of forgings. Preliminary experiments and electronic design work towards these objectives are described.

An interesting development is the use of ultrasonics in nozzle-area determination, wall-thickness measurements on large castings, and liquid-level indication. Possibilities exist for automatic control of machining operations and liquid-level control. Distances and cross sections can be checked with accuracies of 0.1%. As a control device, the feedback nature of the system will tend to suppress dependence on machine or template accuracies.

Analog Versus Digital Techniques for Engineering Design Problems—D. B. Breedon (p. 86)

Nearly every problem encountered in engineering at some time proceeds from the qualitative to the quantitative phase where the results of mathematical analysis must be applied in actual computation. Most often the computation is short enough that automatic means are not necessary. However, more and more problems are requiring powerful aids to calculation. This increase is due as much to expanded thinking encouraged by the mere availability of computers as to any actual backlog of work. Therefore it is to the engineer's advantage to know what computers can do for him, even though he may take his problem to someone else for final preparation and programming.

The following text presents some examples in which automatic calculation is being used. The logic used in choosing the computing methods is shown based on the characteristics of problem and computer. As background for the examples the most important of these characteristics are presented briefly in the next section.

Computers—The Key to Modern Manufacturing Scheduling—J. J. Gravel and T. F. Kavanagh (p. 90)

Manufacturing operations with poor scheduling plans are headed for trouble. Load capacity analysis is a technique for measuring the feasibility and desirability of proposed scheduling plans. Simply stated mathematically, load capacity analysis consists of a series of multiplications and additions. However, the numerous computations in a typical problem usually take more time than can be allowed. The paper describes a special purpose analog computer specifically designed to solve this problem in a matter of minutes.

A Tank Farm Data Reduction System—D. J. Gimpel (p. 94)

A tank farm data reduction system has been developed for the new Tidewater Oil Company installation in Delaware by the Armour Research Foundation and Panellit, Inc. The function of the unit is to secure the temperature corrected volume of fluid in each of the approximately 100 tanks in the field. The inputs to the system are the fluid height and average tank temperature. Fluid volume is tabulated digitally as a function of the height on magnetic tape. The system automatically searches the tape for the indicated volume and multiplies the number by the temperature correction factor. This paper describes the operation of the multiplier, the tape search elements, and the sensing instruments employed in the field. The factors governing the selection of the specific elements in the storage and computing system are also discussed.

(*Paper Presented at the* 1955 *Industrial Electronics Conference, Detroit, Mich.*)

Automation Re-Examined—J. J. Graham (p. 101)

The author re-examines the subject to re-orient thinking along constructive lines which will utilize the concept as we use the many other valuable tools in our industrial storeroom. The mechanization involved in the production of printed boards is discussed. The requirements for numbers and training of people are increased rather than decreased, as outlined by the author.

Military Electronics

Vol. MIL-1, No. 1, March, 1957

Editorial (p. 1)

PGMIL'S "Place in the Sun"—W. R. G. Baker (p. 2)

A Message From Your National Chairman, PGMIL—C. L. Engelman (p. 3)

Electronics and National Defense—C. C. Furnas (p. 3)

Operations Research—P. M. Morse (p. 4)

The Great Discovery of Modern Mathematics—L. R. Lieber (p. 10)

Battle Scars of Military Electronics—The *Scharnhorst* Break-Through—Sir Robert Watson-Watt (p. 19)

Will Science Come to an End?—George Gamow (p. 26)

Contributors (p. 32)

Abstracts and References

Compiled by the Radio Research Organization of the Department of Scientific and Industrial Research, London, England, and Published by Arrangement with that Department and the *Electronic and Radio Engineer*, incorporating *Wireless Engineer*, London, England

NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these pages, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, not to the IRE.

The Index to the Abstracts and References published in the PROC. IRE from February, 1956 through January, 1957 is published by the PROC. IRE, May, 1957, Part II. It is also published by *Electronic and Radio Engineer*, incorporating *Wireless Engineer*, and included in the March, 1957 issue of that journal. Included with the Index is a selected list of journals scanned for abstracting with publishers' addresses.

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.

ACOUSTICS AND AUDIO FREQUENCIES

534.121.2 **975**

A Difference Equation for the Approximate Calculation of the Natural Frequencies of a Membrane (Recurrence Method)—J. Hersch. (*C.R. Acad. Sci., Paris*, vol. 243, pp. 1475–1478; November 12, 1956.)

534.75 **976**

Auditory Reaction Time as a Function of Frequency of the Signal Tone—M. S. P. Rao and N. A. Nayak. (*Cur. Sci.*, vol. 25, p. 255; August, 1956.) Reaction times of the human ear to tones of frequencies between 600 cps and 15 kc have been studied. For a constant intensity of 30 db there is a minimum reaction time for frequencies in the range 1.5–4 kc; this is also the frequency range over which the sensitivity of the human ear is greatest.

534.75:534.862.3/.4 **977**

An Audio Flutter Weighting Network—F. A. Comerci and E. Oliveros. (*J. Soc. Mot. Pict. Telev. Eng.*, vol. 65, pp. 419–425; August, 1956.) The results of listener tests are compared with flutter-index measurements. The meter used incorporates two automatically switched weighting networks, and is thus able to provide a correct objective assessment of flutter effect under different flutter conditions. See also 2507 of 1955 (Comerci).

621.317.7.029.4:537.54 **978**

Narrow-Band A.F. Noise Generator—Steffen. (See 1197.)

621.395.623.7 **979**

Efficiency and Power Rating of Loudspeakers—R. W. Benson. (IRE TRANS., vol. AU-4, pp. 19–23; January/February, 1956.) For abstract see PROC. IRE, vol. 44, p. 716; May, 1956.

621.395.623.7 **980**

High-Fidelity Loudspeakers: the Performance of Moving-Coil and Electrostatic Transducers—H. J. Leak. (*J. Brit. Inst. Radio Eng.*, vol. 16, pp. 681–693; December, 1956.) The advantages and disadvantages of moving-coil-, ribbon- and electrostatic-type loudspeakers with power-handling capacities of about 10 w are discussed. The advantages of the balanced push-pull e.s. loudspeaker are particularly mentioned.

621.395.623.7+621.395.61]:534.61 **981**

An Automatic Integrator for Determining the Mean Spherical Response of Loudspeakers and Microphones—A. Gee and D. E. L. Shorter. (*B.B.C. Eng. Div. Monographs*, pp. 1956.) Detailed description of apparatus designed for use in conjunction with polar plotting equipment; the necessary integrations are effected simultaneously with the measurement of the polar characteristics. When a loudspeaker is tested it is rotated in front of a stationary microphone; the af output from the microphone is amplified, rectified, and converted by a vibrating interrupter to a fixed frequency of 50 cps, and the resulting signal is applied through separate amplifiers to the voltage and current coils of a specially designed kwh meter, which thus registers a quantity proportional to the rate of energy flow per unit area of wave front.

621.395.625.3 **982**

Magnetic Recording, 1888–1952—C. F. Wilson. (IRE TRANS., vol. AU-4, pp. 53–81; May/June, 1956.) An extensive bibliography including 38 important patents.

ANTENNAS AND TRANSMISSION LINES

621.315.213:621.397.24 **983**

Video-Pair Cable System—S. Aoki, O. Kameda, Y. Yokose, and T. Uchino. (*Rep. Elect. Commun. Lab., Japan*, vol. 4, pp. 20–25; June, 1956.) A cable for a television studio /transmitter link is formed by twisting 1.4-mm foamed-polyethylene-insulated wires and screening the pair with Cu tape. Transfer-constant/frequency and characteristic-impedance/frequency curves are shown. The repeater amplifiers and synchronizing-pulse clamping circuits are discussed briefly.

621.372.2 **984**

Dilemmas in Transmission-Line Theory—R. A. Chipman. (*Electronic Radio Eng.*, vol. 34, pp. 64–67; February, 1957.) Errors due to approximations used in calculations of transmission characteristics of electrically-short lines are calculated and the "optimum" and "proper" line terminations are discussed. Some useful relations between line constants are also given.

621.372.2 **985**

The Wave Impedance Occurring in One Kind of Symmetrical Feed System—K. Bochenek. (*Archiwum Elektrotech*, vol. 5, pp. 135–147. English summary, p. 147; 1956.) The characteristic impedance of a particular symmetrical transmission line is determined by a method involving conformal mapping.

621.372.8+621.372.413 **986**

Ferrite Post in a Rectangular Waveguide—P. S. Epstein and A. D. Berk. (*J. Appl. Phys.*, vol. 27, pp. 1328–1335; November, 1956.) "A thin circular ferrite post magnetized lengthwise is placed in a rectangular waveguide with its axis normal to the direction of propagation of the incident waves. The polarization is such that the electric vector is parallel to the post. The reflected and transmitted waves are calculated both with respect to their intensities and phases. The results are also applied to find the influence of a thin ferrite post upon the resonant frequency of a rectangular cavity."

621.372.8 **987**

On Transient Radiation of a Dipole inside a Waveguide—R. Gajewski. (*Acta Phys. Polon.*, vol. 15, pp. 25–41. In English, 1956.) Exact formulas are given for the em field radiated by a dipole of moment **M** inside a waveguide of arbitrary cross section; the time dependent factor of **M** was taken as $1(t)\,[1-\exp(-pt)]\,\sin\omega_0 t$, where $1(t)$ is the Heaviside step function.

621.372.8 **988**

Observed 5–6-mm Attenuation for the Circular Electric Wave in Small and Medium-Sized Pipes—A. P. King. (*Bell Sys. Tech. J.*, vol. 35, pp. 1115–1128; September, 1956.) Measurements are reported on two circular-section waveguides, of internal diameter 7/16 inch and 7/8 inch respectively. The attenuation of the TE_{01} mode is considerably less than that of the dominant mode in both cases; transmission losses as low as 0.5 db/100 ft have been attained. For a given line, the frequency variation of attenuation can be reduced by inserting mode filters. Losses due to oxygen absorption are taken into account.

621.372.8:621.384.622.2 **989**

Determination of the Series Impedance and of the Attenuation Length-Constant of a Helical Waveguide for a Linear Proton Accelerator A. Septier. (*C.R. Acad. Sci., Paris*, vol. 243, pp. 1748–1750; November 26, 1956.) Continuthe interaction between charge carriers and acoustic waves, first discussed by Parmenter (2281 of 1953) are further analyzed.

535.215:537.311.33 1040

Exciton Structure of Spectral Curves of the Internal Photoelectric Effect in Crystals—E. F. Gross, A. A. Kaplyanski, and B. V. Novikov. (*C.R. Acad. Sci. U.R.S.S.*, vol. 110, pp. 761–764; October 11, 1956. In Russian.) MgI_2 and CdS crystals are considered.

537:22 1041

General Problem of the Charge Acquired by a Spherical Particle in an Electric Field associated with Positive and Negative Ions—M. Pauthenier, R. Cochet, and J. Dupuy. (*C.R. Acad. Sci., Paris*, vol. 243, pp. 1606–1608; November 19, 1956.) Analysis shows that there is a limiting value to the charge acquired by the particle.

537.221 1042

Electrostatic Charge Separation at Metal/Insulator Contacts—P. E. Wagner. (*J. Appl. Phys.*, vol. 27, pp. 1300–1310; November, 1956.) Experiments continuing those of Peterson (3516 of 1954) were made with the object of clarifying the effective contact potential mechanism. Insulators used were quartz, Al_2O_3, MgO, NaCl, KCl, KBr and KI; metals used were Ni, Cu, and Pt.

537.311.1:061.3 1043

Electron Transport in Metals and Solids—J. M. Ziman. (*Nature, Lond.*, vol. 178, pp. 1216–1217; December 1, 1956.) Brief report of an international conference held in Ottawa in September, 1956. A full account is to be published as a special number of *Canad. J. Phys.*

537.311.62 1044

Matrix Theory of Skin Effect in Laminations—L. A. Pipes. (*J. Franklin Inst.*, vol. 262, pp. 127–138; August, 1956.) A simplified method for calculating the field and current distribution in composite slabs is presented; matrix multiplication is used.

537.312.62:538.569.4 1045

Transmission of Superconducting Films at Millimetre-Microwave and Far-Infrared Frequencies—R. E. Glover, III, and M. Tinkham. (*Phys. Rev.*, vol. 104, pp. 844–845; November 1, 1956.) A note of measurements made on evaporated films of Pb of thickness $\sim$20 Å and Sn$\sim$100 Å.

537.523 1046

Temporal Growth of Ionization in Gases—G. G. Morgan. (*Phys. Rev.*, vol. 104, pp. 566–571; November 1, 1956.) Rate of current growth in a uniform electric field E in hydrogen at pressure p was measured over a wide range of E/p between 50 and 400 v/cm per mm Hg. Comparison of experimental with analytical data shows a change in the relative importance of secondary processes as E/p changed. For low values of E/p ($\sim$50) the predominant secondary process was photoelectric emission from the cathode; at high values ($\sim$300) 50 per cent of the emission was due to the incidence of positive ions.

537.523 1047

Microwave Studies of the Electron Loss Processes in Gaseous Discharges—R. F. Whitmer. (*Phys. Rev.*, vol. 104, pp. 572–575; November 1, 1956.) Electron loss processes in pure hydrogen have been studied by measuring the phase change and attenuation of microwave signals transmitted through a discharge. For electron densities of 5×10^{13} cm^{-3} the electron ion recombination coefficient was $\sim5.9\times10^{-11}$ cm^{-3} sec^{-1}. The dominant loss process was attachment.

537.533/.534 1048

The Desorption of Positive and Negative Ions due to Strong Electric Fields—F. Kirchner and H. A. Ritter. (*Z. Naturf.*, vol. 11a, pp. 35–37; January, 1956.) Continuation of work reported previously [1360 of 1956 (Kirchner and Kirchner)]. Observations of field-type electron emission from evaporated films of KCl on W points indicate that positive K ions can be pulled off by positive fields and negative Cl ions by negative fields when the thickness of the film is greater than that corresponding to minimum work function; the effective work function for electrons is increased in the first case and decreased in the second. With the thinnest possible films, only positive ions could be pulled off at the field strengths used.

537.533 1049

The Emission of Electrons during Crystallization—G. Bathow and H. Gobrecht. (*Z. Phys.*, vol. 146, pp. 1–8; August 16, 1956.) Investigations of some metals failed to reveal an increase in emission associated with the crystallization process. Increases noted under certain conditions may be due to the liberation of gases when the sample solidifies.

537.533 1050

Higher-Order Corrections to the Field Emission Current Formula—P. H. Cutler and R. H. Good, Jr. (*Phys. Rev.*, vol. 104, p. 308; October 15, 1956.) Approximations involved in analysis presented by Murphy and Good (3694 of 1956) are discussed quantitatively.

537.533 1051

Origin of the Characteristic Energy Losses of Electrons in Solids—E. J. Sternglass. (*Nature, Lond.*, vol. 178, pp. 1387–1389; December 22, 1956.) An explanation is outlined in terms of individual atomic ionization and excitation processes according to the Bohr-Bethe theory.

537.533/.534 1052

Auger Ejection of Electrons from Tungsten by Noble Gas Ions—H. D. Hagstrum. (*Phys. Rev.*, vol. 104, pp. 317–318; October 15, 1956.) Results of a previous study (681 and 682 of 1955) were subsequently found to include an effect due to a small proportion of the ions being in metastable states. Data are here presented on the yield and kinetic-energy distribution of electrons ejected by normal singly charged ions only. In a separate paper (*ibid.*, pp. 309–316) it is shown that ions in metastable states can be detected by their greater ability to eject electrons from a metal surface.

537.533:537.534.8 1053

Auger Ejection of Electrons from Molybdenum by Noble Gas Ions—H. D. Hagstrum. (*Phys. Rev.*, vol. 104, pp. 672–683; November 1, 1956.) Basic measurements of electron yield and energy distribution of ejected electrons have been made for ions in the range 10–1000 kev.

537.533.8 1054

The Distortion of Secondary-Emission Voltage/Current Characteristics in the Region of Positive Potential on the Collector—N. B. Gornyi. (*Zh. Tekh. Fiz.*, vol. 26, pp. 723–725; April, 1956.) A discussion of the previously observed effect that secondary-emission current increases as the collector potential is increased from zero to small positive values. The usual explanations (effect of space charges, of electrons with "insufficient" energy) are regarded as unsatisfactory, and it is suggested that this phenomenon is due to emission of tertiary electrons from the collector.

537.56:523.165 1055

Energy Loss of a Charged Particle Traversing Ionized Gas and Injection Energies of Cosmic Rays—S. Hayakawa and K. Kitao. (*Progr. Theor. Phys.*, vol. 16, pp. 139–148; August, 1956.) The energy loss is calculated taking into account direct collisions with free electrons and plasma excitation. The loss increases with the degree of ionization.

537.56:538.56 1056

Theory of Wave Motion of an Electron Plasma—A. I. Akhiezer and R. V. Polovin. (*Zh. Eksp. Teor. Fiz.*, vol. 30, pp. 195–928; May, 1956.) A theoretical investigation of nonlinear wave motion of an electron plasma with arbitrary electron velocities is reported. The plasma temperature is assumed to be zero and the state of the plasma is described by the particle density given as a function of position and time. The frequency characteristics of longitudinal and nonlinear transverse plasma oscillations are calculated and relations are obtained for complex coupled transverse-longitudinal oscillations.

537.56:538.6 1057

Experimental Study of Ionized Matter Projected Across a Magnetic Field—W. H. Bostick. (*Phys. Rev.*, vol. 104, pp. 292–299; October 15, 1956.) A gun has been developed which is capable of emitting pulses of plasma comprising electrons and metallic and deuterium ions at speeds up to 2×10^7 cm. Experimental evidence indicates that the plasma comes away in the form of expanding toroidal entities (termed "plasmoids") which are shaped by their own magnetic field. Characteristic configurations and interactions of such plasmoids in an external magnetic field are discussed; photographs are reproduced showing structures rather like smoke rings at various stages.

538.3 1058

The Concept of the Infinitely Thin Infinitely Conducting Screen—P. Poincelot. (*C. R. Acad. Sci., Paris*, vol. 243, pp. 1616–1618; November 19, 1956.) The importance in em theory of the particular method chosen for proceeding to the limit of the infinitely thin infinitely conducting screen is indicated. A simple formula for Babinet's principle is given which is not based on the concept of magnetic currents; this is developed more fully in a separate paper (*ibid.*, vol. 243, pp. 1743–1745; November 26, 1956.)

538.3 1059

Electromagnetic Field Solutions for Rotational Coordinate Systems—R. C. Hanson. (*Canad. J. Phys.*, vol. 34, pp. 893–895; August, 1956.) The vector-potential approach is used.

538.3:531.19 1060

Statistical Mechanics of Matter in an Electromagnetic Field: Part 2—On Pressure and Ponderomotive Force in a Dielectric.—P. Mazur and S. R. de Groot. (*Physica*, vol. 22, pp. 657–669; August, 1956.) Ambiguity in the definitions of ponderomotive force and pressure is elucidated on the basis of a derivation of these quantities from the known microscopic interactions between the constituent particles of the system. Part 1: 1390 of 1954 (Mazur and Nijboer).

538.521 1061

Shielding of a Transient Electromagnetic Dipole Field by a Conducting Sheet—J. R. Wait. (*Canad. J. Phys.*, vol. 34, pp. 890–893; August, 1956.) Analysis presented previously for the shielding provided in the steady state (119 of 1954) is extended to apply to the case of a transient field.

538.561.029.6:[621.373+621.375.9 1062

Proposal for a New Type Solid-State Maser—N. Bloembergen. (*Phys. Rev.*, vol. 104, pp. 324–327; October 15, 1956.) "The Overhauser effect (*Phys. Rev.*, vol. 92, pp. 411–415;

(*Physica*, vol. 22, pp. 671–680; August, 1956.) The "pictorial kinetic method" of treating electron transport problems is based on calculations of the average drift velocity in the direction of the applied field. The importance of the particular method used for superposing the drift velocity on the distribution function corresponding to the absence of applied field is demonstrated. Relations valid for semiconductors are derived by averaging over the transport distribution function the corresponding relations for metals.

537.311.31:539.234:538.63 1107
Influence of a Magnetic Field on the Electrical Resistance of Thin Films of Nickel—T. Rappeneau. (*C.R. Acad. Sci., Paris*, vol. 243, pp. 1403–1406; November 5, 1956.) Measurements have been made on evaporated films at normal temperature. With medium-strength fields (up to 500 oersted) the resistance decreases when the magnetization is perpendicular to the current and increases when the magnetization is parallel to the current; hysteresis effects are exhibited. With high-strength fields (1000–6000 oersted) the resistance decreases slightly with magnetization in either direction.

537.311.31:546.56:537.533 1108
Electron Irradiation of Copper below 10°K—J. W. Corbett, J. M. Denney, M. D. Fiske and R. M. Walker. (*Phys. Rev.*, vol. 104, pp. 851–852; November 1, 1956.) Measurements on high-purity Cu foil bombarded by 1.35-MeV electrons give a value of $(8.25\pm1.2)\times10^{-27}\Omega$ cm for the resistivity change per electron per cm^2.

537.311.33 1109
Semiconducting Intermetallic Compounds—L. Pincherle and J. M. Radcliffe. (*Advances Phys.*, vol. 5, pp. 271–322; July, 1956.) A comprehensive survey of published data on the preparation, properties, theory, and applications of these materials, with an extensive bibliography.

537.311.33 1110
Recombination of Electrons and Holes at Dislocations—S. R. Morrison. (*Phys. Rev.*, vol. 104, pp. 619–623; November 1, 1956.) "The phenomenon of hole-electron recombination at dislocations is examined, and it is demonstrated that the space charge barrier surrounding the dislocation may have a dominant effect in determining the characteristics of recombination. In particular, the inclusion of the space charge effect leads directly to the slow decay phenomena observed in silicon and *n*-type germanium. The characteristics of electrical fluctuations due to trapping at these levels are discussed on the basis of the model."

537.311.33 1111
The Statistics of Charge-Carrier Fluctuations in Semiconductors—R. E. Burgess. (*Proc. Phys. Soc.*, vol. 69, pp. 1020–1027; October 1, 1956.) "The statistical fluctuations in the number of charge carriers (conduction electrons or valence band holes) in a given volume of semiconductor in the steady state is calculated from the transition probabilities of electrons between the conduction and valence bands or between either band and impurity levels. The case in which one independent fluctuating variable (either n or p) specifies the electronic state of the system is considered. Simple general formulas are developed for the mean value n_0 of n and its variance and it is shown that for large numbers n tends to be normally distributed about n_0. The relaxation time for small deviations from equilibrium is evaluated. These results are applied to three cases: 1) the intrinsic semiconductor, 2) the strongly extrinsic semiconductor, and 3) the slightly extrinsic semiconductor with all impurity atoms ionized. The relation between the statistical approach and the thermodynamical treatment [793 of 1956] is indicated."

537.311.33 1112
Defects with Several Trapping Levels in Semiconductors—P. T. Landsberg. (*Proc. Phys. Soc.*, vol. 69, pp. 1056–1059; October 1, 1956.) Analytical discussion is presented.

537.311.33:535.215 1113
Structural Characterization of Caesium Antimonide: Temperature Factors in Cubic Crystals—K. H. Jack and M. M. Wachtel. (*Nature, Lond.*, vol. 178, pp. 1408–1409; December 22, 1956.)

537.311.33:535.215:546.482.21 1114
Changes in Conductivity Resulting from Breakdown in Cadmium Sulphide Single Crystals—J. Woods. (*Proc. Phys. Soc.*, vol. 69, pp. 975–980; October 1, 1956.) Experiments are described, the results of which are in general agreement with those of Diemer (2960 of 1954); CdS crystals can be activated to become good photoconductors simply by passing large currents through them.

537.311.33:535.3 1115
The Influence of Electrons on the Optical Properties of Semiconductors—E. Groschwitz and R. Wiesner. (*Z. angew. Phys.*, vol. 8, pp. 391–398; August, 1956.) The contribution of the conduction electrons to the optical properties is investigated in detail for *n*-type Ge. The principal optical parameters are plotted as functions of light frequency, temperature, and impurity content. Convenient measurements are not yet possible in the mm- and tenth-mm-λ ranges where the electron contribution is greatest, but parameters can be predicted from results of experiments on adjoining frequency ranges.

537.311.33:535.34 1116
The Anomalous Skin Effect and the Optical Absorptivity of Semiconductors: Part 1—R. B. Dingle. (*Physica*, vol. 22, pp. 683–697; August, 1956.) The "pictorial kinetic method" (1106 above) is used to derive tentative expressions for optical absorption by semiconductors. The variations of carrier concentration and collision time with temperature and impurity concentration are discussed and the relative importance of the "Drude-Kronig" and "anomalous" terms in the optical absorption are assessed. The anomalous term may be important at wavelengths from 1 to 300 μ for semiconductors with a fairly high impurity concentration, but is comparatively unimportant for nondegenerate systems unless the effective carrier mass is unusually small.

537.311.33:537.32 1117
Thermoelectric Properties of Cd-Sb Alloys—V. A. Yurkov and N. E. Alekseeva. (*Zh. Tekh. Fiz.*, vol. 26, pp. 191–912; April, 1956.) A brief report is presented on an experimental investigation which suggests that the energy structure of CdSb is of the type normal for semiconductors.

537.311.33:539.23 1118
The Use of an Interference Microscope for Measurement of Extremely Thin Surface Layers—W. L. Bond and F. M. Smits. (*Bell Syst. Tech. J.*, vol. 35, pp. 1209–1221; September, 1956.) "A method is given for the thickness measurement of *p*-type or *n*-type surface layers on semiconductors. This method requires the use of samples with optically flat and reflecting surfaces. The surface is lapped at a small angle in order to expose the *p-n* junction. After detecting and marking the *p-n* junction, the thickness is measured by an interference microscope. Another application of the equipment is the measurement of steps in a surface. The thickness range measurable is from 5×10^{-6} cm to 10^{-8} cm."

537.311.33:546.23 1119
Influence of the Physical State and of Infrared Irradiation on the R. F. Dipolar Absorption of Very Pure Specimens of Hexagonal Selenium—J. Meinnel, M. Eveno, and F. Trigolet. (*C.R. Acad. Sci., Paris*, vol. 243, pp. 1761–1764; November 26, 1956.) The energy level of acceptors due to crystal imperfections is determined from measurements of the rf absorption. Irradiation at wavelengths $>1.4\mu$ is ineffective in displacing the absorption bands; peaks in this effect occur at 0.7 and 1.1μ, probably as a result of trapping levels.

537.311.33:[546.28+546.289 1120
Absorption and Emission Spectra of Silicon and Germanium in the Soft X-Ray Region—D. H. Tomboulian and D. E. Bedo. (*Phys. Rev.*, vol. 104, pp. 590–597; November 1, 1956.)

537.311.33:[546.28+546.289]:538.569.4 1121
Cyclotron Resonance Experiments in Silicon and Germanium—R. N. Dexter, H. J. Zeiger, and B. Lax. (*Phys. Rev.*, vol. 104, pp. 637–644; November 1, 1956.) "Experimental techniques are described for cyclotron resonance in silicon and germanium at 9000 mc, 24,000 mc, and higher frequencies. Results are presented for electrons and holes in both germanium and silicon. The parameters for the heavy holes are evaluated, with corrections from an approximate theory of line shape for warped surfaces. Observations of the harmonics of cyclotron resonance of the heavy holes in germanium and silicon are described."

537.311.33:546.281.26 1122
The Mechanism of the Voltage-Dependent Contact Resistance of Silicon Carbide—W. Heywang. (*Z. angew. Phys.*, vol. 8, pp. 398–405; August, 1956.) Examination of experimental results indicates that the boundary-layer model proposed by Jones *et al.* (3168 of 1949) correctly represents the capacitance of SiC contacts and its pressure dependence for voltages below 10 v per single contact.

537.311.33:546.289 1123
Interferometric Wavelength Measurements of Germanium Lines of a Hollow-Cathode Discharge—R. D. Van Veld and K. W. Meissner. (*J. Opt. Soc. Amer.*, vol. 46, pp. 598–604; August, 1956.) Spectral lines of wavelengths from 4685 to 2019 Å have been investigated experimentally. From the results precise calculations can be made of the wavelengths of 29 lines in the range 1998–1691 Å.

537.311.33:546.289 1124
Effects of Growth Rate on Crystal Perfection and Lifetime in Germanium—A. D. Kurtz, S. A. Kulin, and B. L. Averbach, (*J. Appl. Phys.*, vol. 27, pp. 1287–1290; November, 1956.) "Effects of crystal growth rate and growth direction on the density of random dislocations and on the minority carrier lifetime have been observed. The dislocation density increases rapidly with growth rate above a rate of about 0.15 inch per minute and varies somewhat with growth direction. The capture efficiency per unit length of dislocation decreases at high growth rates and it is suggested that this effect is caused by the failure of impurity atoms to segregate at dislocations or by the clustering of dislocations." See also 2435 of 1956.

537.311.33:546.289 1125
Investigation of Single-Crystal Ge Films Prepared by Evaporation in Vacuum—G. A. Kurov, S. A. Semiletov, and Z. G. Pinsker. (*C. R. Acad. Sci. U.R.S.S.*, vol. 110, pp. 970–

subjected to an electric field, as a function of time and temperature; the results indicate that the effect of the substrate may be important when interaction occurs between the PbS film and the substrate.

537.311.33:621.317.3 1145
Direct Method of Measuring the Contact Injection Ratio [of a rectifying barrier]—O. L. Curtis, Jr., and B. R. Gossick. (*Rev. Sci. Instr.*, vol. 27, pp. 828–829; October, 1956.) A method requiring no auxiliary contacts is discussed. The injection ratio is determined by comparing the area on an oscilloscope screen corresponding to a current injection pulse with the area of the resulting hole storage pulse.

537.312.9:546.87 1146
Piezoresistance in Bismuth—R. W. Keyes. (*Phys. Rev.*, vol. 104, pp. 665–666; November 1, 1956.) Piezoresistance phenomena in Bi are consistent with multivalley models proposed.

538.22 1147
Magnetic Compounds with Perovskite Structure: Part 4—Conducting and Nonconducting Compounds.—G. H. Jonker. (*Physica*, vol. 22, pp. 707–722; August, 1956.) It is shown that the antiferromagnetic compound LaMnO$_3$ would be ferromagnetic if the cubic perovskite structure present at high temperatures could be preserved at low temperature. Part 3: 2701 of 1953 (Jonker and van Santen).

538.22 1148
Contribution to the Experimental Study of Interactions of Molecular-Field Type. Case of Solid Solutions of a Ferromagnetic or Antiferromagnetic Metal in Palladium—J. Cohen. (*C. R. Acad. Sci., Paris*, vol. 243, pp. 1613–1616; November 19, 1956.)

538.22 1149
Calculation of the Primary Excitations in Magnetic Substances—P. G. de Gennes. (*C. R. Acad. Sci., Paris.*, vol. 243, pp. 1730–1732; November 26, 1956.) The spectrum of the spin waves can be calculated from measurements of elastic diffusion of neutrons.

538.221 1150
On the Minimum of Magnetization Reversal Time—R. Kikuchi. (*J. Appl. Phys.*, vol. 27, pp. 1352–1357; November, 1956.) "A modified Landau-Lifshitz equation is solved for a single-domain sphere and an infinitely-wide thin single-domain sheet of ferromagnetic material neglecting anisotropy. The external magnetic field is switched from one direction to its opposite instantaneously at the initial time and the behavior of the magnetization vector is investigated thereafter. It is shown that there is a critical value of the damping constant corresponding to the minimum value of the (repetitive) magnetization reversal time."

538.221 1151
Spatial Correlations in a Ferromagnetic Material Near the Curie Point—P. G. de Gennes and A. Herpin. (*C.R. Acad. Sci., Paris*, vol. 243, pp. 1611–1613; November 19, 1956.) The form of the spin correlations is deduced from the theory of the molecular field.

538.221 1152
Fluctuation Magnetic After-Effect Near the Curie Point—D. Pescetti and J. C. Barbier. (*C.R. Acad. Sci., Paris*, vol. 243, pp. 1740–1743; November 26, 1956.) The variation of the effect with temperature is studied; a maximum is observed near the Curie point.

538.221 1153
The Anisotropy Correction in Ferromagnetic Resonance—K. J. Standley and K. W. H. Stevens. (*Proc. Phys. Soc.* vol. 69, pp. 993–996; October 1, 1956.) A method is described for finding the net absorption for a given magnetic field, resulting from the superposition of absorption lines from the randomly distributed crystallites of a polycrystalline material. Owing to magnetocrystalline anisotropy, the maximum in a ferromagnetic resonance curve does not coincide with the center of gravity of the absorption line. The magnitude of the correction required is estimated; it can be important in iron and in some ferrites.

538.221 1154
The Saturation Magnetization of Nickel under High Hydrostatic Pressure—K. H. von Klitzing and J. Gielessen. (*Z. Phys.*, vol. 146, pp. 59–64; August 16, 1956.) Three different methods are described which were used to determine the effect of pure hydrostatic pressure. Results obtained agree more closely with those of Ebert and Kussmann (*Phys. Z.*, vol. 38, pp. 437–445; 1937) than with those of Stacey (3115 of 1956) whose considerably higher values of the pressure coefficient may be due to the combination of unidirectional and hydrostatic pressure.

538.221 1155
The Magnetomechanical Hysteresis Loop of Nickel—M. Kornetzki. (*Z. Phys.*, vol. 146, pp. 107–112; August 16, 1956.) The results of torsion tests on hard and annealed Ni tubes are plotted as eleastic-hysteresis loops and are analyzed. The value of "coercive force" is assessed and compared with that obtained for soft iron.

538.221 1156
Saturation Magnetization in Copper-Nickel Alloys—S. A. Ahern and W. Sucksmith. (*Proc. Phys. Soc.*, vol. 69, pp. 1050–1052; October 1, 1956.) Measurements are reported on six alloys with compositions ranging from 4.7 to 34.4 per cent Cu.

538.221 1157
Spectroscopic Splitting Factors for Iron and Silicon Iron—G. S. Barlow and K. J. Standley. (*Proc. Phys. Soc.*, vol. 69, pp. 1052–1055; October 1, 1956.)

538.221 1158
Neutron Diffraction Study of the Structures and Magnetic Properties of Manganese Bismuthide—B. W. Roberts. (*Phys. Rev.*, vol. 104, pp. 607–616; November 1, 1956.)

538.221 1159
The Temperature Characteristics of the Initial Permeability of Mn$_2$Sb, Cobalt, Iron and Nickel—M. Kersten. (*Z. Angew. Phys.*, vol. 8, pp. 382–386; August, 1956.) An analysis of experimental results of other workers confirms the correctness of the temperature characteristics derived from the theory outlined previously (501 of 1957).

538.221:534.232:538.652 1160
The Dynamic Magnetostriction of Nickel-Cobalt Alloys—C. A. Clark. (*Brit. J. Appl. Phys.*, vol. 7, pp. 355–360; October, 1596.) Ni-Co alloys for transducers are discussed. Measurements of the electromechanical coupling coefficient, the reversible permeability and Young's modulus are described. Two alloys containing respectively about 4.4 per cent and 18.4 per cent Co give good performance.

538.221:537.311.31 1161
The Effect of Spontaneous, True, and Ferromagnetic Magnetization on Electrical Resistance—E. Böhringer. (*Z. Phys.*, vol. 146, pp. 65–74; August 16, 1956.) Resistance changes were measured in ferromagnetic wires under transverse magnetization up to and above saturation, for temperatures from −185° to +232°C. The magnitude of the changes decreases with decreasing temperature; above saturation the fall in resistance is proportional to the magnetizing field.

538.221:538.6:539.23 1162
Magnetic Domains in Thin Films by the Faraday Effect—G. A. Fowler, Jr., and E. M. Fryer. (*Phys. Rev.*, vol. 104, pp. 552–553; October 11, 1956.) Technique developed previously for investigating magnetic domains by examining the rotation of reflected light (2441 of 1954) is adapted to observations of the transmitted light.

538.221:539.234 1163
The Domain Structure of Thin Films of Iron—B. Elschner and D. Unangst. (*Z. Naturf.*, vol. 11a, pp. 98, 48d; January, 1956.) Observations have been made on oriented films deposited on NaCl bases; photomicrographs are reproduced.

538.221:539.234:538.67 1164
Magnetic Domains in Evaporated Thin Films of Nickel-Iron—C. A. Fowler, Jr., E. M. Fryer, and J. R. Stevens. (*Phys. Rev.*, vol. 104, pp. 645–649; November 1, 1956.) Domain patterns have been observed in Ni-Fi films of thickness 500–5000 Å by the longitudinal Kerr magneto-optical effect [2441 of 1954 (Fowler and Fryer)]. Certain unusual features of domain behavior appear characteristic of the thinnest specimens. Films of thickness 10,000 Å and 20,000 Å showed no domain structure by this technique.

538.221:621.318.12 1165
Preferred Orientations and Magnetic Properties of Rolled and Annealed Permanent-Magnet Alloys—W. R. Hibbard, Jr. (*J. Metals, N. ±.*, vol. 8, pp. 962–967; August, 1956.) Pole figures, torque curves, and coercive force have been determined for cunife, cunico, silmanal, vicalloy I, vicalloy II, and Heusler's alloy.

538.221:621.318.134 1166
Properties and Uses of Ferrites—K. J. Standley. (*Nature, Lond.*, vol. 178, pp. 1371–1373; December 22, 1956.) Report of the conference organized by the Institution of Electrical Engineers in the autumn of 1956. Nearly 60 papers were read; these are to be published, with the discussion, in *Proc. Inst. Elect. Eng.* during 1957.

538.221:621.318.134 1167
Method for Forming Large Ferrite Parts for Microwave Applications—L. G. Van Uitert, F. W. Swanekamp, and F. R. Monforte. (*J. Appl. Phys.*, vol. 27, pp. 1385–1386; November, 1956.) Sludge pressing technique is briefly discussed.

538.221:621.318.134 1168
Neutron Diffraction Study of Manganese Ferrite—J. M. Hastings and L. M. Corliss. (*Phys. Rev.*, vol. 104, pp. 328–331; October 15, 1956.)

538.221:621.318.134 1169
Anisotropy Constants and g Value of Nickel Ferrite.—D. W. Healy, Jr. and R. A. Johnson. (*Phys. Rev.*, vol. 104, pp. 634–636; November 1, 1956.) Experimental data are presented for the temperature range 4°–300°K and frequency range 7.9–11.5 kmc. Measured g values show a significant variation with frequency not observed in previous measurements on single crystals.

538.221:621.318.134 1170
Magnetic Properties of Rare-Earth Ferrites 3M$_2$O$_3$·5 Fe$_2$O$_3$, with M = Tb, Dy, Ho, Er, Tm, Yb, Lu. Experimental Results—R. Pauthenet. (*C.R. Acad. Sci., Paris*, vol. 243, pp. 1499–1502; November 12, 1956.)

tion of current carriers in Hg by the field to be measured.

621.317.7.029.4:537.54 1197

Narrow-Band A. F. Noise Generator—D. Steffen. (*Elektronische Rundschau*, vol. 10, pp. 185–188; July, 1956.) The equipment described, comprising glow-discharge generator followed by a selective amplifier and frequency changer, produces a noise band of width variable from about 10 to 165 cps anywhere in the af range. It facilitates qualitative measurements; *e.g.*, of loudspeaker frequency response and distortion because the effects of standing acoustic waves are avoided.

621.317.7.029.6:621.315.212 1198

Short-Circuiting Plunger for Coaxial Lines—H. K. Ruppersberg. (*Arch. Elekt. Übertragung*, vol. 10, pp. 358–360; August, 1956.) A plunger is described which comprises a brass cylinder with radial slits held by a spiral spring at one end so as to exert pressure on the inner and outer conductors at the other end; the short-circuiting plane does not shift with variations of signal frequency.

621.317.7.029.6:621.373.423:621.385.029.6 1199

The Use of Travelling-Wave Valves for Measurements—A. Lauer. (*Elektronische Rundschau*, vol. 10, pp. 190–192; July, 1956.) Wobbulator, frequency-doubler and oscillator circuits using the Type-TL6 valve (4-kmc range) are briefly described.

621.317.726 1200

A Novel High-Voltage Peak Voltmeter—W. P. Baker. (*Proc. IEE*, Part A, vol. 103, pp. 519–522; October, 1956.) The performance of the instrument is made nearly independent of the characteristics of the rectifiers by including them in a feedback loop.

621.317.755:621.3.014.33 1201

A High-Speed-Oscillograph Cathode-Ray Tube for the Direct Recording of High Current Transients—R. Feinberg. (*Electronic Eng.*, vol. 28, pp. 540–541; December, 1956.) The tube described uses an external single-turn coil for direct signal deflection. An oscillogram of a 1650-A, 15-μs pulse with a gradient of 250 A/μs is shown.

621.317.761 1202

Theory and Practice of a Very-High-Accuracy Arrangement for Frequency Measurement—G. Becker. (*Arch. Elekt. Übertragung*, vol. 10, pp. 315–325; August, 1956.) Details are given of an arrangement using frequency multiplication of the unknown, followed by comparison with a reference frequency and counting of the resulting beats. Typical measurement results are discussed in relation to the theoretical results, and the errors are hence determined. Over the range 15 kc–15 mc the maximum error is 1 part in 10^9 for a measuring time of 100 sec. By using averaging methods, the error can be reduced to a few parts in 10^{11} for a measuring time of about 1 sec.

621.317.761 1203

Direct-Reading High-Sensitivity Frequency Meter—J. Lagasse, R. Lacoste, and J. Prades. (*C.R. Acad. Sci., Paris*, vol. 243, pp. 1406–1408; November 5, 1956.) Apparatus for determining frequencies between 47 and 51 cps is based on measurement of the frequency of beats between a multiple of the frequency to be determined and a submultiple of the frequency of a quartz-controlled reference oscillator.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

531.768:534.86 1204

Calibration of Vibration Pickups by the Reciprocity Method—S. Levy and R. R. Bonche. (*J. Res. Nat. Bur. Stand.*, vol. 57, pp. 227–243; October, 1956.)

550.837:621.396.674.3 1205

The Radiation Resistance of a Dipole Antenna above a Conducting Plane, from the Viewpoint of Geophysical Prospecting—Minaw. (See 991.)

621–526:621.387 1206

Grid Control of Thyratrons with Particular Reference to Servomechanism Applications—K. R. McLachlan. *J. Brit. Inst. Radio Eng.*, vol. 16, pp. 695–699; December, 1956.

621.319.3:621.385.822 1207

Use of Electrostatic High-Voltage Machines with the Electron Microscope—W. Herchenbach and H. Düker. (*Optik, Stuttgart*, vol. 13, pp. 375–376; 1956.) A short note indicating that es generators can be used satisfactorily, even without stabilizing devices, for power supply in es electron microscopes and electron diffraction apparatus.

621.384.611 1208

Modes of Acceleration of Ions in a Three-Dee Cyclotron—M. Jakobson, M. Heusinkveld, and L. Ruby. (*Phys. Rev.*, vol. 104, pp. 362–365; October 15, 1956.)

621.384.612 1209

Elimination of the Critical Energy in a Strong-Focusing Synchro-Phasotron—A. A. Kolomenski. (*Zh. Tekh. Fiz.*, vol. 26, pp. 740–748; April, 1956.

621.384.612:517 1210

Hill's Nonlinear Equation and the Stroboscopic Method of Minorsky—A. Blaquière. (*C.R. Acad. Sci., Paris*, vol. 243, pp. 1711–1714; November 26, 1956.) Discussion of stabilization conditions for an equation representing oscillations occurring in a strong-focusing cosmotron.

621.385.833:537.533/.534 1211

The Resolving Power of the Field [-emission] Ion Microscope—E. W. Müller. (*Z. Naturf.*, vol. 11a, pp. 88–94; January, 1956.) Considerations of resolving power indicate that the field-emission microscope should be operated with ion rather than electron emission. Helium is particularly suitable for examining metal surfaces. Cooling to very low temperature enables the atomic structure of the specimen to be made visible. See also 3329 of 1956 (Müller and Bahadur).

621.398 1212

Radio Transmission of an Electrocardiogram—E. Evrard and J. Rens. (*Rev. HF, Brussels*, vol. 3, pp. 193–208; 1956.) Description of a fm telemetry system for recording on the ground the cardiogram of an aircraft pilot in flight.

621.398:621.396.41 1213

Radio System controls Railroad in Venezuela—Sheffield. (See 1232.)

PROPAGATION OF WAVES

621.396.11 1214

Wave Scattering and Meteoric Influences on Short and Near-Ultra-short Waves—H. Wisbar. (*Arch. Elekt. Übertragung*, vol. 10, pp. 343–352; August, 1956.) It is shown that in a frequency band about 30 mc wide above the critical frequency for grazing incidence a certain residual ionization favor scatter propagation even with low-power transmitters; the intensity of this ionization depends on the diurnal and seasonal variations in the E and F layers. At higher frequencies, scattering occurs only as a result of the "background effect," assumed to be directly related to the incidence of sporadic meteors. Turbulence in the ionosphere enhances the reflection effect due to the weak ionization produced by meteoric dust; corpuscular radiation may also make a small contribution at the poles and the magnetic equator. Auroral and other effects on scatter propagation are considered.

621.396.11:551.510.535 1215

The Waveguide Mode Theory of V.L.F. Ionospheric Propagation—J. R. Wait and H. H. Howe. (PROC. IRE, vol. 45, p. 95; January, 1957.) Calculations are made and the results are shown in graphs for the attenuation factor as a function of the reciprocal of the ionospheric conductivity, 1) for different propagation modes, and 2) for different values of ground conductivity.

621.396.11.029.6 1216

Propagation of Ultra-short Waves Far Beyond the Horizon—V. N. Troitski. (*Radiotekhnika, Moscow*, vol. 11, pp. 3–20; May, 1956.) The u.s.w. field strength is calculated taking into account both stratification and turbulence in the troposphere. Fading and distortion of the signal are also discussed and the calculated and published experimental results are compared.

621.396.11.029.6:551.510.535 1217

A Disturbing Factor in Very-High-Frequency Communications via Ionospheric Forward Scatter—D. A. Crow, F. A. Kitchen, G. A. Isted, and G. Millington. (*Nature, Lond.*, vol. 178, pp. 1280–1283; December 8, 1956.) Difficulties experienced with a frequency-shift telegraphy link between Gibraltar and the U.K. on 37.3 mc are discussed. On effectively pulsing the transmitter it was observed that discrete delayed signal components were present. The path of the delayed components is apparently first backward from the transmitter via the E layer and ground, and then forward by normal reflection at the F layer, the critical frequency being near the solar-cycle maximum. In order to achieve a safe signal/interference ratio, the back/front ratio of the array must be greatly increased.

621.396.812.3 1218

The Analysis of U.S.W. Fading–G. Eckart. (*Z. angew. Phys.*, vol. 8, pp. 407–416; August, 1956.) A detailed discussion in physical terms of dielectric-constant variations and turbulence in the troposphere and their effect on propagation at $\lambda > 3$ m, based on mathematical analysis to be published elsewhere.

RECEPTION

621.396.621:621.376.3 1219

Effect of a Discontinuity of the Instantaneous Frequency on an Ideal Frequency-Modulation Receiver—J. Charles and H. Vigneron. (*Rev. HF, Brussels*, vol. 3, pp. 209–219; 1956. The response of a fm receiver with ideal IF band-pass characteristics to a sudden variation of signal frequency, is compared with that of an AM receiver to a sudden variation of amplitude. Differences in the observed overshoot effects are discussed.

621.396.621:621.376.33 1220

Limiters and Discriminators for F.M. Receivers—G. G. Johnstone. (*Wireless World*, vol. 63, pp. 8–14, 70–74; January and February, 1957.) The performance of the Round-Travis, Foster-Seeley, ratio detector, locked oscillator, phase-difference comparator and counter discriminator circuits, and of the grid, anode, dynamic and clipper-type limiters is discussed.

621.396.621.001.11 1221

Interference Immunity of the Correlation Reception Method—A. E. Basharinov. (*Radiotekhnika, Moscow*, vol. 11, pp. 26–34; May, 1956.) The general case of correlation reception when the signal frequency is initially not accurately known is investigated theoretically. The calculations show that the relative interference immunity of the correlation-type receiver with incoherent detection is only $\sqrt{2}$ times that of a receiver with a square-law detector.

621.396.621.54:621.3.018.783 1222
Contribution to the Theory of Nonlinear Distortion—E. Henze. (*Arch. Elekt. Übertragung*, vol. 10, pp. 326–338; August, 1956.) General formulas are derived for the characteristics of nonlinear circuit elements, with particular reference to tubes. The production of harmonics and the mixing process are discussed; IF amplitudes resulting from cross-modulation with an interfering signal are calculated and compared with the normal IF amplitudes. The dependence of these nonlinear effects on the applied bias is investigated.

621.396.621.54.029.6 1223
Wideband V.H.F. Converter—G. P. Anderson. (*Wireless World*, vol. 63, pp. 88–91; February, 1957.) Details are given of the construction of a superheterodyne unit extending the turning range of a s.w. receiver up to 60 mc.

621.396.821:551.594.6 1224
Measured Statistical Characteristics of V.L.F. Atmospheric Radio Noise—Maxwell. (See 1083.)

STATIONS AND COMMUNICATION SYSTEMS

621.39:621.376.5 1225
Pulse Technique with Particular Reference to Line and Radio Communication—E. M. Deloraine. (*J. Inst. Elect. Eng.*, vol. 2 pp. 458–463; August, 1956.) A short review including a discussion of the relative merits of frequency-division AM and time-division PM multichannel systems; a table shows the estimated channel-miles of pulse-multiplex radio links in various countries as at January, 1956.

621.39.001.11 1226
A Theory of Word-Frequency Distribution—A. F. Parker-Rhodes and T. Joyce. (*Nature, Lond.*, vol. 178, p. 1308; December 8, 1956.) A simple experimental relation governing word frequencies in language is explained in terms of a process of scanning the words in the memory.

621.39.001.11:621.372.012 1227
Signal-Flow Graphs and Random Signals—W. H. Huggins. (PROC. IRE, vol. 45, pp. 74–86; January, 1957.) The flow-graph technique discussed previously [*e.g.*, 2985 of 1956 (Mason)] is used to derive formulas for the correlation functions and power spectra of signals; particular cases studied include a random telegraph message, a series of periodic pulses with time jitter, and a series of pulses of alternate polarity with random timing.

621.394:621.376.56:621.375.4.018.7:621.314.7 1228
Transistorized Binary Pulse Regenerator—L. R. Wrathall. (*Bell Syst. Tech. J.*, vol. 35, pp. 1059–1084; September, 1956.) A simple repeater circuit is described which is suitable for use in a 12-channel pcm system over substantial lengths of transmission line. The system is arranged so that distortion due to lf cutoff in the output of one repeater is compensated in the next repeater, special feedback connections being provided for this purpose. Some performance figures and oscillograms are presented. The effect of interference on the production of errors is discussed.

621.396.3 1229
Phase-Shift Radio Teletype—J. P. Costas. (PROC. IRE, vol. 45, pp. 16–20; January, 1957.) A system using suppressed-carrier keyed am with the frequency-shift system and the "predicted-wave" system [see 1954 CONVENTION RECORD, Part 8, pp. 63–69 (Doelz and Heald), also 861 of 1955 (Doelz)]. Coherent or synchronous detection is used at the receiver.

621.396.3 1230
Radio Teleprinter Systems with Automatic Error Correction—F. Hennig. (*Nachrichtentech. Z.*, vol. 9, pp. 341–348; August, 1956.) Methods for increasing the reliability of teleprinter operation via radio links are outlined. They include the adoption of synchronous systems using codes capable of error detection and correction.

621.396.41:621.396.65:621.396.82 1231
Interference in Radio Links and Radio-Frequency Channelling—B. Peroni. (*Ricerca Sci.*, vol. 26, pp. 2483–2511; August, 1956.) An investigation is made of interference in a multichannel system from transmitters external to the system; an expression is derived for the ratio between the unwanted and the wanted signals. The design of terminal equipment to minimize interference effects is discussed. C.C.I.R. proposals for frequency channeling are compared with the method adopted in the TD-2 system, and measurements on systems of both types are reported; the latter type is preferred.

621.396.41:621.398 1232
Radio System controls Railroad in Venezuela—B. Sheffield. (*Electronics*, vol. 29, pp. 158–163; December, 1956.) The installation described permits centralized traffic control by means of a multiplex fm carrier system. Safety measures and a number of mobile radio and other communication channels are also provided.

621.396.65:621.317.3.029.6(43) 1233
Microwave Measuring Devices—Klinger. (See 1191.)

SUBSIDIARY APPARATUS

621.311.6:621.314.7 1234
Transistorized Regulated Power Supply—M. Lillienstein. (*Electronics*, vol. 29, pp. 169–171; December, 1956.)

621.311.62:621.316.722.1 1235
Cathode-Follower-Type Power Supplies—B. J. Perry. (*Electronic Eng.*, vol. 28, pp. 517–520; December, 1956.) The use of triodes as rectifiers in variable-voltage power supplies is examined. A power pack combining series-stabilization with a cathode-follower type rectifier circuit is described; it is suitable for electrophoresis applications and performance details are given.

621.314.6 1236
Current-Rectifying Devices—J. D. Cooney. (*Elect. Mfg.*, vol. 56, pp. 139–157; September, 1955.) A review of thermionic and solid-state rectifiers, providing comparative data for selecting appropriate types for particular purposes.

621.314.63 1237
An Investigation into the Rectifying Properties of *n-p* Junctions: Selenium-Sulphides or Selenides of Tin—V. R. Grimm and D. N. Nasledov. (*Zh. Tekh. Fiz.*, vol. 26, pp. 707–715; April, 1956.) The *n-p* junctions at the boundaries between selenium and sulphides or selenides of tin were investigated experimentally: they possess sharply defined rectifying properties. On the basis of these results, Se rectifiers of a new type have been developed and their properties investigated. In comparison with ordinary Se rectifiers the new types have a decreased voltage drop in the forward direction (of the order of 0.2 v) and allow a higher forward current density. The disadvantages of the new rectifiers are the temperature dependence of the reverse current and the adverse effect of heating on their electrical strength.

621.314.63:[546.28+546.289 1238
Germanium and Silicon Power Rectifiers—T. H. Kinman, G. A. Carrick, R. G. Hibberd, and A. J. Blundell. (*Proc. IEE*, Part A, vol. 103, pp. 533–536; October, 1956.) Discussion on 2885 of 1956.

621.316.722:621.314.7 1239
Transistor Voltage Regulator—R. H. Spencer and T. S. Gray. (*Commun. and Electronics*, pp. 15–17 March, 1956.) A circuit which makes use of the high-voltage gain and low-emitter resistance of the junction transistor is described.

621.316.722.1 1240
A Stabilized Mains Rectifier—H. W. Jaskula. (*Elektrotech. Z. Edn B.*, vol. 8, pp. 298–300; August 21, 1956.) The voltage-supply unit described uses saturated transformer stabilization, full-wave tube rectification and gas-filled- as well as hard-tube stabilizing circuits. It can supply 400V, 0–100 ma dc with a variation of less than 0.005 per cent for mains fluctuations of ±10 per cent.

TELEVISION AND PHOTOTELEGRAPHY

621.397.24:621.315.213 1241
Video-Pair Cable System—Aoki, Kameda, Yokose and Uchino. (See 983.)

621.397.5 1242
A Method for Narrowing the Frequency Band of a Television Channel—D. A. Novik. (*Zh. Tekh. Fiz.*, vol. 26, pp. 900–910; April, 1956.) The proposed method is based on the extension in time of the steeper edges of television signals at the expense of the contraction of the more gradual ones. Storage tubes could be used for such a redistribution of the time scale. The restoration of the original signal at the receiving end is considered, and the saving in bandwidth is estimated. Use of the method for transmission on long-distance lines is suggested.

621.397.5:356/359 1243
Television as a Military Intelligence and Communications Medium—N. Gray and J. C. Jangarathis. (*J. Soc. Mot. Pict. Telev. Eng.*, vol. 65, pp. 415–418; August, 1956.) An outline of essential requirements and possible applications. Equipment used in recent maneuvers includes a slow-scan vidicon camera tube.

621.397.5:535.623 1244
N.T.S.C. Colour Information—E. L. C. White. (*Wireless World*, vol. 63, pp. 75–78; February, 1957.) The efficacy of the N.T.S.C. system of transmitting the color information is criticized on the ground that the amplitude of the color subcarrier is dependent not only on the color saturation but also on the brightness; the particular method of gamma correction used also has disadvantages. An outline is presented of a receiver for operation with a single-gun picture tube, using a "symmetrical-ratio" signal.

621.397.5:535.623 1245
The Choice of a Color-Television System Conforming to the "Gerber" Standards and the Effect of the Chrominance Subcarrier on Monochrome Picture Reception—J. Piening. (*Nachrichtentech. Z.*, vol. 9, pp. 365–370; August, 1956.) Possible systems for German color television and modifications required to adapt the N.T.S.C. system to the 625-line standard are outlined. Transmission in bands IV and V is considered as well as in bands I and III. Test results are given showing the interference caused in monochrome reception by the chrominance signal.

621.397.6.001.4:621.317.755 1246

A Television Line Selector Unit—P. L. Mothersole. (*Electronic Eng.*, vol. 28, pp. 520–523; December, 1956.) The unit described enables a triggered oscilloscope to be used as a line waveform monitor.

621.397.611.2:778.5 1247

Flying-Spot and Vidicon Film Scanners. A Comparison on the Basis of the Gerber [C.C.I.R.] Standard—W. Dillenburger. (*Elektronische Rundschau*, vol. 10, pp. 181–184, 216–218; July and August, 1956.) The comparison indicates that the vidicon arrangement has the advantage that picture quality is largely independent of film density.

621.397.62 1248

Improved Sync Separator—M. P. Beddoes. (*Wireless World*, vol. 63, pp. 83–87; February, 1957.) A circuit is described using a pentode-triode tube the pentode portion serving to separate the composite synchronizing signal from the picture signal while the triode portion separates the frame synchronizing signal, its output consisting of single narrow pulses. Though the accuracy of timing is good, the noise immunity is less than that of some other separator circuits.

621.385.832.002.2:621.397.621.2:535.623 1249

Control of Fluorescent-Screen Dot Size for Colour TV—S. H. Kaplan. (*J. Soc. Mot. Pict. Telev. Eng.*, vol. 65, pp. 407–410; August, 1956.) Photographic methods are outlined for producing fluorescent screens for parallax-mask color-television tubes. Dot size control is facilitated by using an annular light source.

621.397.7:621.3.06 1250

Video Switching for TV Broadcast Centres—E. B. Pores. (*Electronics*, vol. 29, pp. 146–149; December, 1956.) Electronic and electromechanical systems are briefly described and their relative advantages and cost are discussed.

621.397.7:621.325 1251

Carbon Arcs for Television-Studio Lighting—R. B. Dull and J. G. Kemp. (*J. Soc. Mot. Pict. Telev. Eng.*, vol. 65, pp. 432–434; August, 1956.) The performance of typical carbons, including color-corrected types, is summarized.

621.397.8 1252

The Influence of Phase Errors on the Picture Quality of Television Transmissions—H. J. Griese and P. Klopf. (*Elektronische Rundschau*, vol. 10, pp. 212–216; August, 1956.) The effect of various forms of phase delay on transient response and the importance of delay characteristics in specifying television circuits is examined. A method is outlined for measuring sideband phase and amplitude in television transmitters.

621.397.8:778.5 1253

Gradation Problems in Television Film Transmissions—G. Uhlenbrok. (*NachrTech.*, vol. 6, pp. 341–346; August, 1956.) Gamma-control systems are discussed based on use of 1) variable external resistance; *e.g.*, diode, 2) variable slope, depending on the sequential cutting-off of parallel-connected tubes, and 3) variable modulation, also with parallel-connected tubes.

TRANSMISSION

621.376.22 1254

Amplitude Modulation with Diodes—A. D. Artym. (*Radiotekhnika, Moscow*, vol. 11, pp. 35–43; May, 1956.) The modulation method described is designed for low distortion modulation depths up to nearly 100 per cent and modulation frequencies approaching carrier frequency. The circuit is based on a pair of opposed diodes.

621.396.61 1255

The B.B.C. Radio Microphone—F. A. Peachey and G. A. Hunt. (*Electronic Radio Eng.*, vol. 34, pp. 46–48; February, 1957.) Description of a pocket fm transmitter for use by radio commentators. It operates in the range 50–70 mc with an output of ¼ w.

621.396.61:621.385.029.6 1256

Scatter S.S.B. Technique uses Power Klystron—Badger. (See 1276.)

TUBES AND THERMIONICS

621.3.018.783:621.396.621.54 1257

Contribution to the Theory of Nonlinear Distortion.—Henze. (See 1222.)

621.314.63 1258

Surface Leakage Current in Silicon Fused-Junction Diodes—M. Cutler and H. M. Bath. (Proc. IRE, vol. 45, pp. 39–43; January, 1957.) "The forward and reverse current of fused-junction silicon diodes are compared with the predicted equations arising from a simplified model for surface leakage. It is found that analysis of the forward current in the 'exponential' region leads to resolution of the contributions of the junction and the leakage path. The activation energies of the parameters describing these two contributions were determined; the former agrees with the value of the band gap. The implications and deficiencies of the model are discussed."

621.314.7 1259

Accurate Measurement of Emitter and Collector Series Resistance in Transistors—B. Kulke and S. L. Miller. (Proc. IRE, vol. 45, p. 90; January, 1957.)

621.314.7 1260

Approximating the Alpha of a Junction Transistor—A. B. Macree. (Proc. IRE, vol. 45, p. 91; January, 1957.) A simple method based on a second-order power series is presented.

621.314.7:[621.373.4+621.375.4]:621.311 1261

Application of Germanium Triodes in Equipment for the Protection, Telemechanics and Communication Channels of Power Systems—Martynor and Pavlov. (See 1027.)

621.38+537.533](083.74) 1262

IRE Standards on Electron Tubes: Physical Electronics Definitions, 1957—(Proc. IRE. vol. 45 pp. 63—65; January, 1957.) Standard 57 IRE 7.51.

621.383 1263

Wavelength Dependence of Radiation-Noise Limits on Sensitivity of Infrared Photodetectors—J. R. Platt. (*J. Opt. Soc. Amer.*, vol. 46, pp. 609–610; August, 1956.) A formula is derived for the limiting sensitivity as a function of the area and long-wavelength cutoff of the photocell and of the exposure time.

621.383.2 1264

Electron-Microscope Investigation of the Structure of Photocathodes—A. I. Frimer and A. M. Gerasimova. (*Zh. Tekh. Fiz.*, vol. 26, pp. 726–732; April, 1956.) The object of this investigation was to determine the relation between the structure and the sensitivity of complex (oxygen-caesium and bismuth-caesium) photocathodes. A number of photomicrographs are shown.

621.383.2 1265

The Resistance of Semitransparent Photocathodes—W. J. Harper and W. J. Choyke.—(*J. Appl. Phys.*, vol. 27, pp. 1358–1360; November, 1956.) "The resistance of the semitransparent photoemissive films Sb-Cs, Sb-Rb, Bi-Cs, Bi-Rb, Te-Cs, Te-Rb, and Ag-O-Cs was measured as a function of temperature. A thermal activation energy associated with conductivity was determined for each of the materials."

621.383.42 1266

An Anomaly in the Forward and Backward Conduction of a Selenium Photocell Cooled to Low Temperature and Reactivated by Infrared Radiation—G. Blet. (*C.R. Acad. Sci., Paris*, vol. 243, pp. 1753–1755; November 26, 1956.) Experimental evidence indicates that at temperatures below 125°K, and for low values of applied voltage, current is passed in the reverse direction. The effect did not vary with frequency over the range 50 cps–5 kc. The photoelectric current did not exhibit this reversal.

621.385.029.6 1267

International Congress on Microwave Valves—(*Le Vide*, vol. 11, pp. 210–432; September/October, 1956.) The text is given of the following papers presented at the Congress:

The Principal Results Achieved in the Field of Microwave Valves—R. R. Warnecke (pp. 217–225).

Transmitter Valves with Control Grid—F. Hülster (pp. 226–235).

"Moding" in Magnetrons—C. Azéma (pp. 236–242).

Asymmetries in Strapped Resonator Systems of Magnetrons—B. Vallantin (pp. 243–247).

The Use of Getters in Magnetrons—P. Zijlstra (pp. 248–250, in French and English).

An Experimental Cold-Cathode Magnetron—J. R. M. Vaughan (pp. 251–257, in French and English). See 2580 of 1956.

Practical Millimetre-Magnetron Considerations—L. W. Roberts and R. S. Briggs (pp. 258–263, in French and English).

Reflex Klystrons for Millimetre Waves—B. B. van Iperen (pp. 264–269).

A Low-Noise High-Power Klystron Oscillator of Great Reliability—G. A. Espersen (pp. 270–280, in French and English).

Operation and Application of the Retarding-Field Oscillator at Millimetre Wavelengths—C. J. Carter, W. H. Cornetet, Jr., and M. O. Thurston (pp. 281–285, in French and English).

A Transmitter Klystron for Radio Links—C. Azéma (pp. 286–289).

A Travelling-Wave Valve for 4-cm Wavelength—A. Bobenrieth (pp. 290–295).

Wide-Band Travelling-Wave Valves for Wavelengths of 2–3 cm—D. H. O. Allen (pp. 296–302, in French and English).

A 4000-Mc/s Low-Noise Travelling-Wave Valve—P. F. C. Burke and W. J. Pohl (pp. 303–309, in French and English).

Characteristics of a Strophotron Oscillator of 10-cm Wavelength—T. S. Robinson (pp. 310–320, in French and English).

Preliminary Electron Bunching in the Linear Accelerator—M. Papoular (pp. 321–327).

Electrolytic Tank with Current Input Elements for the Study of Space-Charge Distribution in Valves—V. S. Loukochkov [Lukoshkov] (pp. 328–337, in French and English).

Plasma Electron Oscillations—F. Berz (pp. 338–344)

Breakdown of Air at Microwave Frequencies—W. Roberts (pp. 345–351, in French and English).

A Wide-Band T.R. Valve Incorporating an Interdigital Line—D. Reverdin (pp. 352–356).

The Fully-Coupled T.R. Valve—R. Jean and D. Reverdin (pp. 357–361).

Contribution to the Study of Keep-Alive Electrodes of T.R. Valves—R. Jean (pp. 362–372).

Measurements on Gas-Filled [t.r. and a.t.r.] Valves—R. Belbeoch and M. Bricon (pp. 373–376).

Measurement of the Transmission Characteristic of [t.r.] Switching Valves for Millimetre Radar—A. Regeffe (pp. 377–378).

Investigation of Noise in Travelling-Wave Valves—A. S. Tagher (pp. 379–388, in French and English).

Overlapping the Operating Ranges of Gas-Filled Noise Tubes and Noise Diodes by means of Helical Lines—H. Schnitger (pp. 389–399, in French and German).

Oscillograph for the Observation and Photography of Microwave Signal Patterns—A. M. Tchernouchenko [Chernoushenko] (pp. 400–409, in French and English). (See 885 of 1956.)

High-Power Microwave Test Bench—L. Milosevic and Vautey (pp. 410–416).

Shock Sensitivity of Reflex Klystron—J. Boissière (pp. 417–419).

[Use of] Ceramics in Valves—G. Gallet (pp. 420–423).

Resistance Welding of Microwave Valves—R. Paliès (pp. 424–428).

The Development of Microwave Valves in Electronic Aids to Navigation—N. Schimmel (pp. 429–432, in French and English).

621.385.029.6 1268

Anomalies of Power Output and Modulation Sensitivity in Reflex [-klystron] Oscillators—J. Labus. (*Nachrichtentech Z.*, vol. 9, pp. 371–374; August, 1956.) The deviation from the theoretical output characteristic is shown to be due to a spread in the values of electron transit time, and the anomalies in the sensitivity are attributed to space-charge effects near the reflector.

621.385.029.6 1269

Performance and Design of Low-Noise Guns for Travelling-Wave Tubes—R. C. Knechtli and W. R. Beam. (*RCA Rev.*, vol. 17, pp. 410–424; September, 1956.) Discussion indicates that sharp potential discontinuities should be avoided in a low-noise gun; an exponential type of space-charge-wave transformation is hence desirable. Suitable conditions can be established with "multi-region" guns comprising a triode section followed by a number of appropriately space apertured plane parallel electrodes.

621.385.029.6 1270

The Backward-Travelling Power in High-Power Travelling-Wave Amplifiers—P. K. Tien: J. E. Rowe. (PROC. IRE, vol. 45, pp. 87–88; January, 1957.) The discussion of methods of analyzing the large-signal operation of traveling-wave tubes [3577 of 1956 (Rowe and Hok)] is continued.

621.385.029.6:537.533 1271

Confined Electron Flow in Periodic Electrostatic Fields of Very Short Periods—K. K. N. Chang. (PROC. IRE, vol. 45, pp. 66–73; January 1957.) "By utilizing the centrifugal force of an electron, resulting from a magnetic field in the cathode plane as a restoring force, an electrostatically-confined beam flow can be obtained through the strong focusing of a periodic electric field. Because of the extremely steep nature of the potential valley derived from its particular force field, the focusing scheme is far more stable than any previous ones. A uniform magnetic field threading the cathode is employed when a very thin, hollow beam is to be focused. By using a radially varying magnetic field, the focusing scheme can be applied to thick hollow beams, of low as well as of high perveance. Experimental results indicate that the focusing performance obtained is much less critical than that obtained with a periodic magnetic field which has been recently tested extensively."

621.385.029.6:538.566:537.56 1272

Growing Electric Space-Charge Waves—Pierce and Walker. (See 1066.)

621.385.029.6:621.372.2 1273

Approximate Calculation of the Propagation Constants of Transmission Lines in the Presence of an Electron Beam—L. N. Loshakov. (*Zh. Tekh. Fiz.*, vol. 26, pp. 809–820; April, 1956.) A general method of calculation, based on certain simplying assumptions, is proposed for analyzing conditions in a traveling-wave tube.

621.385.029.6:621.372.413 1274

The Excitation of a Cavity Resonator by a Density-Modulated Electron Beam Passing Through the Entire Resonator Cross-Section—Szulkin. (See 1015.)

621.385.029.6:621.385.2 1275

The Behaviour of the Space Charge in a Diode with an Axial Magnetic Field: Part 2—The Probe Method—M. M. Filippov. (*Zh. Tekh. Fiz.*, vol. 26, pp. 1004–1014; May, 1956.) In part 1 (*Zh. Tekh. Fiz.*, vol. 23, p. 1716; 1953.) A report was given of an experimental investigation into the behavior of the space charge in cylindrical magnetron by the method of equivalent currents. The present report deals with measurements of the current flowing through an auxiliary probe electrode in the cathode-anode space of the magnetron. The probe characteristics so obtained are used for appraising the theoretical conclusions regarding the distribution of the electrons and the shape of electron trajectories in a nonoscillating cylindrical magnetron with a thin cathode.

621.385.029.6:621.396.61 1276

Scatter S.S.B. Technique uses Power Klystron—G. M. W. Badger. (*Electronics*, vol. 29, pp. 176–179; December, 1956.) The performance of high-power klystrons in s.s.b. tropospheric-scatter transmitters is improved by using a segmented collector, with successively lower voltages on the segments, and special mixer and modulator circuits which are described.

621.385.029.6:621.396.822 1277

Factors Affecting the Correlation Conditions in Space-Charge Waves—H. W. König. (*Arch. Elekt. Übertragung*, vol. 10, pp. 339–342; August, 1956.) An investigation is made of the effect on the coherence conditions discussed by Haus (3123 of 1955) of passing an electron beam through a linear quadripole. Analysis is based on the transformation properties of the correlation determinant. It is shown that if the quadripole has a specified determinant the voltage and current fluctuations of the beam will be correlated at its output irrespective of the conditions at its input.

621.385.032.216 1278

The Electron Temperature in Oxide Cathodes—D. G. Bulyginski and D. N. Dobretsov. (*Zh. Tekh. Fiz.*, vol. 26, pp. 977–984; May, 1956.) No definite answer has yet been given to the question whether the temperature of the electron gas can exceed that of the crystal lattice in an oxide cathode. A method is proposed for measuring the electron temperature, and experiments are described in detail. These show that an "overheating" of the electron gas does take place and that it increases with temperature. A theoretical interpretation of the results is given; it is pointed out that the emission from an oxide cathode is not of a purely thermionic nature.

621.385.032.216 1279

The Schottky Effect in Oxide Cathodes—G. Déjardin, G. Mesnard, and R. Uzan. (*Le Vide*, vol. 11, pp. 194–205; July/August, 1956.) Measurements on nearly saturated diodes at normal operating temperatures show that the Schottky effect tends to exceed the theoretical value. Various aspects of cathode surface condition are discussed as possible causes of the anomaly, 25 references.

621.385.032.216 1280

Emission of Oxide Cathodes Supported on a Ceramic—G. E. Moore and H. W. Allison. (*J. Appl. Phys.*, vol. 27, pp. 1316–1321; November, 1956.) Experiments made with a (BaSr)O layer applied to a MgO ceramic support, thus eliminating the metal support and interface, indicated that these two latter features are not of fundamental importance for the cathode emission. From the results of treatments with methane and hydrogen, it is concluded that other factors are much more important than excess Ba content for determining the emission.

621.385.032.216 1281

The Decrease of Thermionic Emission of Alkaline-Earth-Oxide and Thoria Cathodes in a Pulsed Regime—G. Mesnard and R. Uzan. (*C.R. Acad. Sci., Paris*, vol. 243 pp. 1502–1504; November 12, 1956.) A comparison is made of the effect in the two types of cathode. The extent of the emission decrease increases with rising temperature in both types, but the variation with duty factor is more pronounced in the case of the oxide cathodes. In these, at temperatures up to a certain level, the decreased emission is preceded by a significant increase which is never observed with thoria cathodes. The mechanism described by Plumlee (3583 of 1956) is thought to apply in the case of the oxide cathodes.

621.385.032.216 1282

Reactions Occurring during Decomposition of Alkaline Earth Carbonates on Tungsten—M. A. Cayless and B. N. Watts. (*Brit. J. Appl. Phys.*, vol. 7, pp. 351–354; October, 1956.) Report of an investigation made to elucidate reactions occurring during the breakdown and activation of an oxide cathode on a tungsten substrate. Analysis shows that CO_2, CO and H_2 are the principal gases evolved. The CO is produced during the formation of a basic tungstate interface of the type $(Ba, Sr, Ca)_3WO_6$. The chemical reactions involved do not reach equilibrium during normal decomposition schedules. The rate of formation of free Ba in the completed cathode is determined by the amount of interface produced during breakdown.

621.384.032.216:537.226 1283

Dielectric Constant of Barium Orthosilicate—C. P. Hadley, H. W. Kraner, and M. R. Royce. (*J. Appl. Phys.*, vol. 27, pp. 1384–1385; November, 1956.) Measurements are reported on specially prepared specimens, as a function of the apparent density. The results are plotted; they are probably valid for frequencies up to several hundred mc, and may be used in calculations of the thickness of oxide-cathode interface layers.

621.385.032.216:621.396.822 1284

New Mechanism for the Generation of Flicker Noise in Tubes with Oxide-Coated Cathodes—W. W. Lindemann and A. van der Ziel. (*J. Appl. Phys.*, vol. 27, pp. 1179–1183; October, 1956.) "Evidence is presented which seems to indicate that a major part of the flicker noise in tubes with oxide-coated cathodes is generated in a thin surface layer of the coating. The effect is shown to be caused by the fact that a dc voltage drop and a noise voltage fluctuation are generated in the surface layer. In tubes with a porous cathode coating this noise voltage modulates the current coming out of the surface pores, thus leading to a true fluctuation in the current. In tubes with a nonporous cathode coating this noise voltage modulates the emission current, thus leading to a true fluctuation in the emission."

621.385.2/.3:621.396.822 1285

Correlation Conditions for Noise Fluctuations at the Potential Minimum of a Diode (Triode)—H. Kosmahl. (*Arch. Elekt. Übertragung*, vol. 10, pp. 353–357; August, 1956.) A rigorous calculation is made of the correlation between the electron current and velocity fluctuations for a particular case. A value of 0.65–0.75 is found for the correlation coefficient in the ideal case; for practical tubes the value is considerably lower. The use of this coefficient for calculating the induced grid noise current is outlined.

621.385.3:621.365 1286

The New Transmitting Tube FTL 3-1 for Industrial Purposes—R. Hübner. (*Brown Boveri Rev.*, vol. 43, pp. 279–280; July, 1956.) Data are presented for an air-cooled triode with a directly heated thoriated-tungsten cathode, for use as an oscillator at frequencies up to 30 mc; outputs up to 6.4 kw are obtainable.

621.385.832 1287

Electrostatic Cathode-Ray Storage Tubes and their Applications—G. Dufour. (*Ann. Radioélect.*, vol. 11, pp. 200–215; July, 1956.) The various types are classified and the principles of operation and applications are detailed. 11 references.

621.385.832:621.396.963.325 1288

Storage Tube projects Radar P.P.I. Display—H. W. Gates. (*Electronics*, vol. 29, pp. 172–175; December, 1956.) A 50-inch remote ppi display is obtained by means of an "iatron" tube. This is a combined storage and projection device which uses a narrow writing beam of low intensity to create an es image of the signal on a thin insulating target supported by a mesh screen. A high-intensity beam continuously floods the image and is thereby modulated on passing through the mesh and striking he phosphor screen. Ancillary circuitry providing erasure and clutter attenuation is also described.

621.385.832.002.2:621.397.621.2:535.625 1289

Control of Fluorescent-Screen Dot Size for Color TV—Kaplan. (See 1249.)

621.387:621-526 1290

Grid Control of Thyratrons with Particular Reference to Servomechanism Applications—K. R. McLachlan. (*J. Brit. Inst. Radio Eng.*, vol. 16, pp. 695–699; December, 1956.)

621.387.002.2 1291

New Method of Filling [gas-] Discharge Valves—R. Hübner. (*Elektronische Rundschau*, vol. 10, p. 227; August, 1956.) A tablet containing HgO and other materials is enclosed in the tube envelope and, after the extraction of gases, an adequate amount of Hg is freed in a chemical reaction started by induced heat. Tubes thus prepared can be used in any position, no pre-heating of the cathode is necessary and the risk of arcing is reduced.

621.385:533.5 1292

Arbeitsverfahren und Stoffkunde der Hochvakuumtechnik, Technologie der Elektronenröhen [Book Review]—H. Steyskal. Mosbach /Baden, Physik Verlag, 185 pp., 1955. (*Acta Phys. Austriaca*, vol. 10, pp. 309–310; August, 1956.) A useful work for tube development engineers.

621.385.029.6 1293

Studien über Travelling-Wave Tubes. Mitteilungen aus dem Institut für Hochfrequenztechnik der E. T. H. Zürich, No. 23. [Book Review]—G. E. Weibel. Zurich, Leemann, 95 pp., 1956. (*Arch. Elekt. Übertragung*, vol. 10, p. 360; August, 1956.) Detailed theory is presented, including a new method of investigating the behavior of the beam on entering a monotonically increasing magnetic field. The construction of a demountable tube is described.

MISCELLANEOUS

621.3.002.2 1294

Automatic Component Assembly [for Printed Circuits]—K. M. McKee. (*Wireless World*, vol. 63, pp. 63–69; February, 1957. *J. Inst. Elect. Eng.*, vol. 2, pp. 515–519; September, 1956.) Description of a multistation in-line conveyor system of a general type in use in the U.S.A. and being introduced in G.B. for the mass production of electronic equipment. Printed wiring boards are transported along the conveyor and the various components are introduced by separate machines. Adjustments for production changeover can be effected rapidly, and individual machines can be mounted as bench units for short production runs.

621.3.002.2:68 1295

The Flowsolder Method of Soldering Printed Circuits—R. Strauss and A. F. C. Barnes. (*Electronics Eng.*, vol. 28, pp. 494–496; November, 1956.) A method is described in which a stationary wave of molten solder is created by pumping the metal upwards through a rectangular nozzle, and the pre-fluxed circuit panels are passed through the crest of the wave.

001.891:621.396 1296

Report of the Radio Research Board for 1955. [Book Review]—London, H. M. Stationery Office, 56 pp., 1956. (*Nature, Lond.*, vol. 178, pp. 1446–1447; December 29, 1956.) Includes the report of the Director of Radio Research, reviewing the work of the Radio Research Station of the Department of Scientific and Industrial Research, and giving a description of the new building.

413=00:[537:621.3 1297

International Electrotechnical Vocabulary (Electronics). [Book Review]—British Standards Institution, London, 2nd edn, 157 pp., 24s. 1956. (*Brit. J. Appl. Phys.*, vol. 7, p. 343; September, 1956.) Gives definitions in French and English and the terms themselves also in German, Spanish, Italian, Dutch, Polish, and Swedish.