VOLUME 20 DECEMBER, 1932 NUMBER 12

PROCEEDINGS

of

The Institute of Radio Engineers

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PROCEEDINGS OF

The Institute of Radio Engineers

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GENERAL INFORMATION

INSTITUTE. The Institute of Radio Engineers was formed in 1912 through the amalgamation of the Society of Wireless Telegraph Engineers of Boston, Massachusetts, and the Wireless Institute of America of New York City. Its headquarters were established in New York City and the membership has grown from less than fifty members at the start to almost seven thousand by the end of 1931.

AIMS AND OBJECTS. The Institute functions solely to advance the theory and practice of radio and allied branches of engineering and of the related arts and sciences, their application to human needs, and the maintenance of a high professional standing among its members. Among the methods of accomplishing this need is the publication of papers, discussions, and communications of interest to the membership.

PROCEEDINGS. The PROCEEDINGS is the official publication of the Institute and in it are published all of the papers, discussions, and communications received from the membership which are accepted for publication by the Board of Editors. Copies are sent without additional charge to all members of the Institute. The subscription price to nonmembers is $10.00 per year, with an additional charge for postage where such is necessary.

RESPONSIBILITY. It is understood that the statements and opinions given in the PROCEEDINGS are views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole. Papers submitted to the Institute for publication shall be regarded as no longer confidential.

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MAILING. Entered as second-class matter at the post office at Menasha, Wisconsin. Acceptance for mailing at special rate of postage is provided for in the act of February 28, 1925, embodied in Paragraph 4, Section 412, P. L. and R., and authorization was granted on October 26, 1927.

Published monthly by

THE INSTITUTE OF RADIO ENGINEERS, INC.

Publication office, 450–454 Ahnaip St., Menasha, Wis.

BUSINESS, EDITORIAL, AND ADVERTISING OFFICES
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33 West 39th Street, New York, N. Y.

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	Los Gatos, 134 Hernandez Ave.	Cole, B. R.
Michigan	Detroit, 5104 Balfour	Byerlay, H. L.
Pennsylvania	Philadelphia, 1321 Arch St.	Leitch, J. G.
England	London N.W. 9, Standard Telephones & Cables, The Hyde, Hendon	Mirk, D. B.

Elected to the Member Grade

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Elected to the Student Grade

Idaho	Idaho City, c/o United States B.P.R.	Wrathall, G.
Missouri	Butler	Henry, R. E.

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

APPLICATIONS FOR MEMBERSHIP

Applications for transfer or election to the various grades of membership have been received from the persons listed below, and have been approved by the Committee on Admissions. Members objecting to transfer or election of any of these applicants should communicate with the Secretary on or before January 2, 1933. These applicants will be considered by the Board of Directors at its meeting on January 4, 1933.

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	Auburndale, 21 Lasell St.	Clapp, J. K.

For Transfer to the Member Grade

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For Election to the Member Grade

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	Los Angeles, 1217 W. 10th St.	Lillyblad, G. F.
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	San Anselmo, 1 Santa Cruz Ave.	Cherry, C. E.
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	Washington, 3382 Stephenson Pl., N.W.	McClurg, G. H.
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	New York City, c/o Popowits, 2210 Lyon Ave.	Temler, H. H.
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	Philadelphia, Arrott Arms Apts. E-9, Arrott and Leiper Sts.	Johnston, E. R.
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	Houston, 215 B Humble Bldg.	Gardner, D. H.
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Washington	Vancouver, 1109 Broadway	Sharon, R. W.
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	Grimsby, Lincolnshire, 28 Mangle St.	Laverack, H.
	London, N.W. 6, 113 Goldhurst Ter., South Hampstead	Boyd, W. J. T.
	Muncastergate, York, "Ravensdene"	Hardy, C.
	Shrewsbury, 15 Claremont St.	Mitchell, A. R.
New Zealand	Christchurch, N.Z. Broadcasting Board, Station 3YA, Gloucester St.	Penton, W. A.
	Waipu, North Auckland, "Bird-Grove"	McLean, C.
North Wales	Llanwnda, Caernarvonshire, Wood Cottage, Glynllifon Park	Williams, W.

For Election to the Junior Grade

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For Election to the Student Grade

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OFFICERS OF CLEVELAND SECTION—1932

INSTITUTE NOTES

November Meeting of the Board of Directors

The regular monthly meeting of the Board of Directors was held at the Institute office on November 2, and was attended by Alfred N. Goldsmith, acting chairman; Melville Eastham, treasurer; Arthur Batcheller, O. H. Caldwell, J. V. L. Hogan, H. W. Houck, L. M. Hull, C. M. Jansky, Jr., R. H. Marriott, E. L. Nelson, A. F. Van Dyck, and H. P. Westman, secretary.

H. L. Byerlay, B. R. Cole, J. G. Leitch, D. B. Mirk, and E. H. Schreiber were transferred from the Associate to the Member grade and H. L. Pitts, John P. Smith, Jr., and W. H. Wise were admitted to the Member grade.

Twenty Associates, two Juniors, and two Students were elected to membership.

A report of the Tellers Committee on the vote cast for officers follows this report.

Dr. Cady reported by letter concerning an address he made on October 21 by transatlantic telephone to a meeting in Copenhagen, Denmark, commemorating the twentieth anniversary of the invention of the Poulson arc transmitter for telephony and also the tenth anniversary of the first Danish broadcasting. In his address, President Cady extended the congratulations of the Institute to Doctors Poulson and Pederson, and paid a tribute to the important part which the Poulson arc transmitter played in the development of long distance radio.

Approval was granted to a conversion ratio of one inch equals 25.4 millimeters which was recommended by a conference held under the auspices of the American Standards Association.

A proposal of the Philadelphia Section to offer prizes of Student memberships in the Institute to the two students in engineering colleges within the Philadelphia Section territory who submit the best papers on a communication subject for presentation at the April 6, 1933, meeting of that section was approved.

Because of economic conditions, it was felt inadvisable to publish a Proceedings index for 1931 and 1932 at this time. Indexes for 1931 are available, and an index for 1932 will be published with this issue of the Proceedings. All issues prior to 1931 are indexed in the 1909–1930 index which was published early in 1931.

E. D. Cook who is chairman of the Electro-Acoustic Devices Technical Committee operating under the Sectional Committee on Radio of which the Institute is a sponsor, was appointed a representative of the Institute on the Sectional Committee on Acoustical Measurements and Terminology.

Report of Tellers Committee

Through an error not under the control of the Institute office, thirty-five ballots of the 1931 form were forwarded to members of the Institute. Some of these were reported to the secretary and replaced by 1932 ballots, a number were voted upon and mailed in regular order, and the balance are still in the hands of the Institute members. The tabulation of votes for the various candidates discloses that in no case would the election be affected by these 1931 ballots other than in the precise number of votes cast for each candidate. In every case a sufficiently wide margin exists between competing candidates to make impossible any change in the results due to these thirty-five incorrect ballots. The ballot has therefore been accepted by the committee and the Board of Directors, and the following have been declared elected for the offices and terms listed:

For President, 1933—L. M. Hull
For Vice President, 1933—Jonathan Zenneck
For Directors, 1933–1935—R. A. Heising
F. A. Kolster
H. M. Turner
For Director, 1933–1934—C. W. Horn
For Director, 1933—M. C. Batsel

Atlantic City Meeting of the American Association for the Advancement of Science

The Philadelphia Section of the Institute has prepared an interesting program of papers to be presented on December 29 in Atlantic City as part of the meeting of the American Association for the Advancement of Science which will run from December 27 to 31.

The program of papers arranged by the Philadelphia Section is listed below:

"Creative Broadcasting from the Musician's Viewpoint," by C. N. Weyl, University of Pennsylvania.

"The Measurement of Over-All Characteristics of Broadcast Receivers," by A. V. Loughren, RCA Victor Company.

"Electrotherapy," by Dr. Richard Kovacs, New York Polyclinic Medical School and Hospital.

"Study of Reception from Synchronized Broadcast Stations," by C. B. P. Aiken, Bell Telephone Laboratories.

"High Quality Ribbon Telephone Receivers," by N. F. Olson and F. Massa, RCA Victor Company.

These papers will be presented during an afternoon session starting with a noon luncheon in room 133 of the Civic Auditorium on the Board Walk.

All members of the Institute and their friends are cordially invited to be present at this meeting. It is not necessary that advance registration be made. Those who must travel by railroad are advised that one-half rate return fare on the certificate plan has been granted for this meeting of the American Association for the Advancement of Science, and certificates should be requested of the railroad agent from whom the one-way ticket covering transportation to Atlantic City is purchased. These certificates must be validated at Atlantic City in order to permit the holder to purchase a return ticket over the same route as covered by the going ticket at half the regular rate.

Incorrect Addresses

On pages IX, X, and XI of the advertising section of this issue will be found the names of those members of the Institute whose correct addresses are not known. It will be appreciated if anyone having information concerning the present addresses of any of the persons listed will communicate with the Secretary of the Institute.

Proceedings Binders

Binders for the PROCEEDINGS, which may be used as permanent covers or for temporary transfer purposes, are available from the Institute office. These binders are of handsome Spanish grain fabrikoid, in blue and gold. Wire fasteners hold each copy in place, and permit removal of any issue from the binder in a few seconds. All issues lie flat when the binder is open. Each binder will accommodate a full year's supply of the PROCEEDINGS, and they are available at one dollar and seventy five cents ($1.75) each. Your name, or PROCEEDINGS volume number, will be stamped in gold for fifty cents (50c) additional.

Institute Meetings

Atlanta Section

The Atlanta Section held a meeting on September 8 at the Atlanta Athletic Club, Chairman H. L. Wills presiding.

Lieutenant O. C. Maier, U. S. A., who is a member of the Signal Corps and is attending the Georgia School of Technology, presented a paper on "Quasi Optical Waves." The speaker outlined clearly the possibilities of the use of quasi optical waves for communication purposes and explained methods used for transmitting and receiving such waves.

The paper was discussed by Messrs. Bangs and Wills of the twelve members and guests in attendance at the meeting. Six were present at the informal dinner which preceded it.

The October meeting of the Atlanta Section was held on the 13th at the Atlanta Athletic Club. Chairman H. L. Wills presided over the meeting which was attended by thirty-three members and guests of whom thirteen were present at the informal dinner preceding it.

F. H. Engel, sales engineer of the Hygrade Sylvania Corporation presented a paper on "New Types of Radio Tubes."

The speaker presented the technical data concerning the various new tubes and outlined the reasons for their particular designs. Characteristics of the tubes were given, and the uses to which they may be put discussed in detail.

Messrs. Bangs, Dobbs, Gardberg, Love, and Wills participated in the discussion of the paper.

Boston Section

A meeting of the Boston Section was held on October 14 at Harvard University, E. L. Chaffee, chairman, presiding.

The first paper of the evening on "Recent Developments in Kennelly-Heaviside Layer Recording Equipment and Observations of Effective Layer Heights During the Recent Solar Eclipse," was presented by H. R. Mimno and S. R. Wang both of Harvard University.

The paper covered developments in Kennelly-Heaviside layer height measurement equipment carried on at Harvard during the past year and observations of the effective layer height for 3492-kilocycle transmissions during the solar eclipse of August 31, 1932.

The second paper on "Observations of Field Intensity and the Effective Height of the Kennelly-Heaviside Layer During the Solar Eclipse of August 31, 1932," was by G. W. Kenrick, of Tufts College, and G. W. Pickard, consultant.

Kennelly-Heaviside layer height measurements made during the solar eclipse on transmissions at 1640, 3492, and 4540 kilocycles were presented together with field intensity measurements taken at Tufts College from Stations WCSH on 940 kilocycles, VE9GW on 6095 kilocycles, and GBR on 16.1 kilocycles.

Due to the lateness of the hour, a discussion on these papers was omitted. The meeting was attended by one hundred and twenty-five members and guests.

Buffalo-Niagara Section

On October 27 a meeting of the Buffalo-Niagara Section was held at the University of Buffalo and was presided over by Chairman L. G. Hector. Sixty-seven members and visitors were in attendance.

A paper on "Work of the Electric Power Company on Radio Interference," by E. P. Peck and J. Burbank of the Buffalo, Niagara, and Eastern Power Corporation was presented by Mr. Peck.

He pointed out that the companies are concerned only with the location of disturbances caused by their own system. However, the majority of the complaints received are found to be due to causes not originating on their own systems. The companies are also anxious to eliminate causes of interference due to their own equipment, but feel that they should not bear the burden of investigating complaints due to other equipment and causes. A questionnaire system has been installed at a number of places including Buffalo. The complainant is requested to fill out a form and answer a number of questions to assist in locating the cause of interference. This system tends to eliminate irrelevant and unjustified complaints. It is successful in doing this to the extent of a sixty per cent saving in calls. Coöperation has been and is being secured from manufacturers of apparatus which cause radio interference, for a correction of this trouble at the factory when possible. Considerable interest has been aroused in manufacturers and individuals on the manufacture and design of devices intended for attachment at the source of interference for its elimination. Space in technical literature and advertising is being devoted to the subject.

The following-up of complaints sometimes results in weeks and months of intermittent search. Sometimes the source is found quite by accident after persistent search. One very unusual case of radio interference in town was found to originate in the country. It appears that a high voltage transmission line induced current in an abandoned telephone line running parallel to it. The induced current arced or passed through a variable resistance to ground. This telephone line radiated radio-frequency current from this disturbance, and the transmission line acted as wired radio to bring the disturbance into town for reradiation.

The power companies find that apparatus which measures radio field intensity does not lead them directly to the source of trouble but only to the nearest source of radiation. The source of radiation may be some distance from the source of trouble creating it. Attempts have been made to standardize an average permissible level of field strength of interference with special consideration for unusually sensitive receivers.

Three thousand eight hundred and fifteen complaints handled in 1931 resulted in the troubles being located as follows: 23 per cent on power companies network; 12.3 per cent, the complainants radio equipment; 9.2 per cent, other utilities equipment; 17.2 per cent, the customers equipment; 0.26 per cent, static and amateur stations; and 38.04 per cent was due to troubles which vanished before a search began.

There was considerable demonstration apparatus on display at the meeting. This included apparatus used by the local company for locating trouble, a radio set, a cathode ray oscillograph, and types of apparatus causing trouble such as violet-ray machines, motors, commutator, etc. Mr. Burbank used the apparatus to demonstrate its effect on the radio loud speaker and the cathode ray oscillograph. He also grounded 2200 volts to a twig from a tree to show the effect of a power line tree ground.

Cincinnati Section

The September meeting of the Cincinnati Section was held jointly with the Cincinnati Section of the American Institute of Electrical Engineers on the 22nd.

A paper on "Program Transmission for Broadcast Stations" was presented by Leo Friedman, district plant engineer of the American Telephone and Telegraph Company.

The author described completely methods used for handling broadcast programs over telephone lines. By means of maps the various telephone lines were shown, and the various chain networks described. Many of the precautions which must be taken in order to insure an uninterrupted and continuous service were outlined, and several examples were given of extraordinary conditions which arose from time to time and the steps which were necessary in order to surmount these difficulties.

At the close of the paper, the one hundred and seventeen in attendance were taken through the Cincinnati branch of the telephone company where an inspection was made of the facilities which were employed in broadcast program distribution.

In October a meeting of the Cincinnati Section was held on the 18th at the University of Cincinnati with C. E. Kilgour, chairman, presiding.

"Tone Compensation at Low Levels" was the subject of the paper by L. H. Matthias, research engineer for the Allen Bradley Company.

An outline was given of the measurements made of the threshold of hearing and of feeling and their relation to each other. Measurements were also made of the sensitivity of hearing to tones of various frequencies. Attempts made to compensate for apparent preponderance of higher frequencies at low levels were described, and a mathematical analysis of the requirements for apparent normal response at low levels given. Two possible circuit arrangements and their constants for the production of automatic compensation by means of tapped level control with tapped circuits were described.

The paper was discussed by Messrs. Glessner, Kilgour, Meyrose, and Osterbrok of the thirty-five members and guests in attendance.

Cleveland Section

Chairman E. L. Gove presided at the Cleveland Section meeting held on September 30 at the Case School of Applied Science.

W. B. Lodge, television engineer of Columbia Broadcasting System presented a paper on "Removing the Camouflage from Television."

With the aid of various illustrations, the author outlined the status of television as exemplified by regular visual broadcasts of the Columbia System. A system for transmitting both sight and sound simultaneously on the same wave was described. It involves modulation of a forty-five-kilocycle subcarrier at either edge of the television wave which has imposed upon it a fifty-kilocycle side band. Special receiving equipment is necessary.

The range of the short-wave television transmitter of the Columbia System in New York City was indicated to be from ten to fifteen miles, and does not extend beyond the ground wave if distortion is to be avoided.

The number of observers of television programs is estimated to be between 1200 and 2500. In these transmissions, the transmitters and receivers are synchronized by the use of synchronous motors operating from the same alternating-current source.

The author pointed out three important problems which must be solved to make television practical. These are scanning in which greater detail than permitted by the sixty-line limit now prevailing, synchronizing within the closer limits which will be necessary when greater detail is available, and the providing for an extremely wide band of frequencies by which the television program may be transmitted. Other important problems cover the design of amplifiers capable of passing wide bands of frequencies and in the case of ultra-high-frequency transmission, the problems of propagation.

It was the author's opinion that chain transmission of television programs is impossible at the present time due to a lack of wire circuits capable of passing the wide range of frequencies necessary. It was pointed out that cathode ray tube scanning may eventually prove more effectual than mechanical methods now in use.

The meeting was attended by seventy members and guests, a number of whom participated in the discussion which followed the paper.

Detroit Section

H. L. Byerlay presided over the October 21 meeting of the Detroit Section held in the Detroit News Conference Room.

"From Power House to Plate Supply" was the subject of the paper by Howard P. Seelye of the Engineering Division of the Detroit Edison Company.

Mr. Seelye described the generation, transmission, and distribution of electrical energy by the Detroit Edison Company. Slides were shown of typical generating stations and associated equipment, and methods of connecting these stations by high tension lines were explained. Various types of substations were described.

The author devoted a substantial amount of time to descriptions of the distribution systems of the Detroit Edison Company, and touched also on the problem of radio interference.

Fifty-four members and guests were in attendance at this first attempt of the Detroit Section to present a paper not directly concerned with radio.

Los Angeles Section

A meeting of the Los Angeles Section was held on September 20 at the Mayfair Hotel, E. H. Schreiber, chairman, presiding.

"Ultra-Short Waves" was the title of the paper presented by A. V. Haeff. Ultra-short waves were defined as those extending from about seven meters down to a few centimeters, and the general properties and uses of these waves were discussed. The main portion of the paper covered methods of producing undamped ultra-short waves and circuits and tubes developed for this purpose were described. Those included were regenerative circuits, standing wave oscillators, and electronic oscillators. Properties of magnetron tubes both with solid and split anodes, and of Barkhausen oscillators were discussed in detail. Characteristic curves of the Barkhausen oscillator were shown and the use of the three fundamental tube constants, which are wavelength, excitation, and saturation were explained. A special tube and circuit developed by Dr. Haeff, in which the tube can be placed in the loop of the standing voltage wave, were discussed in detail. With tubes having water-cooled grids, waves only fourteen centimeters long were obtained.

In conclusion, a table was shown giving the values of minimum wavelength, power, and efficiency obtainable from different types of oscillators.

The meeting was attended by fifty-three members and guests and twenty-one were present at the informal dinner which preceded it.

The October meeting of the Los Angeles Section was held on the 18th at the Mayfair Hotel with Chairman Schreiber presiding. The attendance was ninety-three, and nineteen of those were present at the informal dinner held prior to the meeting.

Paul Johnson of the Southern California Telephone Company presented a paper on "Acoustics and Related Subjects." In it the speaker discussed the fundamentals of sound, defining pitch, timbre, and volume. Slides were used to assist in this discussion. There were then projected two reels of standard thirty-five millimeter sound film produced by the Bell Telephone Laboratories to illustrate various forms of distortion encountered in soundon-film reproduction. These forms of distortion included overloading, lack of bass response, and lack of high-frequency response. Distortion due to variation in the speed of projection equipment, that due to operating the system at too low a level of volume, and due to poor room acoustics were also demonstrated. For comparison, a sixteen-millimeter film with sound on disk was projected. The meeting concluded with the projection of two reels of film produced by the Fox Film Corporation entitled "The Magic Carpet" showing scenes from New York and the Island of Bali.

New York Meeting

The November 2 New York meeting of the Institute was held in the Engineering Societies Building Auditorium, and was presided over by J. V. L. Hogan in the absence of President Cady.

Three papers were presented on the general subject of ultra-short-wave transmission.

The first of these, "A Study of the Propagation of Wavelengths Between Three and Eight Meters," was presented by L. F. Jones of the RCA Victor Company. The author described observations made by autogiro, dirigible, and automobile of ultra-short-wave transmissions from the Empire State Building in New York City. The absorption of these waves when traveling through buildings was discussed quantitatively. Reflections and interference patterns were covered together with distortion arising from multipath propagation. It was shown that traffic movements caused severe fluctuations in ultra-short-wave field strength at certain points. Maps of the interference patterns measured in a typical residential room were shown and observations made at a distance of 280 miles and at a point 37,000 feet below line-of-sight were described. An empirical ultra-short-wave propagation formula was proposed, and curves calculated showing the relation between wavelength, power, range, attenuation, and antenna height.

The second paper by P. S. Carter and Bertram Trevor of RCA Communications on "Notes on Propagation of Waves Below Ten Meters in Length," was presented by Mr. Trevor.

The results of a number of measurements of field strength variation with distance from the transmitter and height above ground for several wavelengths in the range below ten meters were shown. Observations of the two transmitters on the Empire State Building in New York City, operating on 44 and 61 megacycles, were made in an airplane over Long Island. These tests showed the nature of the interference patterns set up by the combination of the direct and reflected waves. With low transmitting and receiving antennas, field strength measurements with distance were taken for both horizontal and vertical polarizations over Long Island sand on 41.4 and 61 megacycles. Similar tests were made over salt water with low antennas on 34.8 and 59.7 megacycles. Another airplane test was made on 34 megacycles with a higher transmitting antenna and increased power up to a distance of 200 kilometers. The intervening territory in this run was partly land and partly salt water.

The experimental data were discussed in comparison with the theoretical curves determined from optical principles. The experimental results were shown to conform in general with the predictions from theoretical considerations.

The third paper by J. C. Schelleng, C. R. Burrows, and E. B. Ferrell of the Bell Telephone Laboratories, on "Ultra-Short-Wave Propagation," was presented by Mr. Schelleng.

The paper was concerned primarily with the laws governing variation of field strength with frequency and topography. The experiments over land were confined to "nonoptical" paths, but over sea water both optical and nonoptical cases were studied. Frequencies between 17 and 80 megacycles were employed and except for a few measurements in an airplane the maximum distance was about 100 kilometers. These experiments are described together with the method used for making quantitative field strength measurements.

One of the aims of this work was to bring out the relative importance of refraction by the atmosphere, reflection from the ground, and diffraction past obstacles such as hills. All of these concepts were found to have varying degrees of importance, and a tentative theory was built up on this basis.

The variation of transmission efficiency with frequency and distance was discussed. Under different circumstances, the experiments disclosed different trends with frequency. An explanation for these was given and it was pointed out that optimum frequencies, dependent on the particular path, should be found.

The meeting was attended by 550 members and guests, and thirty attended the informal dinner which preceded it.

Philadelphia Section

A meeting of the Philadelphia Section was held on April 20 in the Engineers Club with G. W. Carpenter, chairman, presiding.

Leo Behr, chief of the electrical division of the Engineering Department of the Leeds and Northrup Company presented a paper on "Resistance Boxes for Use on Alternating Current." Dr. Behr discussed some new types of shielded and unshielded resistance boxes designed for alternating-current use. He also exhibited a new form of coil construction and two new types of decades which were of considerable interest to the seventy-two members and guests in attendance.

A general discussion followed the presentation of the paper.

The May meeting of the Philadelphia Section was held on the 31st at the Engineers Club with Chairman Carpenter presiding.

"Orchestra Broadcasting from the Musician's Point of View" was the subject presented by C. N. Weyle, Professor at the Moore School of Electrical Engineering of the University of Pennsylvania.

Professor Weyle has been associated with Leopold Stokowski and the Philadelphia Orchestra for the past several years. He has made extensive investigations in conjunction with that organization in the analysis and improvement of orchestra broadcast technique. His paper covered the high lights of these investigations and discussed the various experiments in seating of the orchestra, types of microphones, and other pertinent matters. A general discussion followed which was participated in by several of the 102 members and guests in attendance.

The October 6 meeting of the Philadelphia Section was presided over by the new chairman, H. W. Byler, and was held at the Engineers Club.

At this meeting a paper on "Broadcast Networks" was presented by F. A. Cowan, transmission engineer in the Long Lines Department of the American Telephone and Telegraph Company. He presented an interesting discussion of the networks developed to handle present-day chain broadcasting, and gave considerable detail concerning the construction, switching, monitoring, and booster circuits required to make such a system practical and successful.

A lengthy general discussion took place at the close of the paper, and many of the 107 members and guests entered into it.

At this meeting all of the new officers and the new chairman of the standing committees were introduced.

Pittsburgh Section

The Pittsburgh Section held a meeting on October 18 at the Fort Pitt Hotel, Chairman R. T. Griffith presiding.

"High Power Five-Meter Generators" was the subject of the paper presented by H. V. Noble of the Westinghouse Electric and Manufacturing Company.

Starting with the fundamental analysis of the conventional tank circuit, the speaker showed how it could be replaced by a portion of concentric transmission line forming an integral part of the grid and plate of the tube; the diameter of the cylindrical line conforming to the diameter of the grid and plate and the line being made to a length equal to one-half wavelength.

He then pointed out that the primary characteristic of such a "standing wave oscillator" is a large gain in efficiency and consequently a proportionate increase in the power output. Methods of connecting the load to the oscillator were outlined in detail. One of the new AW-200 tubes embodying the above principles was exhibited, together with one of a smaller type.

Messrs. Kilgore, McKinley, Mouromtseff, Roess, Scott, and Swedlund participated in the discussion of the paper.

The attendance was twenty-seven.

San Francisco Section

C. V. Litton, chairman, presided at the October 19 meeting of the San Francisco Section held at the Bellevue Hotel.

Donald Mackenzie of Electrical Research Products, Inc., presented a paper on "Wide Range Recording and Reproduction." Dr. Mackenzie outlined the various improvements and developments in the sound recording and reproducing equipment, and illustrated various points by the use of lantern slides. The discussion which followed the presentation of the paper was participated in by several of the ninety members and guests in attendance. Sixteen were present at the informal dinner which preceded the meeting.

Seattle Section

The Seattle Section held a meeting on September 29 at the University of Washington with Chairman L. C. Austin presiding.

"The Microphone" was the subject of the paper by Commander Herbert H. Bouson U.S.N., retired. The speaker outlined the history of the developments of the microphone, and then presented a detailed description which was illustrated by sectional drawings projected upon a screen. All of the various modern types of microphones were treated, and a discussion was given of the advantages and limitations of each particular type.

Several of the seventy-eight members and guests in attendance participated in the discussion.

Toronto Section

Two papers were presented at the September meeting of the Toronto Section which was held on the 21st at the University of Toronto with Chairman R. A. Hackbusch presiding.

F. K. Dalton of the Electrical Laboratory of the Hydro-Electric Power Commission of Ontario presented a paper on "The Solar Eclipse" in which he described a trip made with J. C. Burkholder to Quebec to view the recent solar eclipse. He showed several splendid photographs he had secured of the total eclipse and answered a number of questions concerning his interesting experience.

The second paper by J. S. Robb, an engineer for the Radio Condenser Company of Toronto, was on "Variable Condensers and their Application to Radio Receivers." The author reviewed the principles of variable condenser design, and outlined the developments that have taken place since the early days of radio. He showed by means of graphs the effects of various types of variable insulation on the performance of several receivers. He compared padded and shaped plate systems for superheterodyne receivers, and stressed the matter of acoustical modulation due to mechanical vibration of the condensers, indicating various methods of eliminating it.

The paper was discussed by Messrs. Cook, Fox, Hackbusch, Lowry, Pipe, and Smith of the fifty members and guests in attendance.

The Toronto Section held a meeting on October 19 at the University of Toronto with R. A. Hackbusch, chairman, presiding.

A "Symposium on Service" was presented by J. J. Thomson, radio service supervisor of the Northern Electric Company, Limited, of Montreal, and George Baldwin, service manager of the Canadian Westinghouse Company at Hamilton.

Mr. Thomson dealt with service from four angles—how it is regarded by the consumer; how the dealer looks at it; how the serviceman looks at it; and how the development and production engineers and the manufacturers should look at it. He mentioned particularly the ill will created, for example, when a condenser blows and the customer is compelled to buy a whole block at considerable expense. Mr. Thomson stressed the point that the prospective customer thinks nothing of service. It is only once he has bought the set and then has to pay for service that he starts to think along lines that are distinctly unhealthy for the manufacturer of the set which has not measured up to his expectations.

In considering service from the point of view of the dealer, the speaker said that the majority of dealers have now come to realize that they must have their own service departments, properly outfitted, and employing only expert servicemen, if they are to stay in the radio business.

It was pointed out, however, that even the dealer who has gone to the trouble of providing a well-equipped service department, may find himself in difficulties if the set he handles has not been correctly designed, assembled, and inspected before leaving the factory. Finally Mr. Thomson presented a list of suggestions that would aid in turning out a product that will stand up, as obtained from various dealers' servicemen, adding his own comments later on.

Mr. Baldwin told of a number of service troubles experienced in various types of receivers and tubes, covering a period of about four years. He also mentioned a number of cases that were affected by moisture. These were sets that were installed near a water front and on shipboard. He dealt in detail with the causes of these troubles and the cure.

There were ninety members in attendance at the meeting.

Washington Section

"Recent Developments in Radio Receiving Tubes" was the subject of a paper by E. W. Rittner of the RCA Victor Company which was presented at the October 13 meeting of the Washington Section. This meeting was held at the Kennedy-Warren Apartment Hotel, and was presided over by H. G. Dorsey, chairman. About a third of the sixty members and guests present at the meeting entered into the discussion of the paper.

The chairman presented a letter from President Cady emphasizing the need for coöperation on the part of the membership in behalf of the Institute's Emergency Employment Campaign.

A Nominating Committee to prepare a slate of officers for election for the forthcoming year was appointed, and the chairman also announced the appointment of a representative of the section on the Joint Committee on Technical Employment and Relief which has been inaugurated by the Washington Society of Engineers.

Thirty members attended the informal dinner which preceded the meeting.

Committee Work

Admissions Committee

A meeting of the Admissions Committee held at the Institute office on Wednesday, November 2, was attended by A. F. Van Dyck, chairman; H. C. Gawler, C. M. Jansky, Jr., A. V. Loughren, and H. P. Westman, secretary.

The committee considered six applications. Two of these for transfer to the Fellow Grade and two for admission to the Member grade were approved. One application for transfer to the Member grade was approved and another rejected.

Broadcast Committee

A meeting of the Broadcast Committee was held on the evening of November 1 at the Institute office, and was attended by E. L. Nelson, chairman; Arthur Batcheller, A. B. Chamberlain (representing E. K. Cohan), Raymond Guy, J. V. L. Hogan, C. W. Horn, L. M. Hull, C. M. Jansky, Jr., L. F. Jones (representing B. R. Cummings), R. H. Marriott, and H. P. Westman, secretary.

The committee continued its consideration of material for incorporation into reports upon which it is now working.

New York Program Committee

On Tuesday, October 25, a meeting of the New York Program Committee was held at the Institute office, and was attended by E. R. Shute, chairman; C. N. Anderson, Austin Bailey, H. H. Beverage, C. W. Horn, L. J. Reynolds, R. M. Williams (representing R. H. Ranger), and H. P. Westman, secretary.

The committee prepared tentative programs for the January, February, and March, 1933, New York meetings.

Personal Mention

Ivan Bloch formerly chief engineer of General Television Manufacturers Corporation is now doing consulting work at Brooklyn, N. Y.

Previously with the Radio Corporation of America, E. B. Boise has become an engineer on receiving tubes for DeForest Radio of Passaic, N. J.

O. H. Brewster previously chief engineer of the CeCo Manufacturing Company is now factory engineer for the Ken-Rad Corporation at Owensboro, Ky.

Previously with Baird Television, Limited, T. H. Bridgewater has joined the television engineering staff of the British Broadcasting Corporation at London.

J. L. Callahan has become a division head in the engineering department of RCA Communications at New York City.

Formerly an engineer for the RCA Victor Company, C. C. Chambers is now a visiting fellow of the Bartol Research Foundation at Swarthmore, Pa.

E. N. Dingley, Jr., formerly editor of the *Radio Serviceman*, has joined the engineering staff of the U. S. Naval Research Laboratory at Bellevue, D. C.

Lieutenant J. H. Foley, U.S.N., has been transferred from the U.S.S. West Virginia to the U.S.S. Arizona.

W. W. Garstang is now chief engineer of Electronic Laboratories, Inc., of New York City, formerly being associated with P. R. Mallory and Company.

H. J. Geist formerly with RCA Victor has joined the technical staff of WCAU in Philadelphia.

W. E. Gilbert has joined the engineering staff of the Philadelphia Storage Battery Company having previously been connected with the H. H. Eby Manufacturing Company.

G. D. Gillett formerly with Bell Telephone Laboratories has established a consulting practice with headquarters at Washington, D. C., and Engelwood, N. J.

Previously with RCA Victor Company of Massachusetts, H. H. Gleason has joined the engineering staff of Pilot Radio and Tube Corporation of Lawrence, Mass.

Formerly manager of broadcasting for Columbia Broadcasting Company, P. A. Greene has become general manager of American Radio Systems, Inc., at New York City.

Previously with the Chalmers-Godley Corporation, P. F. Godley has set up a consulting service with headquarters at Upper Montclair, N. J.

L. S. Hillegas-Baird is now editor of *Radio Industries* in Chicago.

W. H. Hoffman has left the DeForest Radio Company to become a radio engineer for the Federal Telegraph Company at Newark, N. J.

W. E. Holland formerly the chief engineer is now vice president in charge of engineering of Philco Radio and Television Corporation.

Formerly with International Communications Laboratories, L. A. Kelley has become a member of the firm of Burkholder and Kelley, communications engineers of New York and Toronto.

Previously consulting engineer in Chicago, E. L. Koch has become vice president of Radio Developments, Inc., at New York City.

V. D. Landon formerly with Stewart-Warner has joined the engineering staff of RCA Victor Company of Camden.

R. H. Leffler previously with Radio Air Service Corporation has become chief engineer of the Associated Radiocasting Corporation of Columbus, Ohio.

C. V. Litton formerly with the Federal Telegraph Company has organized the Litton Engineering Laboratories at Redwood City, Calif.

W. A. Nichols has joined the engineering staff of the Northern Electric Company at Montreal having previously been with the Canadian National Telegraphs.

J. C. McNary previously with Bell Telephone Laboratories has organized a consulting service with headquarters at Chevy Chase, Md.

Formerly chief engineer of Dongan Electric Manufacturing Company, R. L. Osborne has established the Osborne Transformer Company of Detroit, Mich.

C. A. Packard has become an engineer for Struthers Dunn, Inc., of Philadelphia, having formerly been connected with the International Resistance Corporation.

Jack Provis has become chief engineer of KID, Inc., at Idaho Falls, Idaho.

H. V. Rao has been promoted to engineering supervisor of Indian Telegraphs with headquarters at Poona, India.

Formerly with the Atwater-Kent Manufacturing Company, W. F. Sands has joined the Engineering Department of the Philadelphia Storage Battery Company.

Previously with RCA Institutes, J. A. Schanz has become a radio consultant with headquarters at New York City.

James Schultz has become chief engineer for Monumental Radio Company of Baltimore, Md.

David Sonkin formerly with Polymet Manufacturing Company has joined the staff of DeJur Amsco Company in New York City.

Previously with RCA Photophone, P. H. Sohon is now a partner in the firm, Sound Picture Engineers, of New York City.

H. M. Thomson formerly with Bell Telephone Laboratories has joined the engineering staff of the American Telephone and Telegraph Company.

Previously doing consulting work, W. W. Weedfall has become chief engineer of the Southern Electric and Transmission Company of Dallas, Texas.

R. I. Weber formerly with Standard Radio Manufacturing Corporation, Limited, has joined the radio engineering staff of Rogers Majestic Corporation of Toronto.

Lieutenant H. W. Wells, U. S. A., formerly at Langley Field is now a scientific observer for the Carnegie Institution in the Department of Terrestrial Magnetism at Washington, D. C.

Previously with National Radio Equipment Exhibition, Lewis Windmuller has become managing director of National Sound Studios of Washington, D. C.

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

TECHNICAL PAPERS

PITTSBURGH'S CONTRIBUTIONS TO RADIO*

By
S. M. Kintner
(Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.)

IT HAS been my good fortune to be intimately associated with several individuals whose part in the development of this art has been of major importance. How real that claim is, can best be appreciated when I mention that continuous-wave generation, the heterodyne reception, the radiotelephone, the radio broadcast utility, and short-wave long-distance operation are some but not all of the outstanding accomplishments of my associates.

I will tell you about some phases of these radio developments which I can do without any feeling of conceit because *my own* contributions have been of such comparative minor importance.

In the year 1897, two of Fessenden's senior students in Electrical Engineering at Western University of Pennsylvania, now the University of Pittsburgh, undertook a study of Hertz waves as their graduating thesis. They followed quite closely in their first experiments the work of Professor Bose, as he described it in articles then appearing in the *London Electrician*. Hertz's work was still quite new and no very radical departures had been made from his original instrumentalities. The waves were always created by an oscillating discharge of a condenser and were always detected by some type of imperfect contact or gap. The two students, one now Professor Edward Bennett of the University of Wisconsin and the other Mr. William Bradshaw, Manager of Engineering of the Westinghouse Electric and Manufacturing Company's Newark Works, followed the lead of the earlier workers. The great number of contrivances that they constructed and tested during their intensive five or six months' thesis work, convinced these students as well as Fessenden and the writer, as a result of the difficulties encountered, that such detecting means were thoroughly unreliable. Results could not be checked from hour to hour on account of the variations that the detecting means introduced. While the results of

* Decimal classification: R090. Original manuscript received by the Institute, July 29, 1932. Presented before Twentieth Anniversary Convention, Pittsburgh, Pa., April 7, 1932.

these students' studies of detectors were quite disappointing to them, it served at least one very useful purpose, that was, in convincing Fessenden, when he later undertook the development of a radio system, that imperfect contact detectors were ruled out.

While this account of Bennett's and Bradshaw's tests may not appeal to you as meaning much, to me it stands out clearly as the foundation upon which certain principles were based that were later to change completely the trend of development of the radio art.

Approximately two years later, as I returned home from my summer vacation, I was met, on my front porch, by Fessenden, with a proposition that I join him in a plan to report, by radio, for the New York Herald, the yacht races that were to take place within a few weeks off Long Island. Fessenden had a new kind of detector, which consisted of a minute silver ring mounted in the field of a coil connected in the circuit of the antenna. The received signal currents caused the ring to move. The movement could be observed by changes in position of a spot of light or by listening to the effects produced by mounting the ring as part of a microphone.

We were unable to get the apparatus in condition in time to use for yacht-race reporting, but the results of the early tests convinced us we had a method of operation that made quantitative results possible and that was of immeasurable service in studying the effects of various factors in the questions under consideration.

Fessenden was convinced that the successful detector of the future wireless art, if there was to be such a commercial activity, must be (first) constantly receptive, instead of requiring the resetting characteristic of the coherer; (second) must have low resistance, so as to best take advantage of resonance; and (third) give response proportional to the received energy.

It is perhaps difficult for you to realize that these principles were not apparent to every one. But remember the coherer was generally supposed at that time, to have an order of sensitivity not even approached by any other known device. It was the very heart of the then young wireless system. It took real courage in the face of such conditions to hang on to the other type of detector; but Fessenden had it and did just that, even resisting my earnest pleas just to try the coherer out for comparative purposes.

Fessenden devoted his efforts to improvement of his detector and produced a hot-wire barretter similar in general arrangement to a minature lamp of which the filament was made of Wollaston wire. From it he produced, as the result of an accident during the process of making his hot-wire barretter, a liquid barretter. The hot-wire barretter needed to have the silver coating removed for a very short length by a nitric acid treatment. It was during such treatment that Fessenden observed that one of several of such barretters, in this silver-dissolving part of the process, was giving indications, on a meter attached to the circuit, of signals received from an automatic test sender making D's. An examination revealed that this one had a broken filament while the others were complete. A brief investigation disclosed the fact that this Wollaston wire dipping into the 20 per cent nitric acid solution was far more sensitive and reliable than any other known type. This detector was the standard of sensitivity for years, in fact until it was displaced by the vacuum tube about 1913.

This detector, when the operators listened by means of a telephone receiver in a local shunt circuit to the signals from various sending stations, gave such accurate reproductions that the several stations could be identified by different characteristic sounds, just as a friend's voice is recognized by its peculiarities of tonal quality. This difference suggested to Fessenden that, if some means could be found to modulate the radiation by the voice, just as on a wire line the current is changed, *radiotelephony* was *possible*. He tried to modulate the current in an antenna, by placing an ordinary telephone microphone directly in the circuit, then while he listened at a receiver he heard the voice of his assistant as it came to him over the radio. Thus the radiotelephone was born in 1901.

The first experiments were made with spark transmitters, but, of course, the crash and noise of the sparks were very disturbing and were useful only in proving the correctness of a principle. Higher spark frequencies improved the conditions but even at frequencies of several thousand sparks per second there was a great amount of noise.

Fessenden had previously observed the desirability of more sustained wave trains to improve resonance selection, and one would naturally think of 100 per cent sustained waves if he had become convinced of the advantage of more sustained wave trains. That part had previously been thought out and published by Lodge and others, but how to make the continuous waves was not so apparent.

Fessenden boldly said, "Take a high-frequency alternator of 100,000 cycles per second, connect one terminal to the antenna and the other one to ground, then tune to resonance." That looks simple now, but it wasn't then, I assure you. I remember very distinctly the impression I formed when Fessenden told me of his plan. First I asked how he could get sufficient voltage and he said, "Several hundred volts will be ample, as by resonance I can raise the voltage in the antenna one hundred times, which will be all I require." Even then I was skeptical because I didn't know of any 100,000-cycle machines—neither did he, but he was already working on it and after about five years of strenuous effort and considerable expense, his first machine was delivered to him at Brant Rock, Massachusetts, in September, 1906. From this machine he was able to get about 750 watts at 80,000 cycles.

Fortunately we don't have to rely on present recollections, because in J. A. Fleming's 1906 edition of his Electro-Magnetic Waves, in discussing Fessenden's patent No. 706, 737 (Re 12168) August 12, 1902, he says, "(1) There is no suitable high-frequency alternator of the kind described by Fessenden, and (2) it is doubtful if any appreciable radiation would result if such a machine was available and was used as Fessenden proposes."

It is perhaps useless for me to add that this statement did not appear in subsequent editions of Fleming's book.

Judge Mayer, in his opinion upholding Fessenden's patent on this invention says in effect—"It has been established that the prior art practiced spark- or damped-wave transmission, from which Fessenden departed and introduced a new or continuous-wave transmission for the practice of which he provided a suitable mechanism which has since come into extensive use." These two references are cited, because of the difficulty the younger radio engineers experience in properly evaluating this great contribution of Fessenden.

The high-frequency alternator received by Fessenden in September, 1906, was immediately put to use in radiotelephone experiments and so successful were these that on Christmas Eve, 1906, the general call "CQ" was sent out from Brant Rock, then followed a song, the reading of a verse, a violin solo, a speech, and an invitation to report the results of the reception by all who heard. This was the first radiotelephone broadcast. One can well imagine the feelings of surprise of the lonely ship operators, accustomed to the cold colorless dash and dot of the Morse code, when music suddenly burst upon their ears, to be followed by understandable speech. It would be quite a shock and I don't doubt that some superstitious operators gave rather serious thought to their mode of living.

He received a number of letters from operators on ships all over the North Atlantic asking all about how it was done.

This experimental and development work of Fessenden's was made possible by the financial support and business guidance supplied to Fessenden by two other courageous Pittsburghers. These two men, Messrs. T. H. Given and Hay Walker, Jr., in wholesome contrast to the methods followed by most of the radio companies of the period prior to the war, dug down into their own pockets for the necessary funds to carry on. Mr. Given remarked to me several times, "If this radio business turns out as I expect it will, I'll be satisfied with my returns on what I've put into it; if it does not, I, at least, will not have on my conscience the thought that I've wasted the savings of poor scrub women, widows with dependent children, or others who fall such easy prey to the high-powered stock salesmen."

The courage of these two men, who put more than $2,000,000 of their own money into this radio company, is one of the most striking recollections I hold of genuine confidence in the future of radio. Unfortunately, neither reaped the benefits of their sacrifices, as Mr. Given who bought Mr. Walker's interest during the war, died about one year before broadcasting raised radio to its full stature, and it has always been a great regret to me that he could not have lived to see his dreams come true.

The company organized by Given, Walker, and Fessenden was operated solely for the purpose of developing the latter's inventions. It was called the National Electric Signaling Company and not one dollar's worth of stock was offered for sale to the public. Particular emphasis is laid upon this fact because those were the days when selling stock in a new wireless company was the racket of the time.

This particular company devoted its energies to developing a system to engage in the communication business. A number of stations were constructed for development uses; first, there were three, one at Old Point Comfort, a second at Ocean View, and the third one at Cape Charles. These were small stations with gasoline engine driven dynamos and plain spark gap oscillation generators. Next a pair of stations, one at Jersey City and the other at Collingwood, N. J., were built. There was then erected a third station at Washington, D. C. These stations exchanged code messages at times but were not sufficiently free from interference and fading to give a reliable service.

Then, with the experience gained in the operating of these several stations, an ambitious program was undertaken of erecting two stations for experimental transatlantic operation, one located at Brant Rock, Massachusetts, and the other at Machrihanish, Scotland. These stations were constructed in 1905 and were powered by 35-kilowatt, 125-cycle alternators, with rotary spark gaps that gave a spark frequency of 250 sparks per second. The antenna systems consisted of a single straight tube, 36 inches outside diameter and 420 feet long. This tube was built in eight-foot sections, bolted together. It rested on a steel sphere at the bottom and was guyed at four points along its length, both the guys and the tower being insulated from earth.

At first the tube alone constituted all of the antenna. Later, a form of umbrella structure carrying an additional spread of wires at the top of the tube was added.

On New Year's night, 1906, the first exchange of messages took place between these two stations. The power was not sufficient to insure reliable communication and for weeks at a time it was not possible to get messages across.

In July, 1907, the tower at Machrihanish blew down in a wind storm. The station was so badly damaged that it was never rebuilt.

Subsequent attempts to secure a license from Great Britain to operate a radio station in a commercial service were unsuccessful and that ended further transatlantic operations. However, in the interval between the time of the first trials, which proved the power available insufficient and the destruction of the Machrihanish station, a larger equipment was designed and was in process of construction. This was a 100-kilowatt, 500-cycle, rotary spark set. This outfit was completed and installed at Brant Rock and gave such wonderful results that a companion outfit was completed and sold to the U. S. Navy.

It was expected that this outfit would enable the Navy to keep in touch with the North Atlantic fleet at all times. It was the results of an elaborate series of tests of this set installed at Brant Rock and a set on a Navy cruiser, detailed on this test, that formed the basis of the Austin-Cohen formula of transmission. This formula was the accepted one for years and gave reasonably good results over the range of wavelengths tested in securing the data.

The 100-kilowatt set was not installed in its final station, erected by the Navy at Arlington, for about three years and its final acceptance test was made in March, 1913.

Another invention made by Fessenden in 1905, takes rank as one of the outstanding ones in this art—the heterodyne receiving system. This was another bold stroke of Fessenden, in which he departed radically from methods practiced by others. Like his other great inventions, it was made before he had suitable equipment with which to practice it. He required a source of local oscillations of adjustable frequency, and a high-frequency alternator or oscillating arc was all that was available. These could be made to work, but with considerable inconvenience and a high degree of unreliability.

The discovery of the oscillating tube provided the principal need of this great system to make it what it has proved to be, the best method of reception thus far devised. Upon it, Major Armstrong, six or seven years later, built his superheterodyne system, so well known, by name at least, to all of you.

The opening of the World War seriously interfered with all plans for operating outside of the United States and, as Fessenden had fallen out with his partners two or three years previously and had withdrawn from the company, there seemed to be nothing more urgently in need of immediate attention than the enforcement of certain patent rights then being quite generally infringed.

Several suits were filed by N.E.S. Company against others, and two in retaliation by the Marconi Company were filed against it. In these suits the continuous-wave and the heterodyne patents were sustained by N.E.S. Company, and the Marconi four-circuit tuner and Lodge inductance coil patents were sustained by Marconi Company.

About this time, with patent infringements, suits, and court decisions causing radio confusion, the United States entered the World War. One of the government's first acts was to seize all the radio stations and close up all save a selected number operated by the U. S. Navy Department. Of course, all energies were centered on the war for the next year and a half, and radio operations were all in the Navy's hands; in fact, the seized stations were not returned to their owners until March, 1919.

During this period of government operation the then Secretary of War was strong for government ownership of all radio. He thought he saw an opportunity to take over all the shore stations by buying those seized and getting an agreement on the part of the sellers not to rebuild. The law provided that the government station could handle commercial business when there was no commercial station available. The N.E.S. Company owned three or four stations at that time, rather strategically located around New York and along Long Island Sound, and refused to sell. This blocked the secretary's plan and the commercial business was passed again through the regular commercial channels.

Radio was not, however, a profitable business, and with its patent rights gradually passing away the N.E.S. Company faced a very discouraging outlook. It was at this time that the large electrical companies showed an interest in radio. This was no doubt due to their contact with it during the war, as a result of their manufacture of war radio materials.

This, at first, made it appear that the going would be even harder with this added competition, but it proved not to be. This competition from the large companies was with due recognition of patent rights. They sought licenses to enable them to manufacture apparatus for sale to any one who wanted to buy it. The N.E.S. Company did not want to sell as that would block their plans for a communication business;

i.e., one selling a *service* instead of one selling apparatus, and so they refused.

Negotiations with the Westinghouse Company finally resulted in the organization of a radio operating company in which N.E.S. Company and Westinghouse Electric and Manufacturing Company each held an equal interest.

The organization agreement, however, provided that Westinghouse Electric and Manufacturing Company would manufacture all apparatus required by the new radio company, known as the International Radio Telegraph Company, and further had rights to operate radio stations between plants in its own business where no toll charges were made. The new company at once started to make plans for transatlantic stations, expecting to compete with the cables and RCA.

The chairman of the new company's board of directors and your speaker started for Europe to make traffic arrangements with other companies in the several European countries. Visits to England, France, Germany, Sweden, and Denmark failed to get a single agreement. Several doubted our ability to build a satisfactory station, but said that if we were able to do so then they would be willing to talk to us. We returned with rather dampened spirits but determined to go ahead with the building of a big station in the hope that something would show up. It was apparent that the money earned in the operation of the several shore stations along the North Atlantic coast would not support the company and that other operations must be found.

The manufacture and sale of apparatus to amateurs was considered when, what proved to be, a very happy thought of Mr. H. P. Davis produced the solution to the problem.

All during the war one of the busiest of the Westinghouse engineers was Dr. Frank Conrad. He was devising all kinds of equipment from hand grenades to radio sets. This interest in radio and development of it for the Government gave him special privileges and he was permitted to operate various sending sets in the perfection of apparatus under development all during the period of the Government seizure of the radio stations.

At the close of the war, when the necessity for radio development was no longer present, he continued as a result of his own interest. He was a Morse operator, but not particularly speedy, and so concluded that the substitution of a microphone for the key would speed up his communications. This was done, and he continued his experiments from his station, then located on the second floor of his garage at his home at East End and Penn Avenues, Pittsburgh. His listeners were amateurs, but they gradually increased in numbers when they were no longer required to read the code to understand what was going on. From the vast majority of amateur messages that I've read in log books of others, I never could see that anyone missed very much real information by such lack of code reading ability. Finally these amateurs called up Conrad on the telephone so frequently and at such inconvenient times that he established regular times when he would operate his station. This generally was Wednesday and Saturday nights. The information regarding these concerts of Conrad's was gradually passed by word of mouth until quite a number knew of it. Then after about a year, some enterprising maker of radio receiving sets persuaded the Joseph Horne Company to place them on sale. Their advertisement in the Pittsburgh Sun, on the evening of September 29, 1920, caught the eye of Mr. H. P. Davis, vice president of the Westinghouse Electric and Manufacturing Company. The next day he called together his little "radio cabinet," consisting of Dr. Frank Conrad, L. W. Chubb, O. S. Schairer, and your speaker. He told of reading the Horne advertisement and made the suggestion that the Westinghouse Electric and Manufacturing Company erect a station at East Pittsburgh and operate it every night on an advertised program, so that people would acquire the habit of listening to it just as they do of reading a newspaper. He said, "If there is sufficient interest to justify a department store in advertising radio sets for sale on an uncertain plan of permanence, I believe there would be a sufficient interest to justify the expense of rendering a regular service—looking to the sale of sets and the advertising of the Westinghouse Company for our returns." Mr. Davis asked us whether we could get a station in operation by November 2nd, in time to report the election returns of the Harding-Cox election. We, of course said "yes," and Dr. Conrad, assisted by Mr. D. G. Little, did the most of the work in completing the installation.

It was tested out on the evening of the 1st and, while not as strong as we had hoped, it was passably good. However, the next day, by more careful adjustment it was considerably improved and pronounced ready for use. Conrad stayed at his home, prepared to shift over to his station, in the event of a failure of the East Pittsburgh Station, then known as "8ZZ." No such trouble was encountered and the little transmitter, with its two 50-watt oscillators and its four 50-watt modulators, completed its first schedule without trouble.

The few available receiving sets were distributed around to the best advantage. Some were placed in clubs, where crowds got the benefit of them, others were in the homes of the Westinghouse Electric and Manufacturing Company's officers. The results were quite surprising in the interest that was aroused. We were sorely tried in efforts to provide suitable programs and the phonograph was our best available talent.

The interest grew so rapidly that supply stores were unable to keep up with the demands for telephone receivers and B batteries. Everything that looked like a telephone receiver was pressed into service and there was scarcely even a watchcase receiver in the downstairs hallway of any apartment house in the city—they had all been conscripted by some radio broadcast enthusiast.

It appeared incredible that anything could take the public favor as broadcasting had. I confess I was skeptical as to its permanence, but Mr. Davis apparently never doubted it, if we could only improve the quality of the reproduction, so that it had more than a novelty or mystery attraction.

I had realized for a number of years the technical possibility of such a performance, but not its economic feasibility. As evidence of this, I will quote from an article of L. R. Galvin of RCA, the following:

"The City of Pittsburgh may lay claim to the honor of being the cradle of broadcasting. For it was there that Professor Fessenden did some of his very earliest work in radiotelephony in 1900. Years later, in 1914, it was the theater for experiments in radiotelephony, conducted by Professor A. F. Van Dyck of the Carnegie Institute of Technology, for the benefit of wireless amateurs in the district. Van Dyck had been with the National Electric Signaling Company at Brant Rock, Mass., during 1911 and 1912 and was familiar with Fessenden's work. His Pittsburgh broadcast in 1914 was the result of a dispute among the amateurs of a wireless club as to whether radiotelephony could be received by means of a crystal detector. Van Dyck staged the experiment to prove that it could, and for several nights his programs were received by many amateurs at scattered locations. In 1915, Van Dyck staged another broadcast for the assistance of S. M. Kintner, who was delivering a lecture before the Concordia Club of Pittsburgh. This was received by Kintner and heard by the audience, as a practical demonstration of radiotelephony.

"That Kintner glimpsed the opportunities of this new art is evidenced in the account of the experiment which appeared in *The Pittsburgh Sun*, on November 9th, from which is copied—'The use of wireless,' Mr. Kintner says, 'is quite practicable for concerts and operas. A transmission apparatus where music is being played could carry the airs readily to hundreds of people not in the music hall.'

"Kintner was the kind of prophet who labors to see his prophecy fulfilled, and he was an active member of the Westinghouse Company's technical staff as manager of Research Department when broadcasting was given its great push in 1920."

In spite of the terrible quality of reproduction the interest kept growing. At first there was very little improvement in this quality, although some of the best research specialists were giving various parts their undivided attention. Finally, by careful analysis, the several principal causes of distortion were located, and very shortly thereafter greatly improved results were secured. About this time, the necessity of having available to them several of the International Radio Telegraph Company's patents, particularly those concerning the heterodyne, superheterodyne, and regenerative tube circuit inventions, caused the RCA to seek some arrangement and the International Radio Telegraph Company's need of rights under RCA tube patents made them willing listeners. The broadcast developments made rights under the tube patents vital to the International Radio Telegraph Company.

Arrangements were completed very shortly thereafter, and additional broadcast stations were installed at Newark, N. J., Springfield, Mass., and at Chicago, Ill. A similar acceptance by the public followed at each of these several installations and then additional stations started up all over the country at a tremendous rate. No large department store seemed able to get along without a broadcast station.

The quality of the reproduction kept getting better and better by improvements in both microphone and transmitter equipments and by improved receiving sets. The audience kept getting harder and harder to satisfy, as the novelty wore off, and, had it not been for the fascination of the long-distance hunt for new stations, I'm afraid we would have lost a great part of the audience. This, remember, was the time before talent was paid. In fact, up until a certain amount of improvement had been made in the quality of reproduction, it would have been a waste of money to have used good talent because no one would have known the difference. When the reproduction was reasonably good, the demand for better and better talent increased and is still with us. In fact, today no talent is too good for the radio, and there is little, if there is any, of it that has not yielded to the temptation of using this means of displaying their talents to millions instead of hundreds.

One of the most annoying interferences that the early broadcast listener was compelled to endure was produced by the neighborhood amateur, generally a "kid" who pounded away on his spark set every evening; always at the time when the most interesting program was on. This crashed through and simply could not be successfully tuned out. In fact, about the only successful eliminator of such interference was a long bare wire fastened to a water pipe on one end and a brick on the other—the brick, after attachment to the wire, being thrown over the antenna system of the interfering transmitter. This method was used with great success and for a time appeared to be the only satisfactory one. Then the radio clubs took up the problem and to their credit let it be recorded that they did an excellent job, for within a few months a trouble that appeared quite serious had completely vanished.

Then a new kind of trouble started up, that is a trouble for the broadcast station operator. The increasing number of stations, with consequent crowding, necessitated suppression of harmonics to avoid complaint of interference. Dr. Conrad constructed a short-wave receiving set in order to observe the various harmonics sent out by various stations. He observed the rather surprising fact, i.e., surprising at that time, that some of the distant stations were heard more distinctly, i.e., louder and freer from interference, when listening on the third or higher harmonic than when listening to it on the fundamental. This observation was so contrary to the beliefs of the time that Conrad had difficulty in convincing others of the truth of his statements.

The broadcast band of wavelengths had ended at 220, because those shorter were thought to be of no value and had been handed to the amateurs to be used as playthings. The Austin-Cohen formula also indicated that the short waves would be absorbed before they reached far from the transmitter. However, Conrad proved his case by constructing a short-wave transmitter and operated it with an amateur in Boston, a Mr. Ramsey, to whom Conrad supplied a suitable receiver. A few nights of operation with the enthusiastic reports that Ramsey sent back of the louder signals and greater freedom from static appeared to establish the fact that here was something that others had overlooked.

This new method was immediately tried out on other transmitters of still shorter wavelengths and more power at East Pittsburgh. This experimental station was operated regularly on schedules every night for years. In fact, this same service, though from different equipment, which is changed from time to time to keep it up to date, is still being maintained. A new experimental station was established in Hastings, Nebraska, which was used as a relay station and programs produced on KDKA, at Pittsburgh, were sent by short wave to Hastings, where they were picked up and sent out on another wave. This station was placed in operation about eight months after Conrad's first operations with Ramsey at Boston.

A rather startling effect was soon observed as Conrad shortened the lengths of the transmitter wave. At Sharon, Pa., where one of the

Westinghouse Company's plants is located, about seventy miles from Pittsburgh, it was found to be impossible to receive a message from Pittsburgh, although it was received at Hastings without trouble—though Hastings was over 1000 miles away. At times when necessary to send a rush message to Sharon, it was first sent to Hastings and sent back from there. This was very mysterious and we didn't have sufficient data to suspect the skip phenomena.

All previous users of short waves had done so because of their supposed limit in range, or because of the greater ease of forming beams, and so limiting their field of influence, and not for the virtue that Conrad discovered they possessed as means of reaching great distances.

By 1925 short-wave broadcasts had been sent to Australia, halfway around the world. These were received with sufficient strength and regularity to permit rebroadcasting. In fact, on one occasion a program was prearranged and carried out as planned, in which an orchestra played dance music in Pittsburgh at 7 A.M., breakfast, which was rebroadcast in Sydney, Australia, at dinner the same evening, the speed of travel playing havoc with the clock and habits of the people.

Long-distance programs to remote places on the earth, such as Arctic and Antarctic explorers in the polar regions, became quite common.

Many interesting problems relating to antenna structures, insulation behavior, dielectric losses, etc., arose, and each had to be solved before the next advance was made. For waves approximately twenty meters length with considerable power, it was observed that all lamps in the adjacent dwellings remained partially lighted when the transmitting station was operating regardless of whether the controlling switches for the lamps were open or closed. It was also noticed that operators working near these transmitters quite frequently had their temperatures raised from inductive fields. This was particularly noticeable if they took hold of large conducting surfaces like pipe railings enclosing the sets.

This short-wave work of Conrad's has given us a wonderful new field in which to operate. It has added to our one hundred and thirty-five 10-kilocycle wave channels of the previously used radio field more than five thousand additional ones.

These short-wave channels will no doubt play a very important part in the newer developments, as they find useful applications. One of these no doubt will be for television and, some time I would like to add a chapter to this to record what Pittsburgh has contributed to it.

There are many other Pittsburgh contributions of great merit, that a full record would mention, and it is with sincere regret that the limited time prevents my mentioning them individually.

We Pittsburghers feel proud of the accomplishments of our fellow citizens in this new art, just as we have in many of the older ones.

The name "Pittsburgh" is always linked with iron and steel—with window and plate glass—with coal and with electrical equipment—but, to our distant neighbors in the frozen north who know us principally by our radio broadcasting, it is indelibly fixed, for the name "broadcasting"—in their language—is KDKA.

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

AN INVESTIGATION OF VARIOUS ELECTRODE STRUCTURES OF CATHODE RAY TUBES SUITABLE FOR TELEVISION RECEPTION*

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Summary—*The use of cathode ray tubes for television reception involves problems not encountered when the tubes are used for oscillograph work. This paper takes up various constructions which were tried showing the characteristic curve of each as well as the behavior of the spot under various conditions. It was found that it was possible to design a tube which would operate with a negative bias on the focusing (or modulating) electrode, and which required only a small input signal to modulate fully the intensity of the beam. Furthermore, it was found possible to keep the size of the spot constant while being modulated. By properly designing the elements, a variable control constant caused the curve of focusing electrode volts vs. accelerating electrode current to become steeper as the bias approached zero. This is desirable, as for higher light intensities a larger change in light is necessary to cause the corresponding reaction on the eye. Tubes made up with dual accelerating electrodes enabled higher intensities to be obtained and also permitted a separate adjustment of the size of the spot.*

IN MAKING an analysis of the requisites of a cathode ray tube suitable for television reception there is one outstanding difference between it and one used for oscillograph work. The tube used for television work must be so designed that it is possible to vary the intensity of the spot without changing its diameter. This is not necessary in oscillograph tubes as the size and intensity of the spot is once adjusted for the particular problem in hand and left that way until the test is completed. The common oscillograph tubes which contain one of the rare gases are so designed that the spot can be be focused to any desired size either by filament current adjustment or the adjusting of the voltage on the focusing electrode. Either one of these adjustments also vary the intensity. It is apparent that some new means must be provided to vary the intensity and at the same time keep the diameter of the spot constant.

The characteristic curve of focusing electrode volts vs. accelerating current of gas-filled tubes usually shows a negative resistance characteristic as the focusing electrode bias approaches zero. This same curve of a "hard" tube is similar to that of a standard triode, and the cathode ray tube for television reception may be considered as a triode which

* Decimal Classification: R388×R583. Original manuscript received by the Institute, May 25, 1932. Revised manuscript received by the Institute, August 25, 1932. Presented before New York meeting, May 4, 1932.

in addition to its regular functions also must provide a stream of electrons which is utilized to form the picture. Because of this last function the elements do not take the form of the conventional grid and plate but may take one of the constructions shown on the following pages.

In the tubes to be described the vacuum is of the order of a millionth of an atmosphere. In a few of the tubes an inert gas such as argon or helium has been admitted to a pressure of only several millionths of an atmosphere. All of the tubes have the elements mounted on one press and the leads taken through the one stem. In the smaller bulbs lead glass has been used and on the larger types pyrex glass has been used because of its greater mechanical strength. For instance, on the tubes with a 9-inch face there is a pressure of 960 pounds on the screen

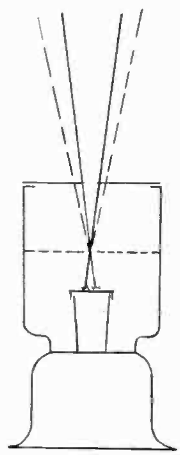


Fig. 1

surface, due to the difference between the atmospheric pressure and the high vacuum in the tube. Extreme care has been taken to anneal the glass and remove all strains from it which might cause it to collapse under changes in temperature or mechanical shocks. The elements used are made of high purity nickel. The filaments or cathodes used are made of a material composed of nickel, chromium, and iron. These are coated with barium and strontium carbonates which are applied with a suitable binder. During the exhaust process these are decomposed by heat into the oxides and the CO_2 removed by the vacuum pumps.

The construction shown in Fig. 1 is used for the purpose of testing various salts for brillance, but it shows very well the fact that the electron beam travels in straight lines and at right angles to the surface of the filament. It also shows how the size of the spot can be varied without any focusing electrodes by varying the size of the hole in the accelerating electrode, and also by varying the distance between the filament and the accelerating electrode, and also the distance between the accelerating electrode and the screen.

Constructions Utilizing Cylinder as Focusing Electrode

The tube shown in Fig. 2 illustrates how the beam can be focused by using a cylinder surrounding the filament. When no bias potential

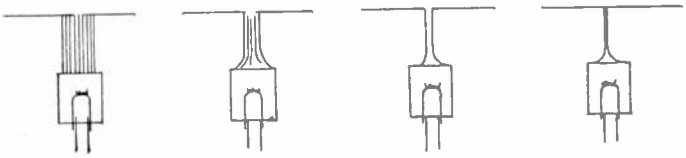


Fig. 2

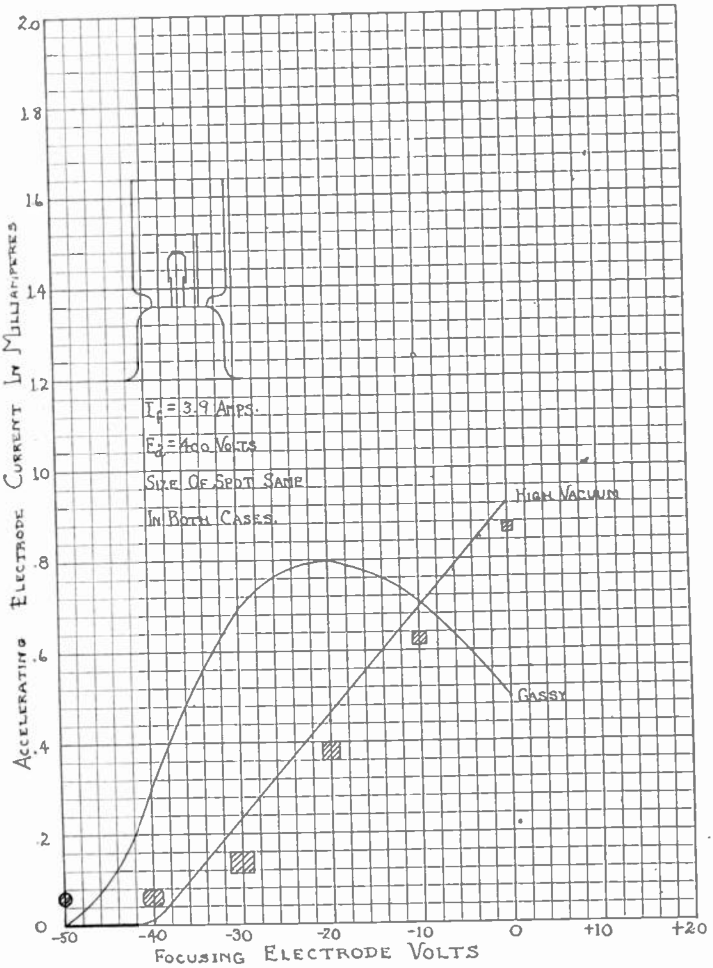


Fig. 3

is applied between the focusing electrode and the filament, the electron beam is quite wide and parallel to the sides of the focusing electrode. As the potential applied to the focusing electrode is made negative with respect to the filament, the beam is concentrated until at an optimum value the beam is the size of a pin point. Increased bias past this point, although focusing the beam at a point, does not permit the beam to travel in parallel lines past the point of focus. The beam spreads out past the point of focus similar to a light beam from a parabolic mirror when the light source is not at the focal point but is between

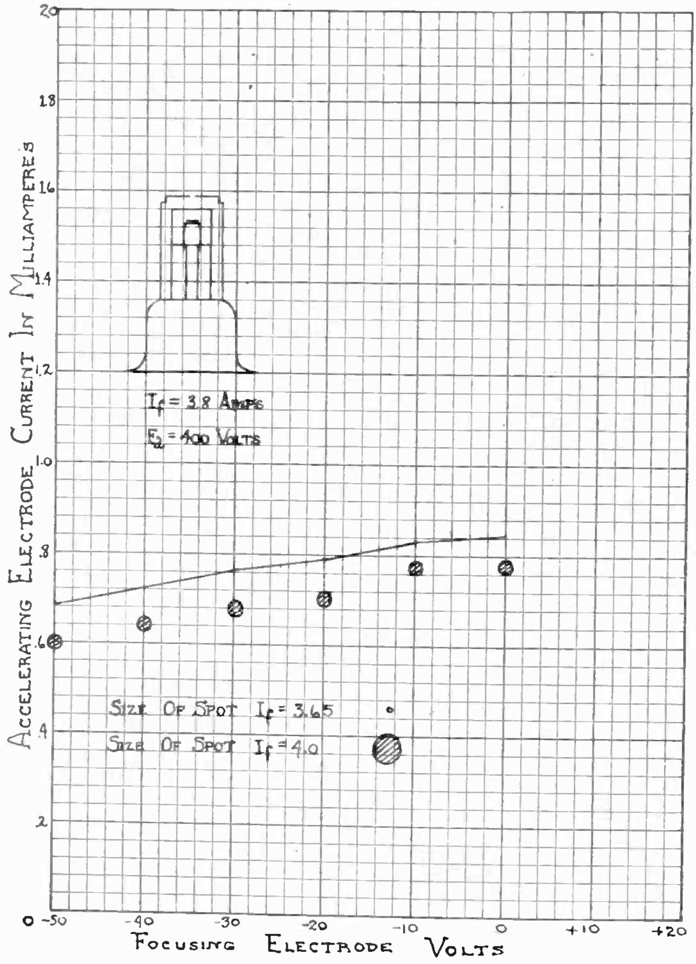


Fig. 4

the focal point of the mirror and the mirror. The concentration of the beam is due to the electrostatic field set-up. It is apparent that this type of construction cannot be used for modulation as the change in bias varies the size of the spot. In Fig. 3 are shown curves taken keeping the accelerating electrode potential constant and varying the bias voltage of the focusing electrode. It will be noticed that with the high vacuum tube, the curve is practically a straight line, and that as the bias is increased to -30 volts the spot becomes larger but still retains the same shape as the filament. For bias voltages higher than −30 volts the edges of the spot become rounded and finally it becomes a circle. The other curve on Fig. 3 is for a tube with similar construction but which was not exhausted to as high a degree of vacuum. The curve is not linear although the size of the spot follows the same general changes. By increasing the filament current a brighter spot is obtained

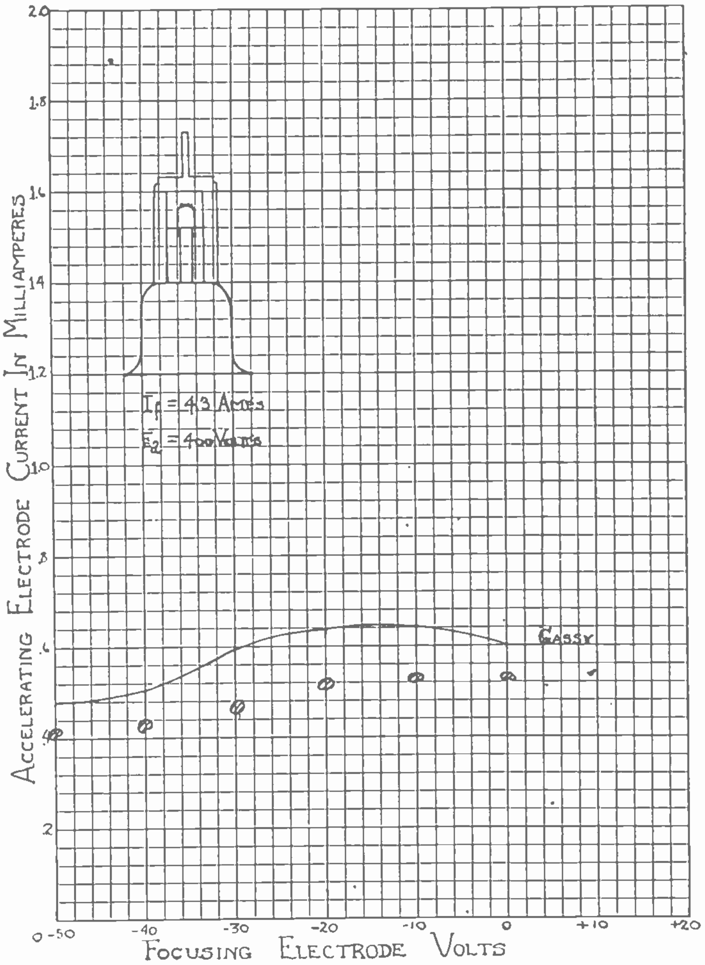


Fig. 5

and the accelerating electrode current is proportionally higher, but the spot remains very nearly the same size as with the lower filament current with varying focusing electrode bias.

Fig. 4 shows another construction tried. In this case the spot remains the same size over the entire focusing bias voltage range and the accelerating electrode current changes only very slightly. By reducing the filament current 5 per cent the spot becomes about 1/16 of an inch in diameter, and by increasing the filament current 5 per cent the spot becomes almost a half inch in diameter. Although this construction is very similar to that shown in Fig. 3, except that the accelerating electrode is much closer to the plate, the accelerating electrode current change is much less for a given change in focusing electrode voltage. Apparently the size of the spot does not change in this case, but if the bias voltage on the focusing electrode is made sufficiently negative the spot changes in size.

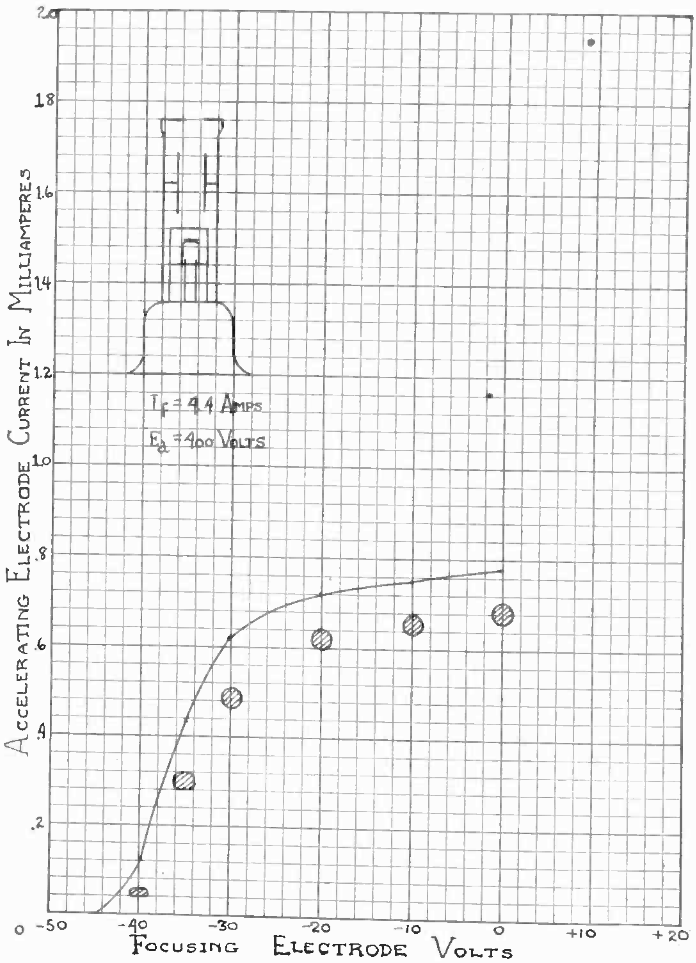


Fig. 6

In Fig. 5, the construction has been changed from the preceding type by adding an "electron" gun to the accelerating electrode structure. The results are quite similar, the bend in the curve being caused by the presence of gas. In this particular model the spot was quite irregular due to the fact that the filament was not exactly centered in the focusing electrode. The use of a "gun" on the accelerating electrode also tends to indicate in operation any slight mechanical misalignments in the mount assembly.

Fig. 6 shows the effect of an accelerating electrode which has a set of plates and a ring at different distances from the focusing electrode. It is interesting in that it shows how the characteristics are changed by a distributed electrode.

Fig. 7 shows a construction which has two accelerating electrodes. The curve shown was taken with 135 volts applied to the first accelerat-

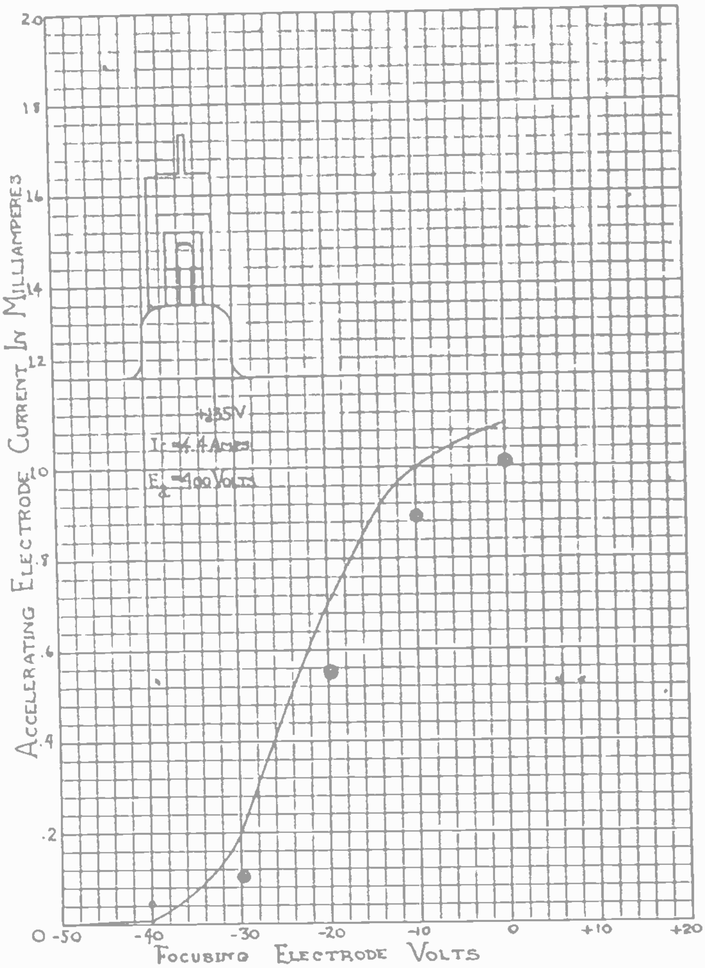


Fig. 7

ing electrode and 400 volts applied to the second one located at a greater distance from the focusing electrode. The spot stays quite constant in size except when a high bias voltage is applied. This also shows the nonlinear curve obtained when the accelerating electrode is distributed.

Figs. 8 and 9 show several constructions tried. From present indications neither of these offer any advantages, both types being insensitive to changes in focusing electrode bias voltage.

The construction shown in Fig. 10 has three accelerating electrodes, each operating at a different potential. The curve obtained also

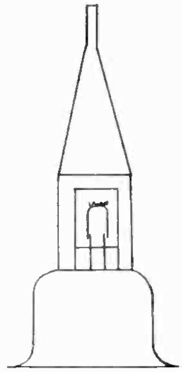


Fig. 8

shows nonlinear characteristics and is quite similar to the curve shown in Fig. 7. An interesting point in this tube, however, is the action when

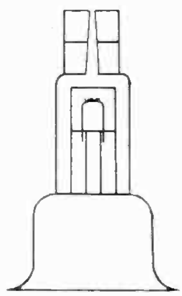


Fig. 9

the first accelerating potential is removed and the lead from it shorted momentarily to the filament. This stops the flow of electrons to the sec-

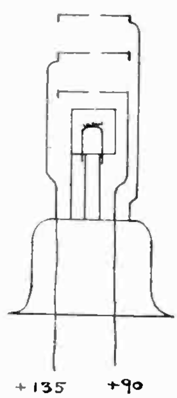


Fig. 10

ond and third electrodes. The electron flow can be started again by reapplying the voltage to the first electrode.

In summing up the results obtained on the constructions shown in Figs. 3 to 10, all of which had similar filaments and focusing electrodes but various accelerating electrode arrangements it is apparent that:

1. Linear curves are obtained when a single accelerating electrode is used, provided the electrostatic effect from it is concentrated at one point, and provided that the degree of vacuum is of the order of a millionth of an atmosphere.

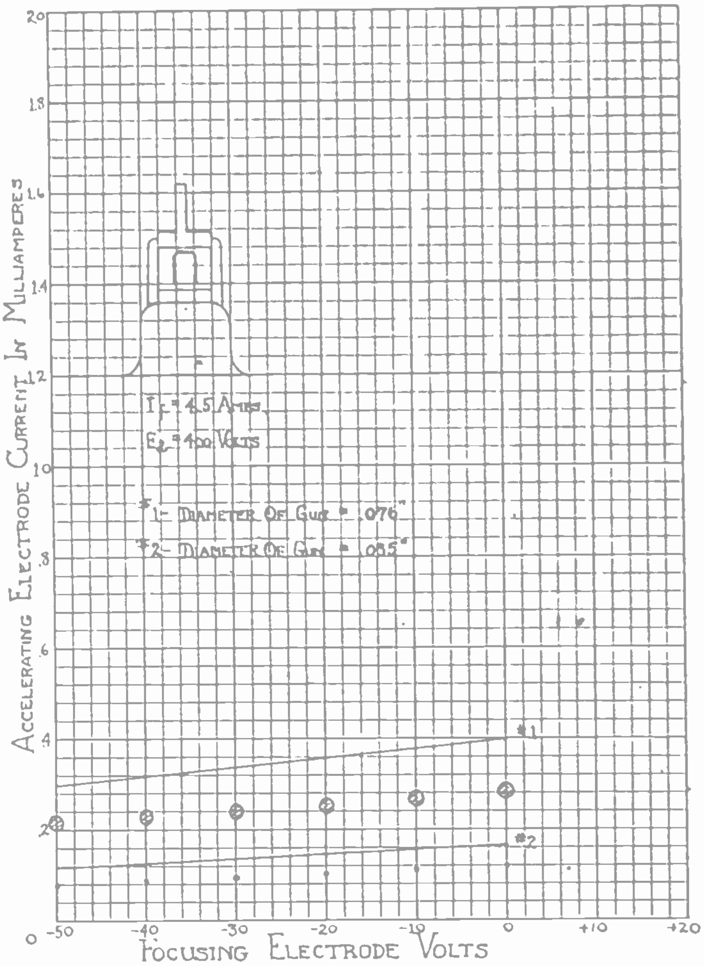


Fig. 11

2. Nonlinear curves are obtained with gas-filled tubes and with tubes having a vacuum in excess of approximately 5 microns.

3. Nonlinear curves are obtained with tubes having more than one accelerating electrode.

4. The use of a hollow cylinder as a focusing or modulating electrode tends to change the size of the spot with varying bias voltage.

5. The sensitivity of the tube to changes in focusing electrode bias

voltage increases as the distance between the focusing electrode and the acclerating electrode increases.

Practically all of the constructions shown can be used for oscillograph work, where the intensity of the spot remains constant, by properly adjusting the filament current and the focusing electrode bias voltage. For television work the nonlinear characteristic of the gas-filled

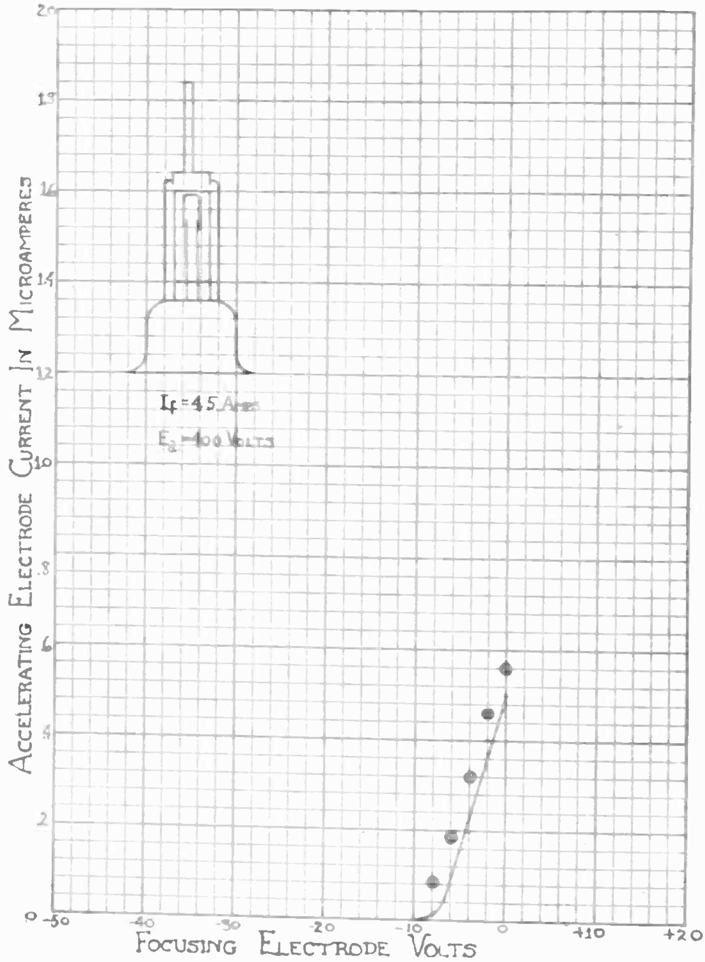


Fig. 12

tube is particularily objectionable, because as the bias voltage approaches zero the current decreases instead of increasing. The curves for the tubes with several accelerating electrodes are also objectionable in that they flatten out as the bias voltage approaches zero. A linear curve is not necessary for television work but the ideal condition would be to have the curve become steeper as the bias voltage approaches zero. This is desirable as for higher light intensities a larger change in light is necessary to cause the corresponding reaction on the eye.

Constructions Utilizing Cylinder with Cap as Modulating Electrode

In the tubes to be described below the construction of the focusing electrode and the position of the filament has been changed. Instead of having a hollow cylinder for the focusing electrode, a cap with various

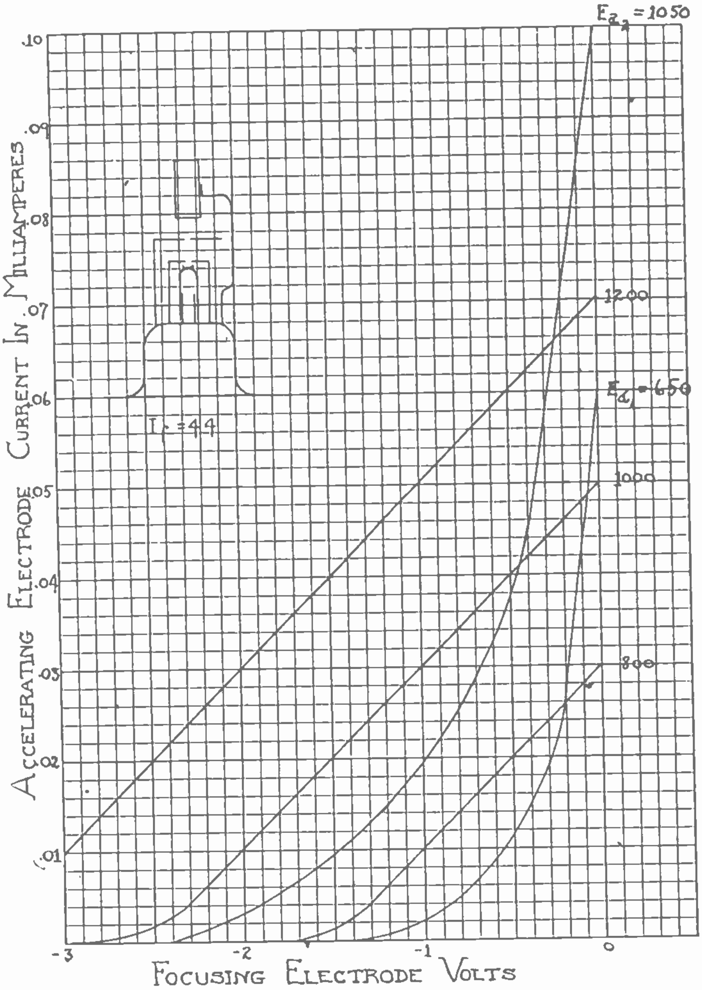


Fig. 13

sized holes in it is placed at the end of the cylinder nearest the accelerating electrode.

In Fig. 11 a curve is shown for a tube having a rather large hole in the cap and "a gun" approximately 0.076 inch in diameter, and also a curve for a tube having a "gun" 0.035 inch in diameter. It will be noticed that a much finer spot is obtained with the smaller "gun." Because of the relatively large size of the hole in the cap and the closeness of the focusing electrode to the accelerating electrode the control constant (which corresponds to the amplification factor in a triode) is low, being of the order of 4.0.

The construction shown in Fig. 12 is similar to that in the preceding figure except that the hole in the cap is exceedingly small. It will be noticed that the effect of this change is to increase considerably the control constant of the tube.

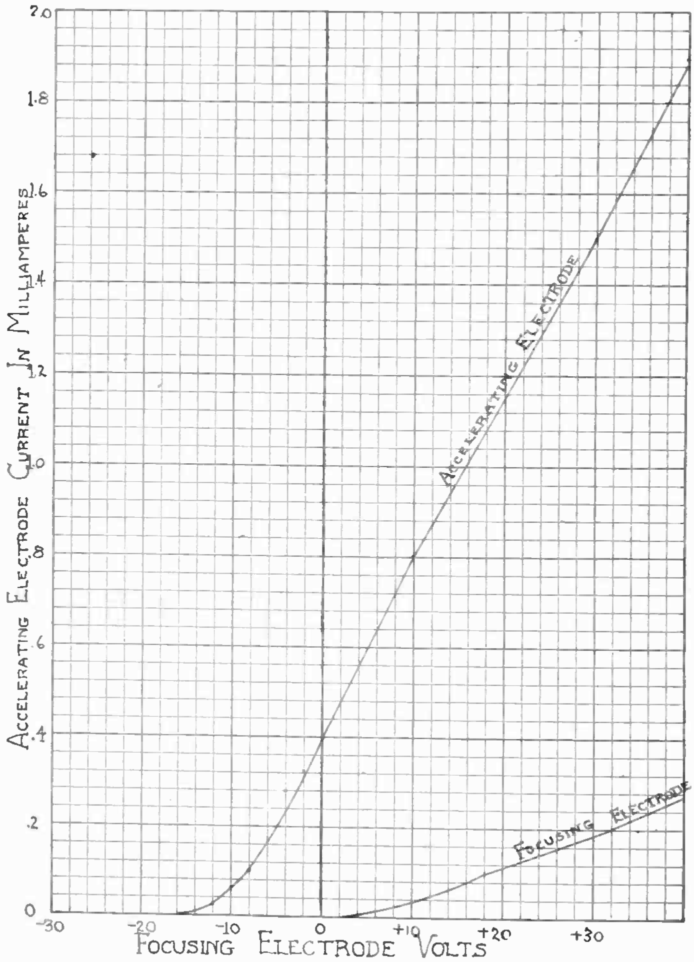


Fig. 14

Dual Accelerating Electrodes

In Fig. 13 a construction with two accelerating electrodes is shown. The first accelerating electrode is in the form of a disk with a hole in it, and the second electrode takes the form of a hollow cylinder. The focusing electrode is similar to that in the preceding figure. The curves marked 800, 1000, and 1200 were taken with the second accelerating electrode disconnected and the above voltages applied to the first accelerating electrode. The control constant of the tube under these conditions is 200. The other two curves show the current in the accelerating electrodes with the voltages applied as given. It will be noticed that the curves become steeper as the bias voltage approaches zero, which make this type of construction adaptable for television work.

In the constructions shown in Figs. 11, 12, and 13 the filament is placed approximately 0.020 inch from the modulating electrode. It is

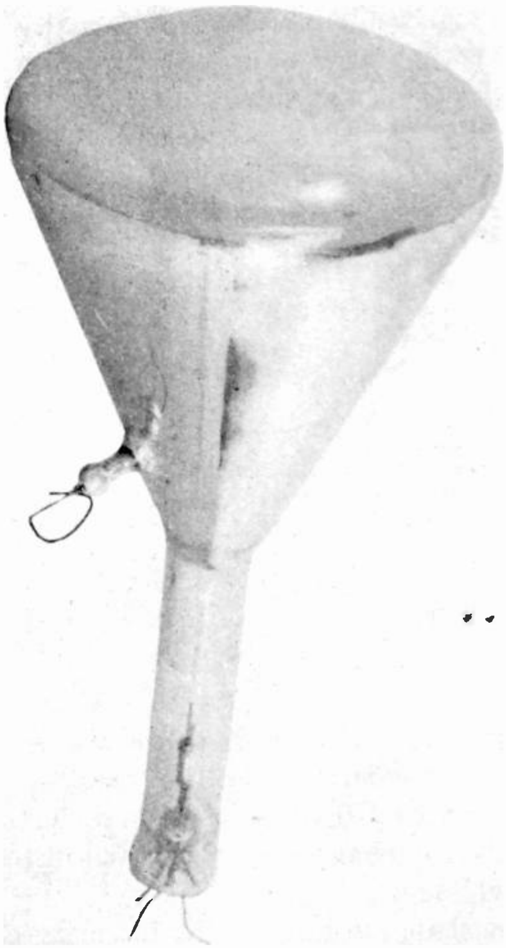


Fig. 15

found that when this is placed at a greater distance it is necessary to apply a positive bias to the focusing electrode in order to vary the accelerating electrode current. When so used the focusing electrode also drew current. Fig. 14 shows a characteristic curve when the filament is close to the focusing electrode.

In order to provide means for increasing the intensity of the spot without sacrificing the loss of sensitivity, various tubes were tried using an anode of silver coated on the inside of the bulb in the funnel-shaped portion. A photograph of one of these bulbs is shown in Fig. 15. By applying three to five thousand volts to this electrode an intensely bright spot is obtained, the size of which can be changed by varying the voltage applied to the accelerating electrode in a construction as shown in Fig. 12.

When the voltage on the first accelerating electrode is approximately 23 per cent of the voltage on the second electrode (on the side of the bulb) a spot of minimum size is obtained. For instance, with 3000 volts on the second accelerating electrode and 700 volts on the first accelerating electrode, a minimum size of spot was obtained. Likewise with 1500 volts on the second accelerating electrode and 350 volts

Fig. 16

on the first, a minimum size of spot was again obtained. However, with 950 volts on the second accelerating electrode, a minimum size of spot was obtained with 270 volts on the first electrode. In this case the ratio between the two changed to 28 per cent instead of 23 per cent as with the higher voltages.

This type of construction enables the intensity of the spot to be increased without losing sensitivity due to the fact that the deflection coils can be placed near the low voltage electrode at which point the electrons are traveling at a lower velocity.

Fig. 16 shows the changes in the size of the spot produced by varying the voltage on the first accelerating electrode.

In summing up the results of the tests which were conducted, the most satisfactory tube for television reception makes use of a dual accelerating electrode similar to the construction of Fig. 13. An additional anode of silver is coated on the funnel-shaped portion of the bulb and the tube is exhausted to a vacuum in the order of one millionth of an atmosphere. This gives a spot which remains of constant diameter as the modulating electrode voltage is varied. The tube is normally operated with a small negative bias, and draws no current in the modulating electrode circuit. A signal of several volts will modulate the spot from minimum to maximum brightness, and the variable control constant of the tube causes greater changes in light intensity at the higher intensities for a given change in modulating electrode voltage. Tubes made up with a construction similar to that shown in Fig. 12 operated very similar to the type just described, although having only one accelerating electrode (and the silver electrode on the neck) and having a linear characteristic curve.

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

APPLICATIONS OF THE CATHODE RAY OSCILLOGRAPH*

By
Ralph R. Batcher

Summary—*In the application of cathode ray tubes to oscillographic measurements, certain factors affect the accuracy of the results. The most important of these items are discussed and methods outlined whereby the effects of this distortion can be minimized or compensated for. A description is included of several oscillograph tubes, and associated apparatus, in which simplicity of operation is a feature.*

CATHODE rays were first discovered by Plucker[1] in about 1859 and were so named by Goldstein in 1876. This term is subject to some criticism under modern views, but has been used for so many years that other designations have received but little support. The name "oscillograph" was first applied by Blondel to apparatus adapted for showing instantaneous values of electrical current.

The fundamental principles of the tube have been published so many times that they need no repetition here.* However, in view of recent developments in several laboratories it would seem that the handicap of rarity and expense has been largely overcome, and a review of the fundamental operational features might be of interest to many who desire to start using them.

The hot-cathode low voltage type of tube only will be considered here. For several years active work has been undertaken toward the development of a type of cathode ray tube particularily suitable for industrial testing processes that is simple to operate and inexpensive. A part of this work was directed toward the design of a very small tube, in which the fluorescent screen was less than about two inches in diameter. Since the usual magnification of the deflection due to a long path was missing, the use of external magnification, using optical systems, was resorted to.

For general commercial usage the outfit must have the following operational characteristics:

1. Simple to operate, with self contained filament, bias, and anode potentials. When once adjusted should return to correct focus each time it is switched on and off.

2. High order of brilliance, especially for visual studies.

3. High "figure of merit" for focus. The ratio of diameter of the

* Decimal classification: R388. Original manuscript received by the Institute, May 25, 1932. Delivered before New York meeting in part as a portion of a paper "Applications of the Cathode Ray Oscillograph," May 4, 1932.
[1] Refer to bibliography.
* References (1) and (6) of bibliography.

screen to the diameter of the spot should be high. Factors of several hundred are often obtainable.

4. "Spattering" or a corona around the spot should not be very

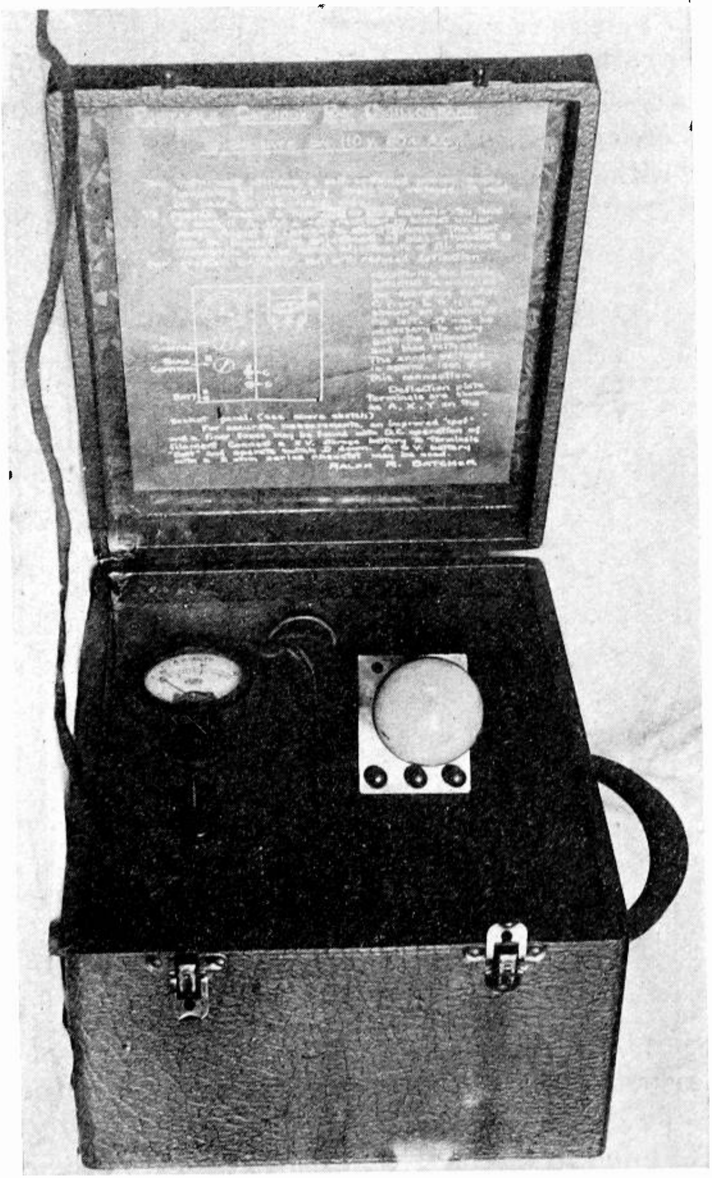


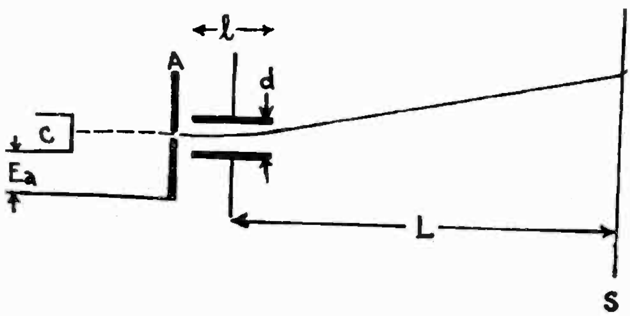
Fig. 1—Photograph of Portable Cathode Ray Oscillograph.

noticeable. This effect is usually due to the inability of the charge due to the electrons to leak off the screen.

5. The calibration should be substantially linear so that displacements represent applied potentials with fair accuracy.

A representative outfit for this type of work is shown in Fig. 1. This case supplies all necessary voltages and controls for operating the usual tube, from potentials of 1000 volts or less and also contains a mounting socket for the tube itself, adapted for tubes up to 12 inches in length. The tube can be folded down when the case is closed for convenience in carrying.

While the cathode ray tube oscillograph cannot be called an instrument of precision, with care excellent results can be obtained. Many other forms of recording instruments give results equally inaccurate, but are used without question.



$$h = \frac{1}{2} \cdot \frac{e}{m} \cdot \frac{E'}{d} \cdot \left(\frac{l}{v}\right)^2 \cdot \frac{L}{l/2}$$

$$\text{where} \begin{cases} v = \text{velocity of electrons} \\ \dfrac{e}{m} = 5.316\ 10^{17} \text{ e.s.u.} \\ E = \dfrac{E'}{300} \text{ and } E_a = \dfrac{E'_a}{300} \\ \text{v} = \sqrt{2E'_a \dfrac{e}{m}} \end{cases}$$

Fig. 2—Electrostatic deflection relations.

In studying the mechanism of deflection it will be found that the distance the spot travels on the screen depends upon the following items:

1. The field due to the deflection plates, which depends upon the voltage applied to them, and inversely as their separation.

2. The square of the length of time that an electron is affected by this field. This time is proportional to the effective length of the plates in the direction of travel of the rays, and inversely as the speed of the rays. This is evident since the higher the speed the less time they are under the influence of the field. The effective length of the field is usually greater than the actual length of the plates since there is some

edge effect. The problem is not unlike that of the deviation of a projectile due to the effect of gravity; i.e., $1/2\ at^2$.

3. The magnification of the tube. The ray is deflected only a small amount while under the influence of the field but after leaving this space continues on in the new direction until it reaches the screen so that the longer the tube—the greater the deflection.

4. The ratio of the charge to the mass of an electron; i.e., e/m.

Combining these factors and substituting the values indicated in Fig. 2 gives a theoretical deflection equal to

$$\frac{0.5ElL}{E_a d} \tag{1}$$

In this analysis the velocity of the rays has been assumed to be equal to

$$v = \sqrt{2E_a'\frac{e}{m}} \text{ whereas} \tag{2}$$

actually it is more nearly equal to

$$v = c\sqrt{1 - \frac{1}{(1 + .00197E_a)^2}} \tag{3}$$

where c is equal to the velocity of light and E_a is in kilovolts. The latter equation has been plotted in Fig. 3, which shows that the simpler form (2) is valid up to about 50 kilovolts.

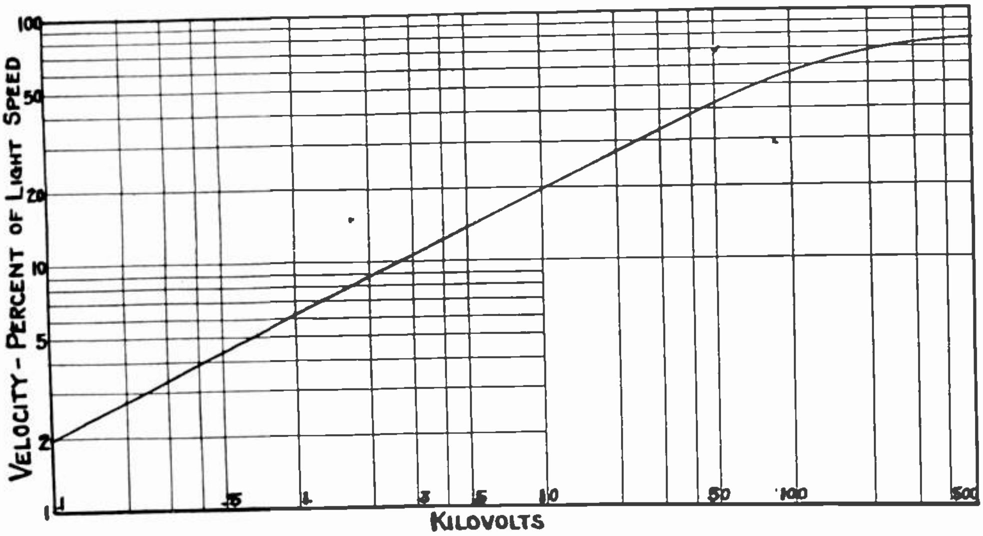


Fig. 3—Velocity curve.

Modifications must be made when the cathode ray tube has two anodes in which the deflecting system is placed between the first (low potential) anode and the second anode to which a higher voltage is applied.

Inasmuch as the extent of the field is rather difficult to determine, it is customary to make up a calibration curve of the sensitivity factor experimentally (6) (21). Deviations between the actual and the experimental calibration constants should not be considered as errors. Factors that tend to distort the diagrams and to make linear measurements upon them questionable will be listed later.

The ionized gas surrounding the electron stream, together with the charge that becomes attached to the tube wall, usually exerts a retarding force on the electron stream so that the effective accelerating potential is somewhat less than the actual anode voltage. This decelerating force is especially noticeable in low potential tubes, where the velocity of the stream is apparently reduced as much as 50 percent in certain cases. The gas pressure has considerable effect on the beam velocity so that it seems that there is a definite potential drop near the cathode that reduces the effective anode potential.

In calibrating a tube for electrostatic deflection, a series of steady and known voltages, having definite steps in value are applied in one direction, while alternating potentials† of sufficient value to produce a full-scale deflection are applied to the other plates. A series of parallel lines are obtained which can be photographed or traced on a translucent paper. The connections are then reversed and the test repeated, whereby a coördinated screen is obtained as a calibration of the reflections.

By making the steady potential increments exactly integers, say five- or ten-volt steps, this graph can be used directly without interpolation. A screen of this type can be placed against the diagram and potentials producing any deflection can be determined directly. Fig. 4 contains several types of screen scales, which were transfered to a transparent piece of celluloid and which have been found useful in some measurements.

Fig. 4a represents an ordinary rectangular scale, which requires no explanation. This scale has not been corrected for errors in the tube, however. A representative scale which bears some corrections for tube deflection discrepancies (the threshold error and a small angular displacement of the axes) is shown in Fig. 4b. The other scales are (c) one for radial measurements and (d) one which horizontal divisions are proportional to the sine of angles. Scale (d) is used when a sinusoidal timing wave is used. The maximum deflection in the horizontal direction must be adjusted to coincide with the 90 degree-ordinates in this case.

† When a photographic record of this calibration is made by focusing a camera on the succession of lines, it is preferable to use a saw-tooth wave form since the lines will be more evenly exposed.

It will be found that if the electromagnetic deflection coils are accurately made and tightly clamped to the tube parallel with the plates, they may be used to obtain a calibration curve, in situ:

The normal location of the axes is found by successively removing each applied voltage, and marked by cementing threads across the

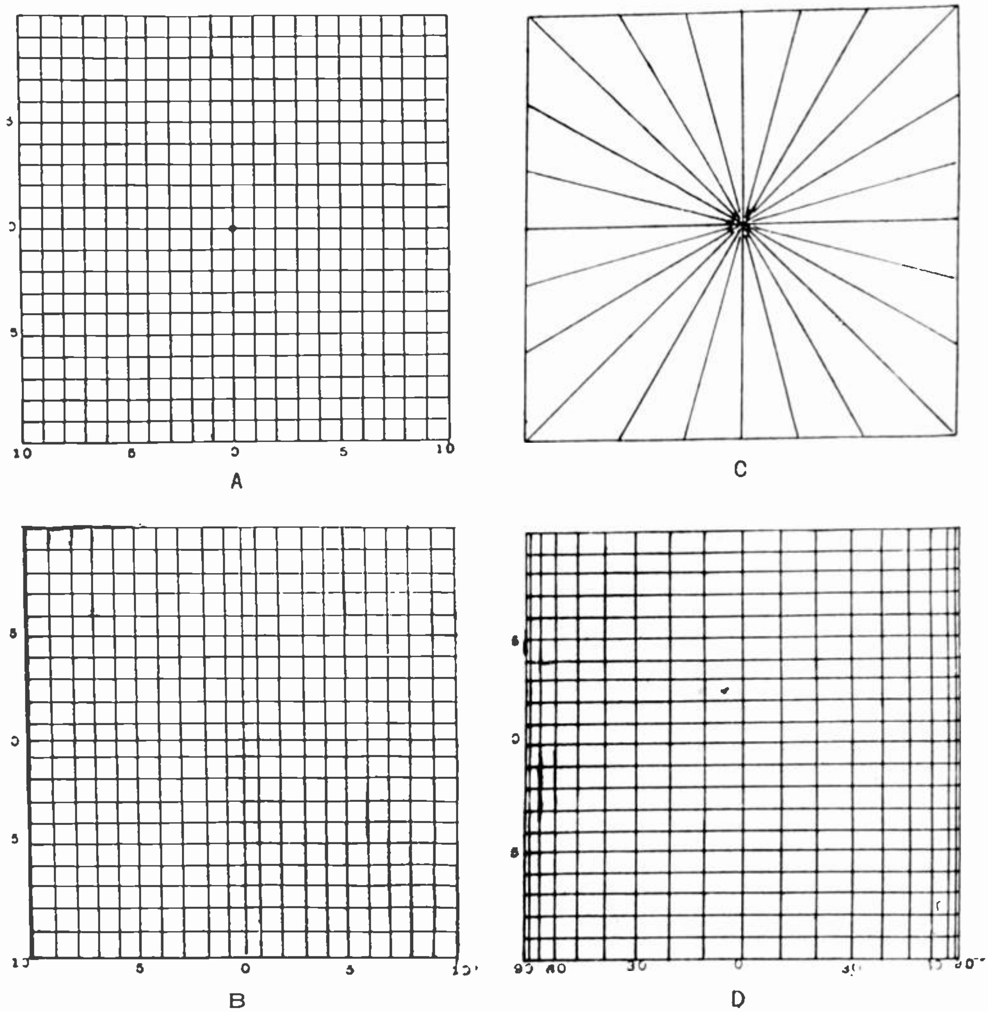


Fig. 4—Screen calibration templates.

surface of the screen. When the required figure is obtained, a direct current of sufficient strength is sent through the proper pair of coils to shift the figure so that the point under consideration coincides with the axis. A voltage calibration is thus made in terms of equivalent ampere turns. A curve showing the relation between ampere turns and volts required for equivalent deflections, having been previously made up for deflections in both directions.

This arrangement is also useful in centering the figure and is superior to permanent magnets in that the applied field is not distorted.

In the case of tubes that are not highly evacuated the deflection produced by small voltages applied to the deflection plates will be at a smaller rate than with larger voltages, an effect which has been noticed by a number of investigators. It has been called the "threshold effect" by Eckersley, (22) who first called attention to the problem. It seems to be due to two causes, the first being the ionization of gas molecules in the path of the electron stream. These ionization currents accumulate on the walls of the tube and on the deflection plates themselves, and cause those plates to become charged, and a small potential is required to neutralize this charge.

Since most of the commercial tubes now available have a rather large gas content (in such tubes the electron stream is visible by the ionization of the gas and the stream is easily seen by the fluorescent path of purple light passing down the tube) a definite leakage path will be found between the plates, which might be of the order of one megohm. The tube is thus not strictly an electrostatic device since this conductive path places an additional load on the circuit.

This leakage varies with the impressed voltage on the deflection plates and may differ in each direction; that is—it may be considerably less from the momentarily negative plate than in the opposite direction. This produces an effect somewhat as if some rectification took place in the deflection plate circuit, which tends to shift the axes back and forth, producing the second cause of the threshold effect.

This effect is reduced if the potential level of the deflection plates is kept somewhat below that of the anode immediately preceding them. This, of course, is not possible when the anode is internally connected to one of each pair of deflection plates. The effect is also less if a definite conductive path is provided between the plates by a circuit across them, even if the resistance of this path is as high as one megohm.

In many tubes sufficient compensation for this discrepancy is obtained by making all measurements to the outside edge of the spot, whereby the diameter of the spot is added to the total deflection. This is usually an easier method anyway, and if the spot is about 3/32 inch in diameter the threshold error will be usually compensated for in most of the soft tubes available, expect for very small deflections at the center of the screen.

This effect will not be found with deflection coils, if all deflection plates are shorted.

Other distortional effects may be produced by deflecting potentials acting in one direction producing small deflections at right angles to that direction. One cause is due to the fact that when the ray moves across the field between the deflecting plates diagonally due to the action of the preceding deflection plates, it is acted on for a longer interval than when it passes through the field in an axial direction.

The same effect is sometimes found when magnetic deflection coils are used. It is essential that each pair be in parallel planes and coaxial, and that the four coils be at right angles to each other, and that a pair be well balanced as to the number of turns. The latter factor is often neglected with a result that a stray field is found that produces considerable coupling between the separate pairs of coils, which not only affects the deflecting fields but also may disturb the circuits to which they are connected.

Coaxial magnetic focusing fields, surrounding the tube at a point near the anode, will usually rotate the axes of the figure when this longitudinal field intersects the transverse deflecting fields (either magnetic or electrostatic). If the longitudinal field rotates the vertical and horizontal axes equally no great harm is done but this usually is not the case. For this reason the use of magnetic focusing arrangements surrounding the tube are usually avoided.

In the usual tube the fluorescent material is coated directly on the inner surface of the glass, so that the screen is not flat. Some distortion is introduced but it is usually of minor importance. Since measurements are usually made along the surface of the glass the error is nearly compensated for. When photographs are taken by means of a camera a different correction factor must be applied which depends upon the dimensions of the tube and the curvature. It is seen that no correction is required when all points of the diagram are approximately equidistant from the center. The correction must also include the error in the lens system of the camera which is usually more important than those due to screen curvature.

When magnetic deflection coils are placed on tubes containing deflection plates, eddy currents set up in the latter may distort the field somewhat. While theoretically the potential drop across the coils may produce an electrostatic field it is found that the inner wall of the tube is soon charged by the stray ions in the tube which effectively shields the tube against external electrostatic fields from any source.

When magnetic deflecting coils are used two additional effects are possible, one due to a certain component of the stray field that is parallel with the axis of the tube, and the other due to the returning flux outside of the coils that cuts through the path of the rays. The first effect is briefly summarized as follows: the general direction of the rays being toward the screen, is deflected upon entering the magnetic field (let us say upward). Due to this additional component of motion the ray is acted on by additional forces, one along the axis of the tube (which only speeds up or retards the electrons slightly) and the other force acting in the direction of the axis of the coils caused by the vertical movement of the rays through the leakage flux from the coils.

The stray external return field from the coils produces a counter deflection that is proportional to the deflection itself. If the total deflection is small these effects are usually small. However, when both magnetic and electrostatic deflections are used at the same time the former should occur ahead of or simultaneous with the latter if possible.

Generally the greatest distortion is experienced due to stray magnetic fields. When horseshoe magnets are used for centering the diagram a very distorted field usually occurs, which varies over wide limits in both direction and intensity. The earth's field may affect the centralization of the spot, but this field is constant and produces no distortion other than that due to the curvature of the screen. When a spot is sharply focused at the center of the screen it may become broader at other points due to a change in path length. Usually better results are obtained if all focus adjustments are made while the spot is in motion. An elongated spot is found if the anode potential is not sufficiently filtered. In case there is a small alternating component in this supply the spot will flicker to and fro as it moves off center, this motion being in a radial direction, and having an amplitude proportional to the radial displacement of the spot at each point.

When an alternating-current filament supply is used a field produced by the filament loop will affect the direction of the ray unless this field is carefully balanced out, either by a specially shaped filament assembly, or else with a coil of wire having a few turns connected in series with the filament and so located outside of the tube opposite the filament and oriented to counteract the filament's field.

The effect of this field is to move the spot back and forth at a rate corresponding to the filament current frequency an amount sometimes as much as 1/8 inch or more. The direction of this motion is not necessarily parallel to either axis and depends upon the axis of the filament.

While the deflection plates in well made tubes are generally parallel and flat, sometimes the leads connecting these plates to lead out wires through the stem, set up distortional fields. For most of the items on this list the correction is self evident when it can be made on the physical equipment.

Summarizing the above effects the most important are:

(1) The threshold effect should be considered when measurements of small amplitudes are important. The extent of the error can be obtained by a calibration curve for the anode potential used.

(2) Deflection plate leakage is important when high-impedance, low-power circuits are being measured, when that leakage is liable to affect the circuit itself.

(3) Effect of the diagonal path can usually be neglected. It is of the same order as the screen curvature error and is opposite to the latter.

(4) Unbalanced magnetic deflection fields show up on calibration curves and can be corrected by physical changes in the coil assembly. The coupling between the pairs of coils should be measured for future reference.

(5) Screen curvature can usually be neglected over the major portion of the screen. This effect also shows up on the calibration.

(6) Stray fields should be eliminated by external magnetic shielding, and the effect of filament field distortion can be eliminated by the use of a direct current filament supply if the field cannot be balanced out.

Item 2 above should be considered when a voltage divider of any type is used to reduce the amplitude of the deflection. Cathode ray tubes can usually be operated at frequencies at least as high as a few megacycles without serious errors due to the frequency if the tube contains a high vacuum.

In tubes utilizing a gas pressure to assist in the focusing the lateral speed of the beam may move faster than the ionized gas does and the focus is impaired. Tests have indicated that somewhat better focusing at high frequencies is obtained if the large end of the tube is heated, although definite conclusive tests on this effect have not been completed.

Incomplete experiments also seem to show a deflection amplitude change at high frequencies that cannot be explained entirely by the effect of the finite impedance of the deflection plates, possibly also due to changes in the velocity of the stream with rapid lateral movements due to the varied effects of the space charge.

In addition, it is evident that a cathode ray tube has an increasing error as the frequency is increased beyond a few megacycles, due to the finite speed of the electrons. In order to give accurate indications, the potential on the plates should not change appreciably during the interval that any electron is traversing the space between them.

For simplicity the problem can be studied by comparing the wavelength of the applied potentials to the deflection time interval.

With an effective anode potential of say 400 volts, the velocity of the ray is about four per cent of the speed of light, as shown in Fig. 3. With deflection plates 2 centimeters long an electron takes about 0.0016 microsecond. If the frequency of the applied potential is great enough, say 20 megacycles, the applied potential may vary considerably during such an interval and incorrect deflections occur. While the error can be computed for a given set of conditions the problem is complicated by the fact that the deflection depends not only upon the average potential difference of the plates during this time interval, but also on whether the potential is increasing or decreasing. In gas tubes the actual velocity of the beam should be used instead of that indicated on Fig. 3, working backwards from equation (1). An amplitude calibration curve taken at these frequencies will, of course, take care of these errors, but wave form studies of very short waves are of little value.

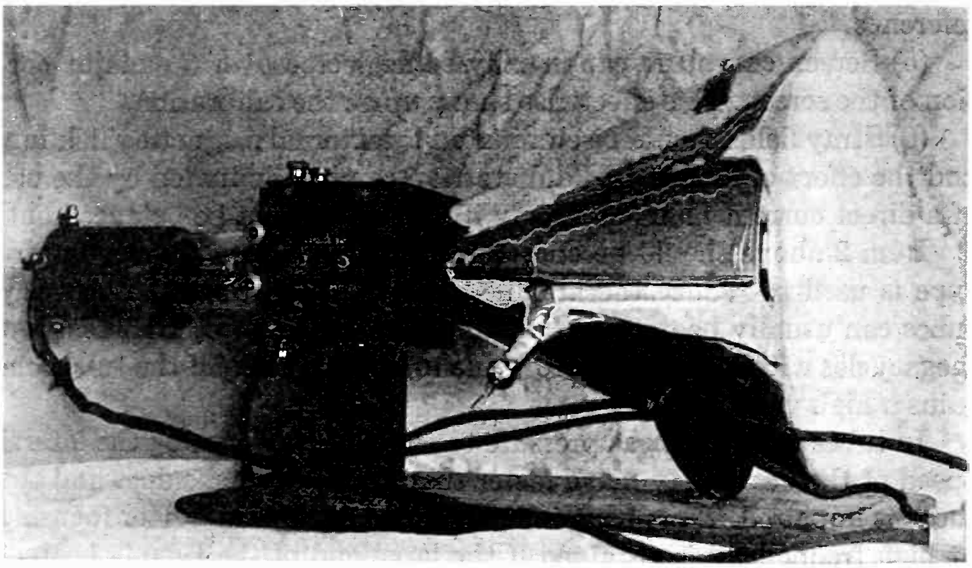


Fig. 5—Photograph of cathode ray tube with magnetic deflection coils.

Quite often measurements of phase displacements are required at the higher frequencies. Such measurements are generally made upon the elliptical figure resulting from the resultant of the applied potentials. If both pairs of deflection plates were equidistant from the screen this figure would correctly indicate the phase. However, the beam is acted upon consecutively so that phase measurements are in error by an amount

$$\text{error in degrees} = \frac{lcf\, 1.2 \times 10^{-2}}{v} \tag{4}$$

where l and v represent factors as in equations (1) and (2) and f represents the frequency in megacycles, and c the distance between axes of plates.

Fig. 5 shows a tube adapted for magnetic deflection coils only. This tube has a sensitivity of about 28 ampere turns per inch with an anode voltage of 800. The latter anode potential is sufficient to give a brilliance great enough to be easily visible in daylight. The coils shown have 6000 turns each and a resistance of about 1200 ohms. The two coils are connected in series so that a potential of 5 volts across them will give a little more than one inch deflection. The design is arranged so that they may be operated directly from the plate circuit of usual vacuum tube amplifiers. The tube is 20-inches long and has a 9-inch screen.

Although it is impossible to determine accurately the calibration factor for magnetic deflections, an analysis of the problem may be of interest. It may be shown that the deflection is equal to

$$h = \frac{0.298BlL}{\sqrt{E_a}} \tag{5}$$

where B is the magnetic field density (in Gauss) assumed to be of constant intensity for a distance l along the tube axis and then to drop abruptly to zero, a condition not found with applied fields. For this reason the calibration factors are necessary.

In computing the value of B for a given set of coils the relation

$$\beta = \frac{0.4\pi nI}{\lambda} \tag{6}$$

is sometimes used. However, the length of the flux path λ can be roughly determined only (this refers to the mean length of path of the lines of force through the coils).

It may be shown however that if the coils are roughly circular and each has n turns, (bound sufficiently close together into a small bundle so that a mean radius can be assumed for all the turns) that the field due to both coils at a point midway on the common axis is

$$\beta = \frac{0.4\pi r^2 ni}{\sqrt{\left[\left(\frac{d}{2}\right)^2 + r^2\right]^3}} \tag{7}$$

where r and d are the coil radius and the distance between the coils respectively, in centimeters. In Fig. 6 the values of the quantity

$$q = \frac{0.4\pi r^3}{\left[\left(\frac{d}{2}\right)^2 + r^2\right]^{3/2}} \tag{8}$$

have been plotted. The field intensity at the midpoint is thus equal to $ni\, q/r$.

It is to be noted that the direction of curvature for the value of q changes at $d=r$ and the value of q at this point is substanially linear with respect to small movements of the point of reference. A system of

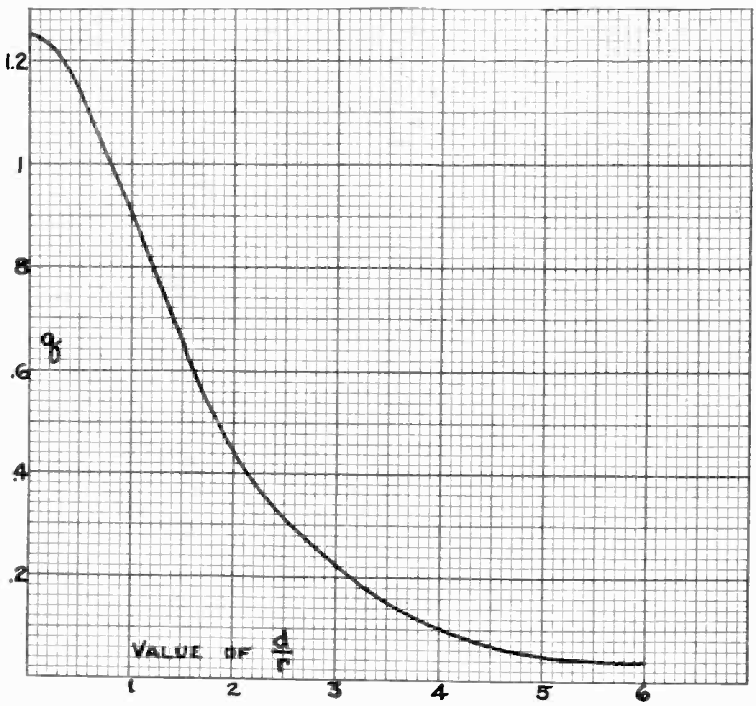


Fig. 6—Field constant for magnetic deflection coils.

coils whose radius is equal to the spacing will thus produce the most uniform field with the least distortion.

The problem is not completely solved however because this relation does not give the average intensity of the field along the axis of the tube.

Magnetic deflection coils require considerable more power than deflection plates. Still, however, the system is not so inefficient for magnetic control as might be imagined. Twelve volts across the coils described above (see Fig. 5) gives a deflection equal to the maximum swing of the pointer of the usual small panel meter. The coils thus absorb about 0.060 watt. As a voltmeter this is about equivalent to 200 ohms per volt, which is directly comparable with direct current meters of this type and much superior to the alternating current meters.

The difference between the electrostatic and electromagnetic deflection systems is less noticeable as the velocity of the rays is increased by applying higher anode potentials.

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Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

THE RADIATION CHARACTERISTICS OF A VERTICAL HALF-WAVE ANTENNA*

By

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Summary—*Extensive measurements have been made of the field distribution about a vertical antenna operating at 29 megacycles over sea water. With the help of a small, nonrigid airship observations were made at various altitudes which permitted the plotting of the space characteristic and the determination of the attenuation as dependent on altitude. The experimental results are compared with field intensities computed for the given physical conditions from the theoretical expressions of Sommerfeld and Strutt. Of interest is the manner in which the field is attenuated in the immediate vicinity of the ground plane and the marked effect on the general intensity distribution of the effective height of the antenna above ground.*

Details are given of the design of the apparatus required for carrying out the measurements.

PART I

THE spatial distribution of radiant energy about an antenna is essentially determined by its configuration, its location with respect to the ground plane, the mode of oscillation to which it is excited, and the electrical constants of the ground plane in the immediate vicinity of the antenna. Of the various configurations found in practice, the vertical wire is the most frequently employed and admits of the simplest theoretical treatment. This case has been discussed in a large number of papers, the best known and most fundamental being those of Sommerfeld[1] and Weyl.[2] In these two last named, account is taken of the effect of a finite conductivity of the ground plane on the attenuation of the field at great distances from the antenna. The assumption is made, however, that the vertical wire may be treated as a simple dipole, an assumption which is certainly justified with regard to the horizontal components of radiation but which may be questioned with respect to the high angle components. The problem as handled by Sommerfeld and Weyl is essentially that of calculating the diffraction of a spherical wave from a fixed dipole source by a plane of known electrical constants. In the actual problem the current distribution in the wire is determined by the nature of the ground plane in the vicinity, and consequently the source must be represented

* Decimal classification: R120. Original manuscript received by the Institute, May, 31, 1932.

[1] A. Sommerfeld, *Ann. d. Phys.* vol. 28, p. 665, (1909); cf. also, Riemann-Webers, "Differentialgleichungen der Physik," vol. II, Chap. XVI.

[2] H. Weyl, *Ann. d. Phys.* vol. 60, p. 481, (1919).

not only by a dipole but by a series of higher order multipoles as well. If the field is resolved, as is customary, into static, induction and radiation components, it may be shown that the radiation field plays little part in the reaction on the antenna. The distribution of current in the antenna is determined principally by the reaction of the static and induction fields reflected from the ground plane, and since these fields decrease very rapidly with increasing distance from the source, it appears that only the nature of the ground in the immediate neighborhood affects the current and consequent spatial radiation distribution. There are to be found in the literature numerous calculations of the radiation on the basis of an arbitrarily assumed sinusoidal current distribution, but a complete solution of the problem in which the current is determined by the properties of the ground and the field then calculated for large distances from the antenna appears to be as yet outstanding.

During the year 1930 an extended series of measurements was made at the Round Hill Experimental Station of the Massachusetts Institute of Technology of the field intensity about a vertical antenna. Through the courtesy of the Goodyear-Zeppelin Corporation a small nonrigid dirigible was available for this purpose, making possible an accurate determination of field distribution in the vertical plane. The results of this investigation are presented in the first section of this paper, together with a comparison with calculations carried as far as the existing status of the theory allows. It is hoped that a theoretical investigation now in progress of the type suggested in the previous paragraph will complete our knowledge of this problem.

In the second part of the present paper will be found the details of the apparatus employed in obtaining the data.

In order that the attenuating effect due to the finite conductivity of the ground might be observed within a relatively short distance of the source, the measurements were made in a field of high frequency. The radiating system adopted consisted of a vertical, half-wave antenna operated at a frequency of 29 megacycles per second. Previous experience had indicated that at such a frequency any irregularity in the properties of the ground plane would render the data extremely difficult to interpret. To eliminate this possibility the measurements were made entirely over sea water, the constants of which were accurately determined. The antenna was located about 200 meters from the shore line and was entirely free of surrounding objects with the exception of a wooden building housing the transmitter. This building was placed over the water on pilings at a distance of 3.6 meters from the antenna. The antenna system was held in a vertical position, the lower end one-eighth of a wavelength above the water at all times by means of a system of weights and floats which maintained this condition irrespective of the height of the tide. The details of the antenna system are to be found in Fig. 1.

The data were obtained during a series of horizontal flights at various uniformly spaced altitudes, each flight starting at a distance of about 9 kilometers from the antenna and proceeding directly towards it. The measuring equipment was located in the forward part of the airship, thus reducing the distortion of the field at the point of

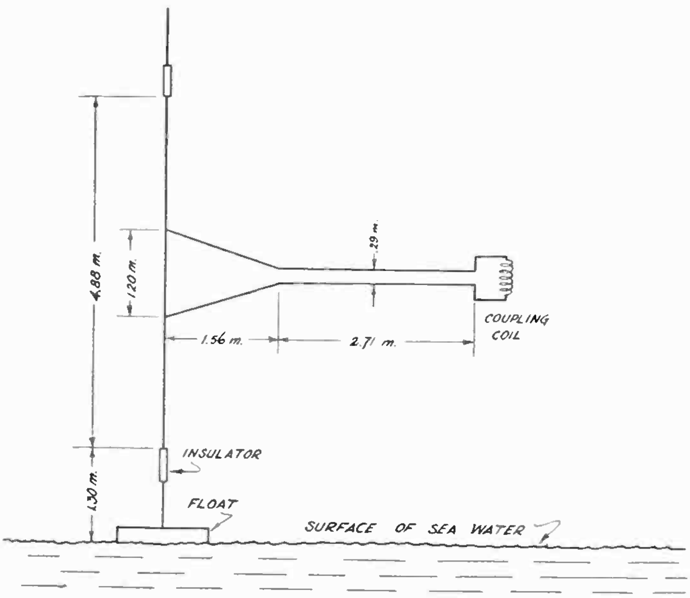

Fig. 1—Details of half-wave, vertical antenna used for the experimental work on 29 megacycles

observation due to the motors, cabin, control wires and the like to a minimum. The great superiority of a dirigible over an airplane for this type of work lies in the possibility of very low ground speeds. The course of flights was laid out to take advantage of the prevailing winds and thanks to skillful pilots the ship was maintained at constant altitude and almost zero ground speed in the vicinity of the antenna where rapid changes in field intensity are observed. During the course of the investigation several vertical flights were carried out to assist in the correlation of the data, although this operation cannot be performed with the smoothness of horizontal flight.

The receiving antenna was a short, straight rod maintained in a vertical position throughout the flights and consequently the measured values were directly proportional to the *vertical component* of electric field intensity at the point of observation.

The results of the measurements at distances from the antenna greater than 50 wavelengths, (500 meters) are represented in Figs. 2

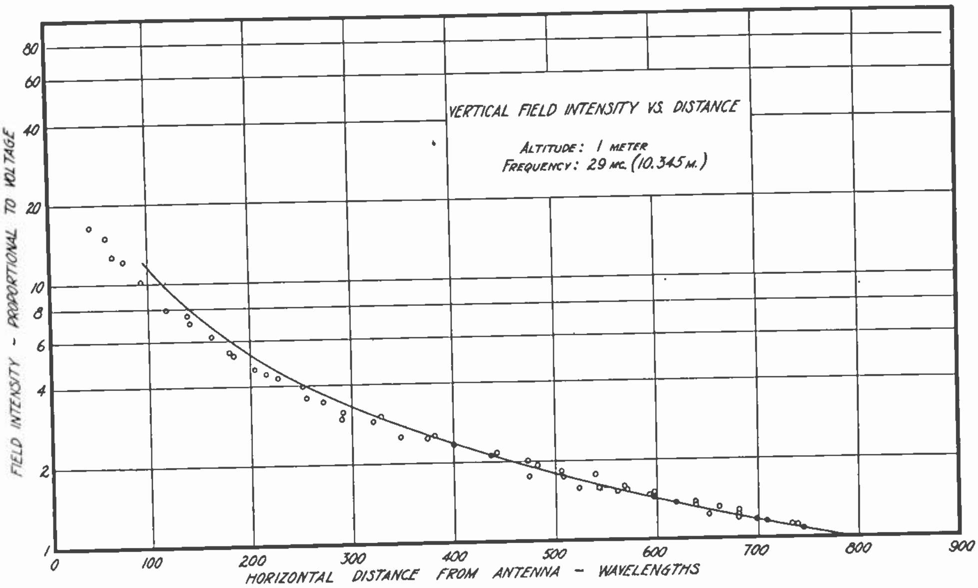

Fig. 2—Theoretical (Sommerfeld) and experimental vertical field intensity vs. horizontal distance from the antenna. Measurements made just over the surface of sea water.

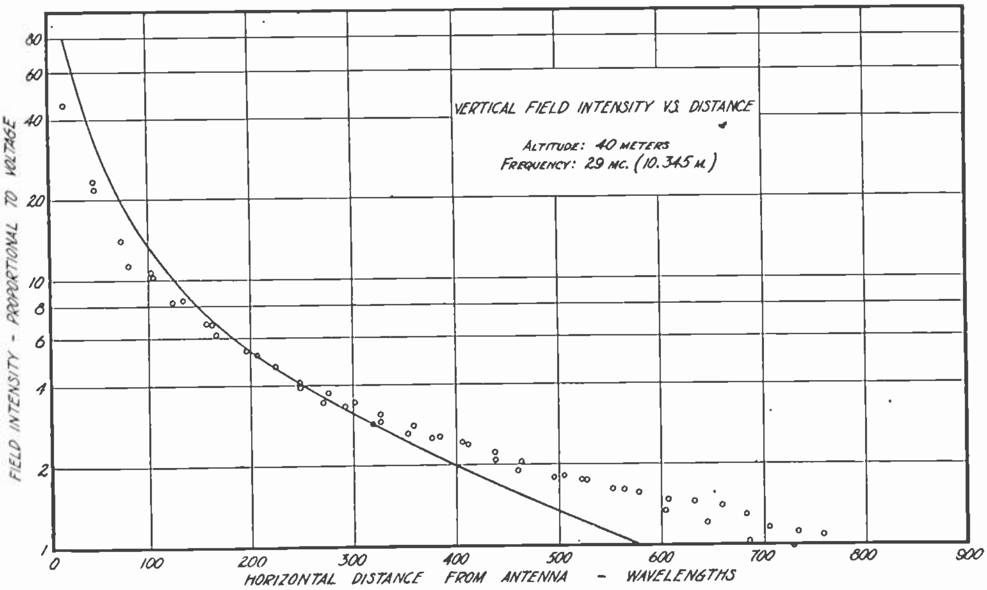

Fig. 3—Theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 40 meters.

to 11 inclusive. These charts give the measured vertical component of field intensity plotted against the horizontal distance from the antenna for a given altitude, this being the form in which the data were taken. It was not feasible to maneuver the airship to exactly the same altitude for each measurement and consequently the altitudes

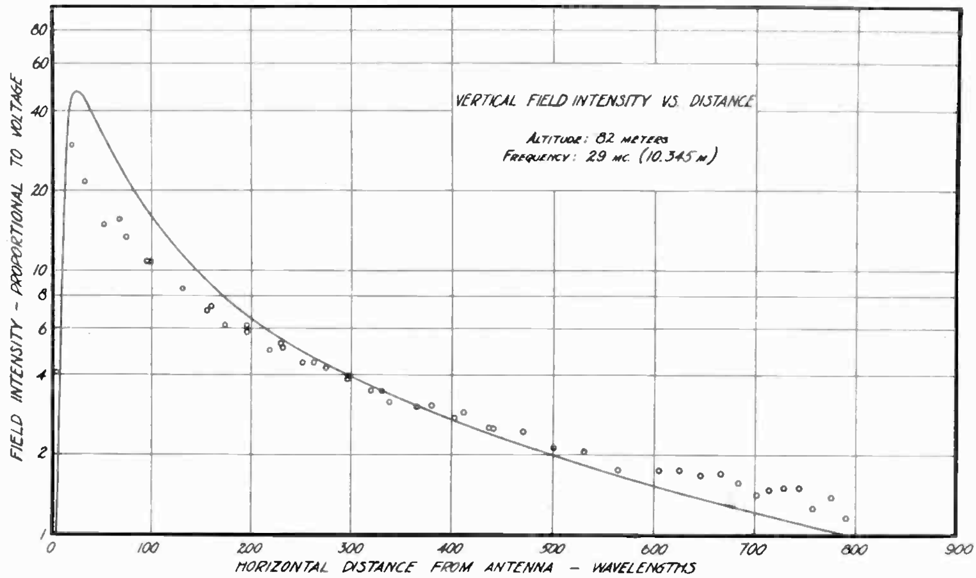

Fig. 4—Theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 82 meters.

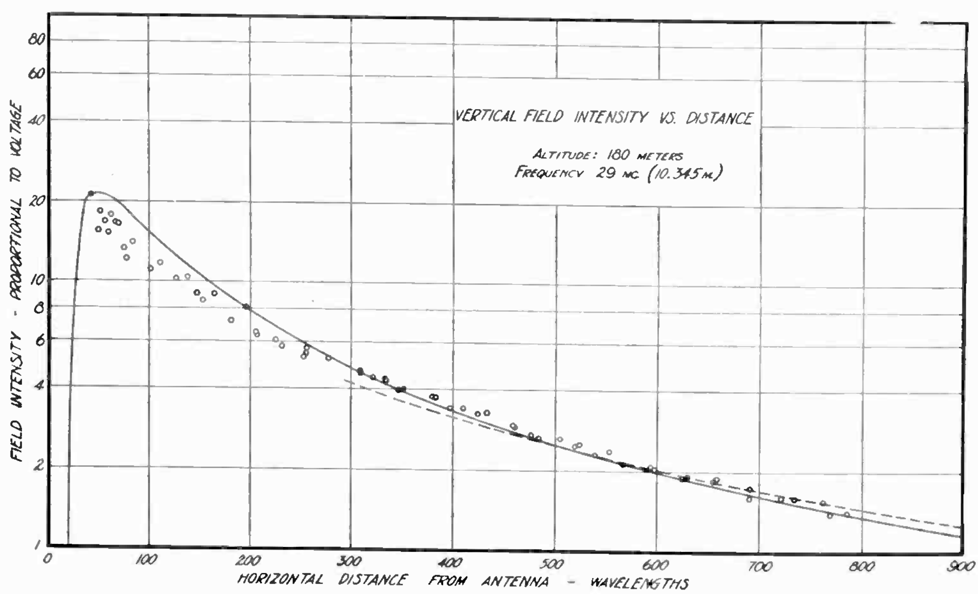

Fig. 5—Theoretical (solid curve: Strutt; dotted curve: Sommerfeld) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 180 meters.

assigned the various figures represent the average altitudes of all the points plotted on a particular chart. The actual deviation from this average value was no greater than 5 per cent in the most extreme cases. Inasmuch as the exact altitude at which each measurement was made is known, it would be possible to apply the necessary corrections. Such a refinement of the data, however, appears unwarranted.

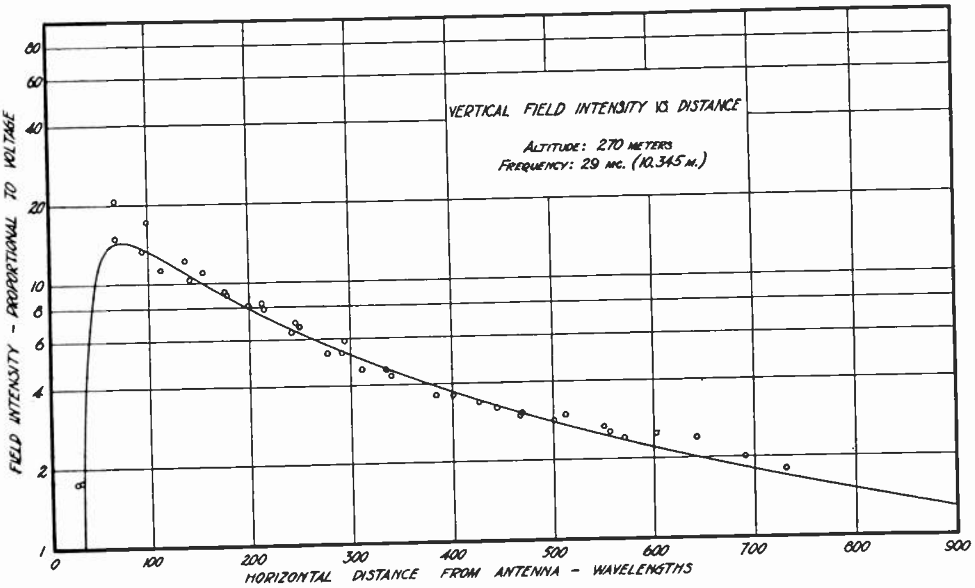

Fig. 6—Theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 270 meters.

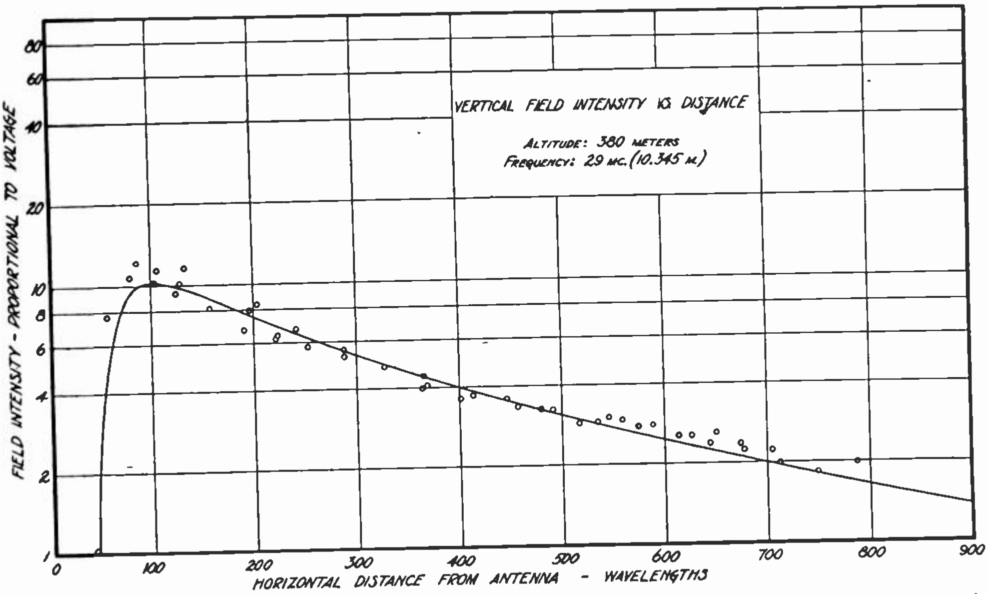

Fig. 7—Theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 380 meters.

The data plotted in any given chart were not obtained in a single flight but are the results of measurements made over a period of weeks. Data for a particular altitude were intentionally taken at various times throughout the course of the investigation and then plotted together in order to verify, in actual practice, the accuracy of the methods used. In Figs. 2 to 11 the experimental points are indicated

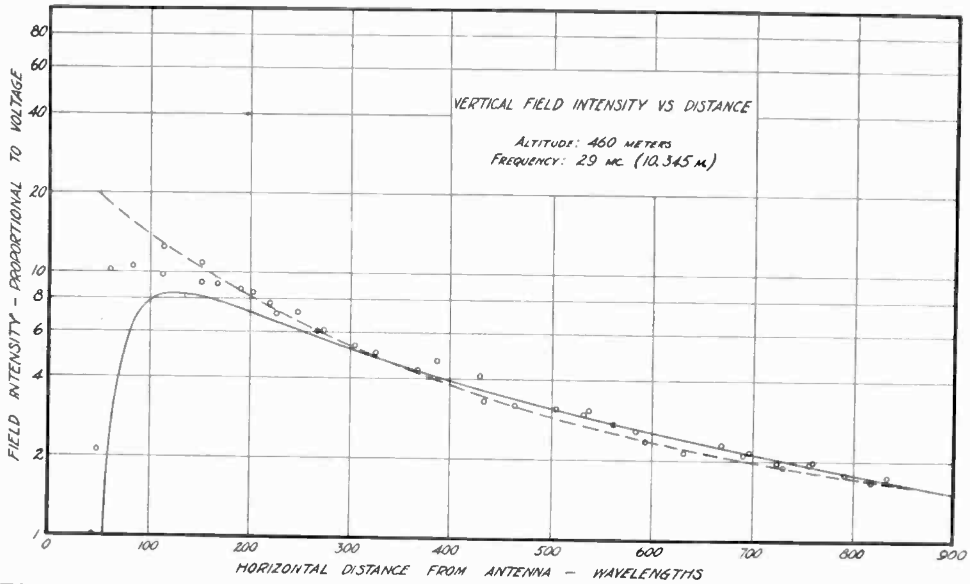

Fig. 8—Theoretical (solid curve: Strutt; dotted curve: Sommerfeld) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 460 meters.

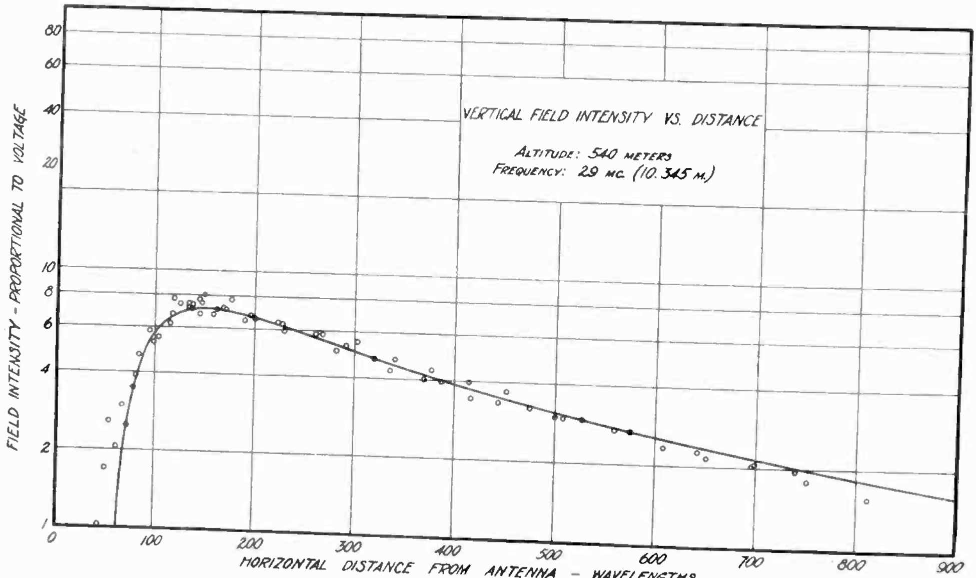

Fig. 9—Theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 540 meters.

by small circles while calculated field intensities are represented by the smooth curves. The solid curve of Fig. 2 and the dotted curves of Figs. 5, 8, and 11 corresponding to altitudes of 1, 180, 460, and 730 meters have been calculated from the Sommerfeld theory. The series expansions on which the computations are based are to be found in the appendix. It will be observed that except in the immediate vicinity

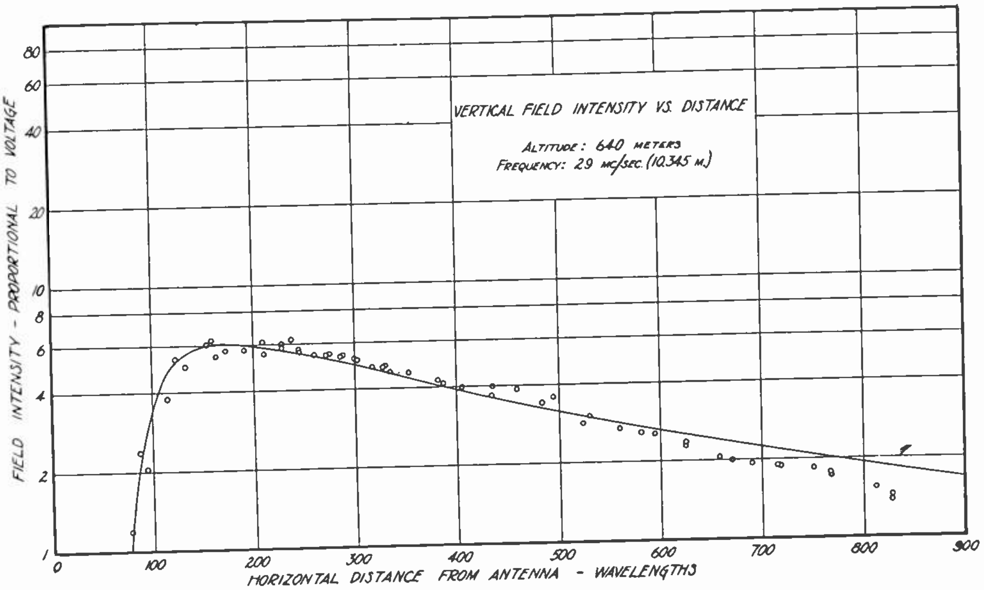

Fig. 10—Theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 640 meters.

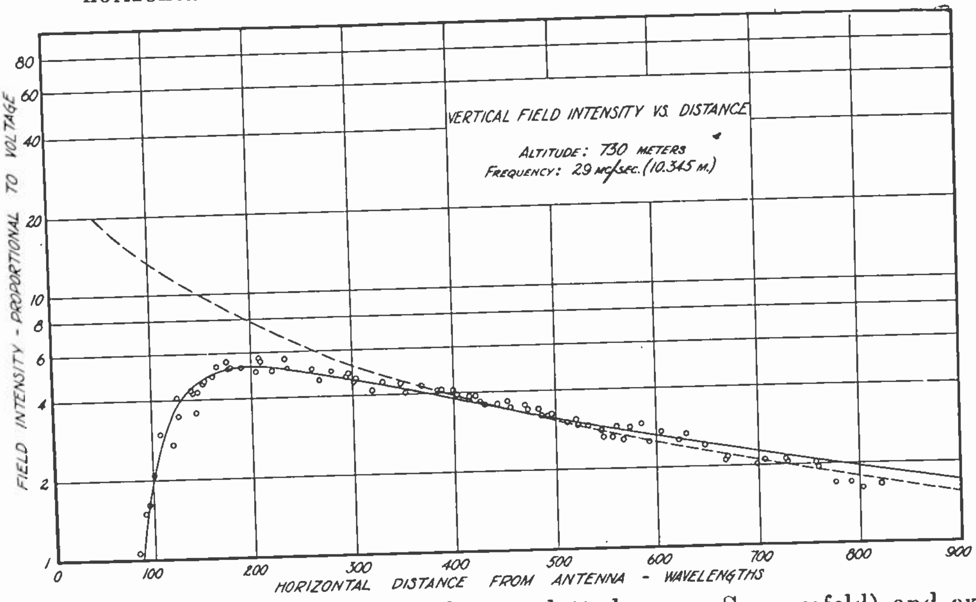

Fig. 11—Theoretical (solid curve: Strutt; dotted curve: Sommerfeld) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 730 meters.

of the antenna the correspondence between measured and calculated values is as close as could be expected. The deviation of the calculated curves from the experimental points at the upper ends is due partly to the nature of the series expansions used for computation and the physical assumptions on which they are based, but also partly to the fact that whereas the lower end of the antenna was actually suspended one-eighth of a wavelength above the ground plane, in the calculations the equivalent dipole was assumed to be located at the ground level. The height of the antenna above ground is of particular importance in determining the nature of the radiation characteristic at high angles, as will be shown in succeeding paragraphs.

The remaining curves appearing in Figs. 3 to 11 have been computed from approximate expressions derived from the Sommerfeld theory by Strutt.[3] It will be observed that in the vicinity of the horizontal ground plane the calculated curves deviate greatly from the actual values, but at higher altitudes the correspondence is exceedingly good. This discrepancy at low angles is to be expected, since the Strutt approximation does not include those terms in r^{-1} which according to the Sommerfeld theory determine the surface wave in the vicinity of the antenna, and consequently is not valid in this region. This is illustrated graphically by the polar plot of Fig. 19, curve II, which shows that according to the Strutt approximation the radiation in the horizontal direction is zero. One concludes that the low angle radiation must be computed from the Sommerfeld series expressions, but at higher angles the field intensities may be obtained most satisfactorily from the approximate formulas. It was for precisely this case that the Strutt expressions were derived.

It will be recalled that the behavior of the radiation field near the surface of the earth depends primarily not on the absolute distance from the antenna but on a quantity ρ which Sommerfeld calls the numerical distance, with

$$\rho \cong \frac{ik_0{}^3 r}{2k_2{}^2}, \quad (|k_2{}^2| >> k_0{}^2)$$

wherein $k_1{}^2$, $k_2{}^2$ are the quantities defined in the appendix of this paper. The measured conductivity of the sea water was 0.41 mhos per centimeter cube (4.64×10^{11} e.s.u. rational) at 18 degrees centigrade. Taking the frequency as 29 megacycles and dielectric constant of sea water as 81 the numerical distance is

$$\rho \cong 0.119r \ (r \text{ in km}).$$

For 9 kilometers the maximum distance at which measurements were made, we have

$$\rho \cong 1.07.$$

[3] M. J. O. Strutt, *Ann. d. Phys.*, vol. 5, p. 721, (1929).

If now one considers a radiation frequency of, say, 1 megacycle ($\lambda = 300$ meters), one finds

$$\rho \cong \frac{\omega^2 r}{2\sigma c} \cong 1.41 \times 10^{-4} r$$

and for the same numerical distance as before, r must be 7600 km. One may expect therefore that in virtue of this "principle of similitude" the data of Figs. 2 to 11 represent the dependency of field on

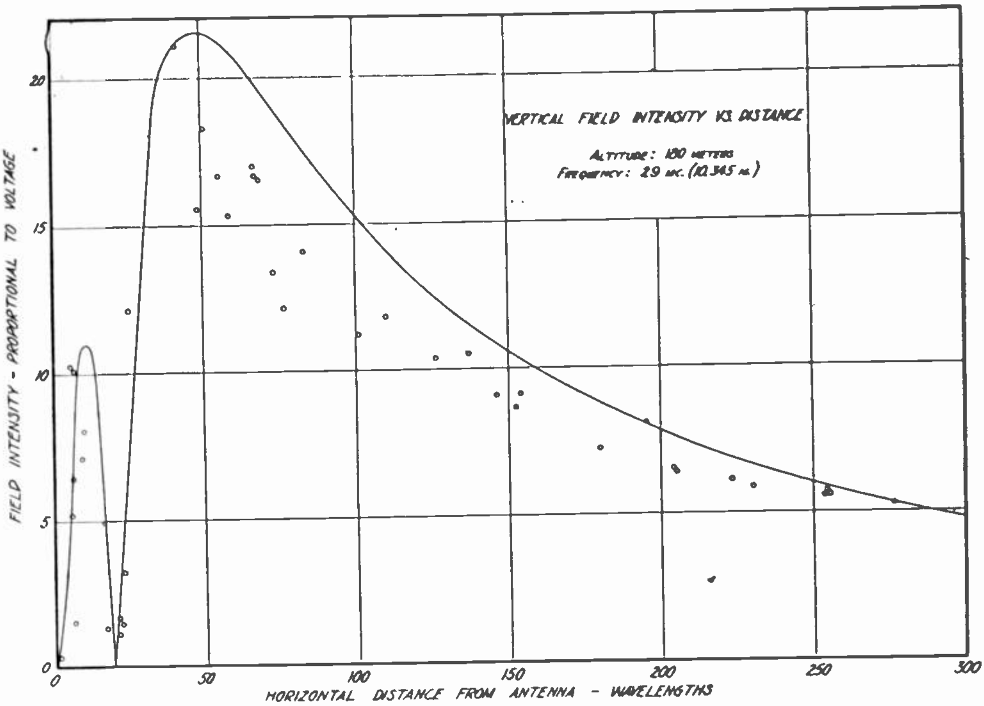

Fig. 12—Detailed theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 180 meters.

distance for other wavelengths, provided the horizontal scale be extended in the manner illustrated by the foregoing example. The remarks apply, of course, only to the direct "ground wave" and take no account of disturbances due to waves reflected from an upper ionized layer.

The nature of the field near the antenna is given in greater detail by the set of curves of Figs. 12 to 17 inclusive. The smooth curves appearing in this set of charts again represent field intensities computed from the Strutt approximation for the case of a dipole located three-eighths of a wavelength above the horizontal plane, this corresponding to the center of the actual antenna. Again it will be observed that at the higher altitudes, specifically in that region 50 or more wavelengths above ground where the surface wave may be neglected, the correspondence is exceedingly good.

A composite figure of all these curves is plotted in Fig. 18. It will

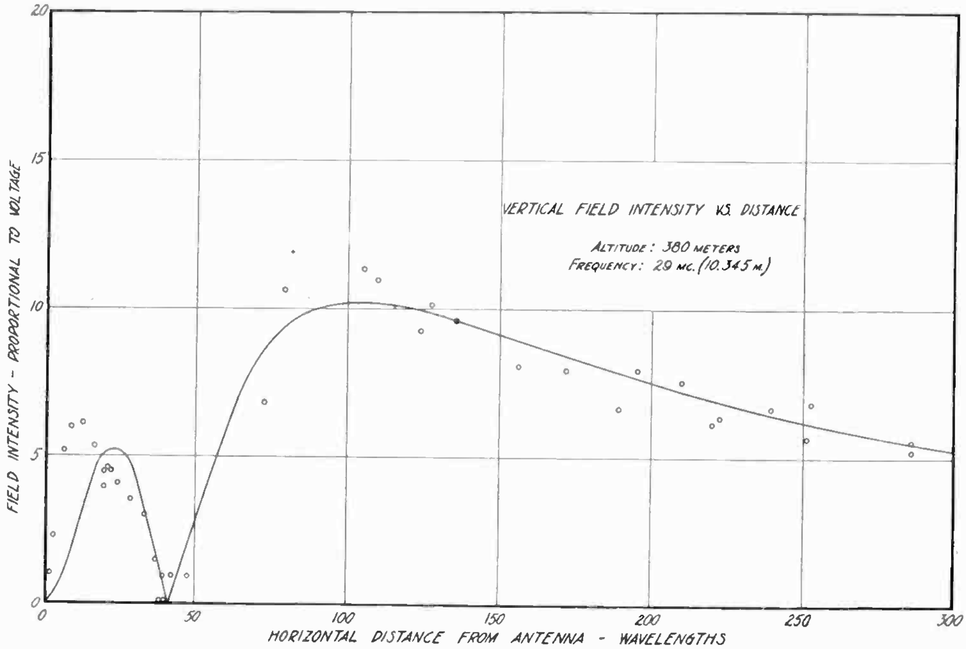

Fig. 13—Detailed theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 380 meters.

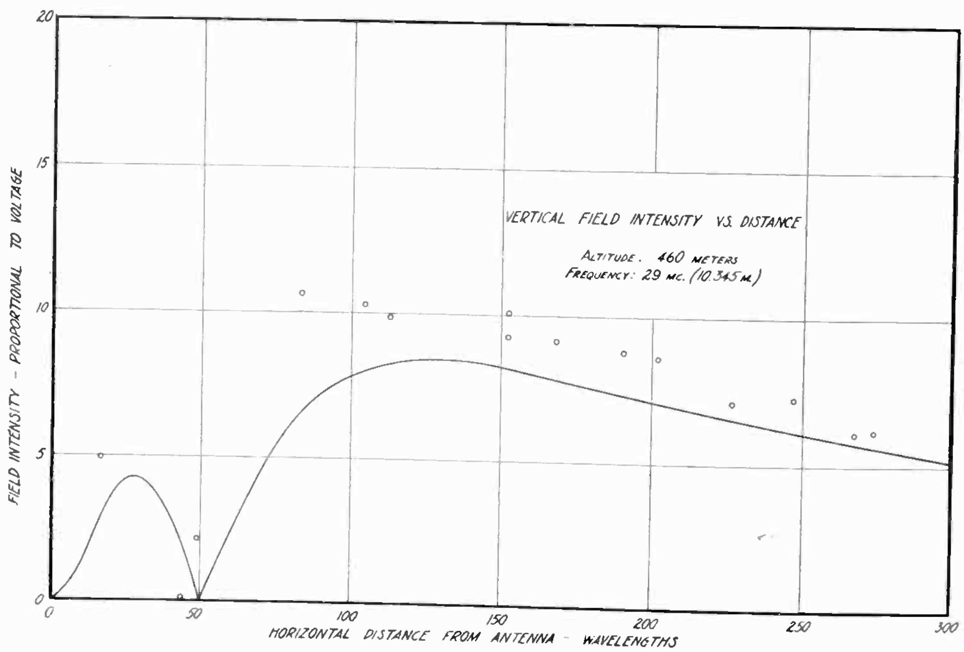

Fig. 14—Detailed theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 460 meters.

be observed that in addition to the expected null point directly over the antenna, there is evidence of a "leaf" in the radiation characteristic. This is made clearer by the polar plots of Fig. 19. The leaf has a

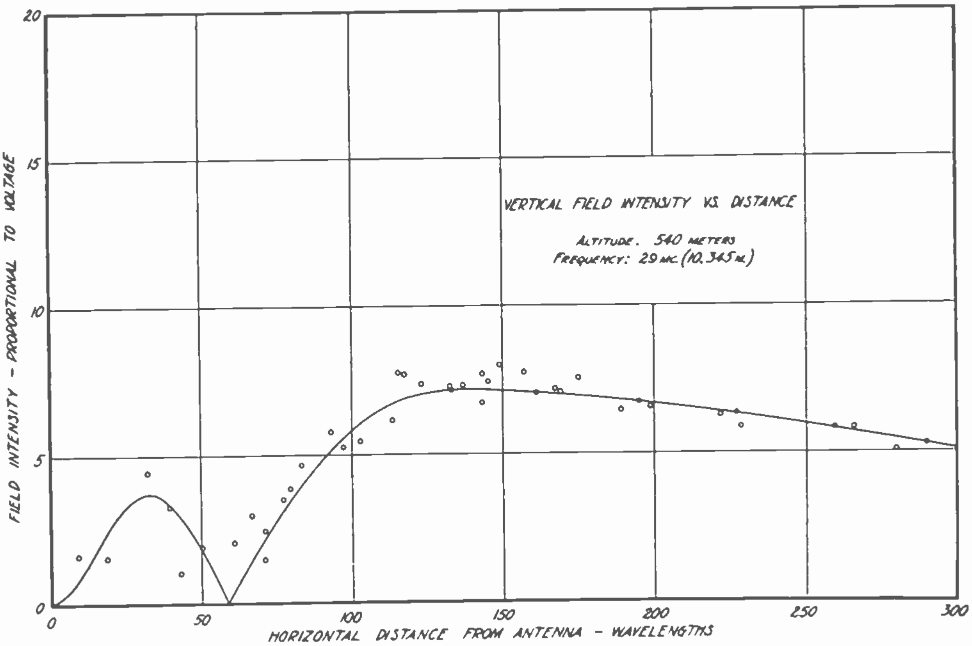

Fig. 15—Detailed theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 540 meters.

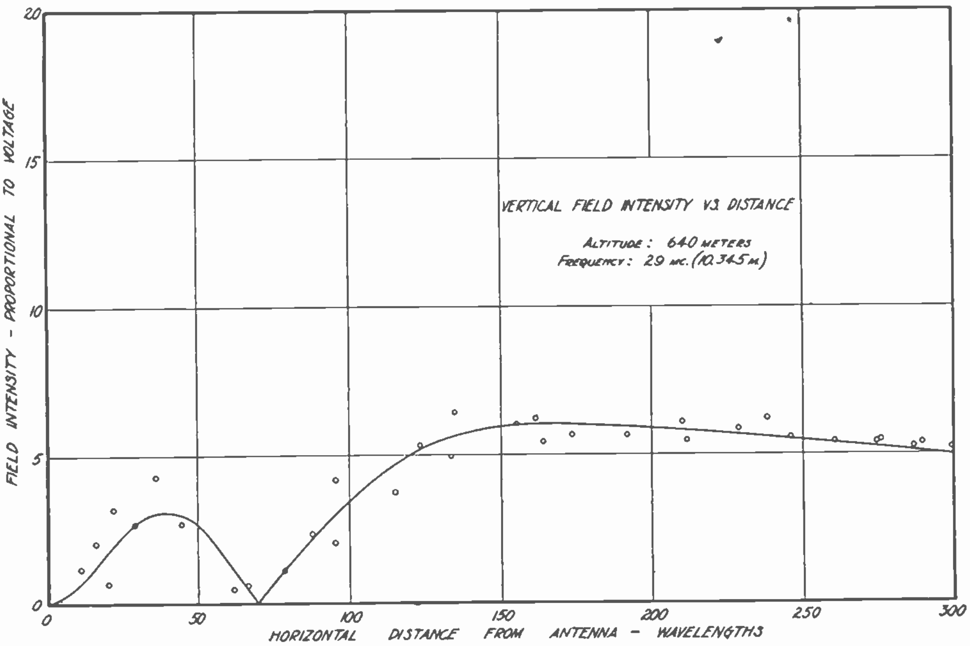

Fig. 16—Detailed theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 640 meters.

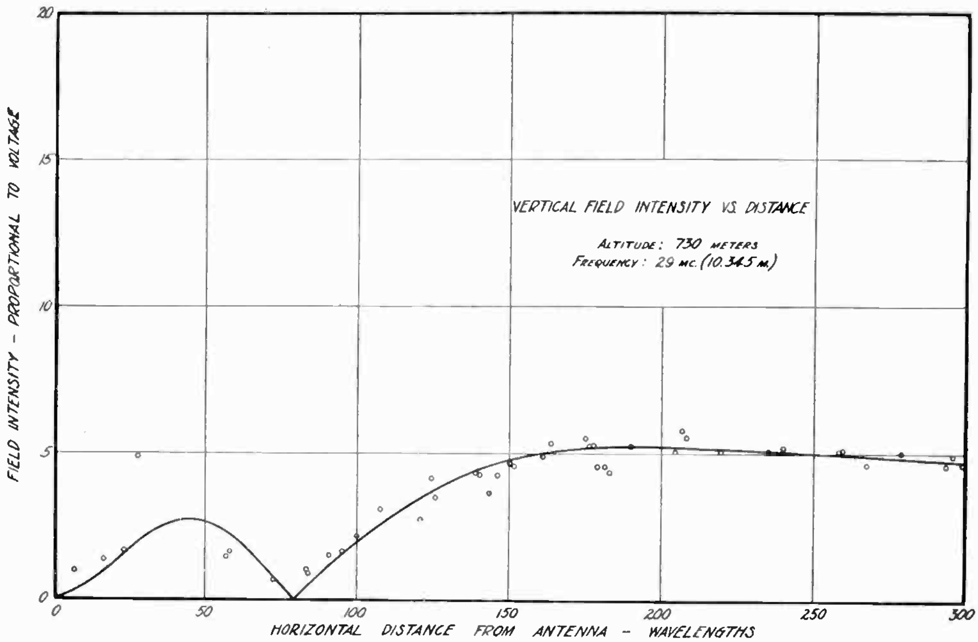

Fig. 17—Detailed theoretical (Strutt) and experimental vertical field intensity vs. horizontal distance from the antenna for altitude of 730 meters.

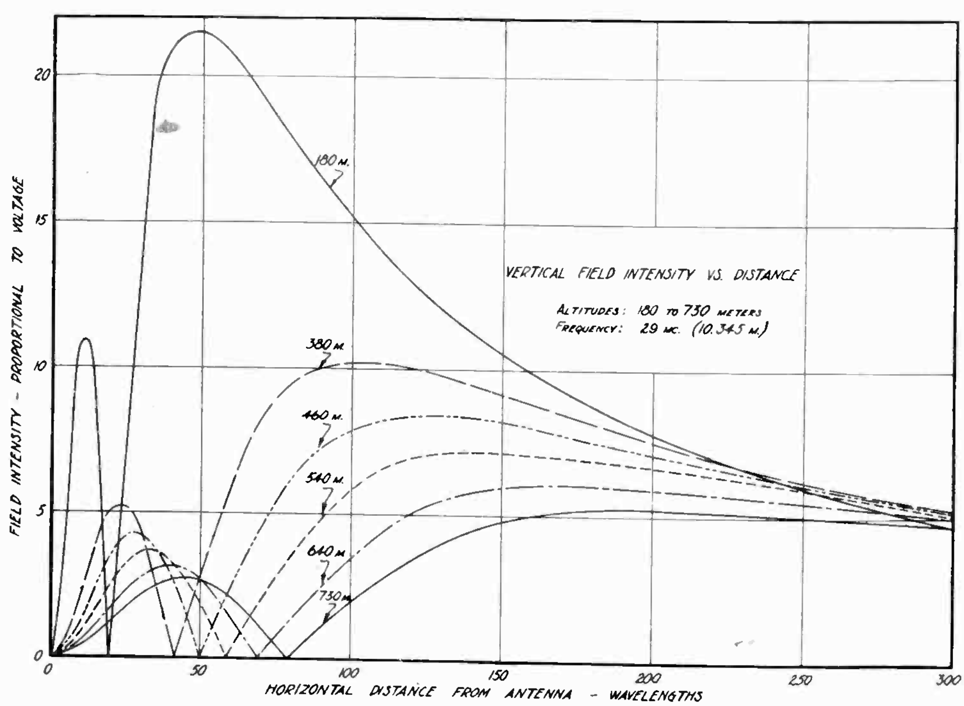

Fig. 18—Composite detailed theoretical (Strutt) vertical field intensity vs. horizontal distance from the antenna, curves for altitudes from 180 to 730 meters.

maximum at an angle of about 65 degrees with the horizontal, and minima occur at 45 degrees and 90 degrees. Unfortunately, the experimental data do not extend to sufficiently high altitudes to permit the completion of the high angle leaf for radial distances greater than 750 meters. The existence of this maximum is to be ascribed principally to the fact that the center of the antenna is located above ground

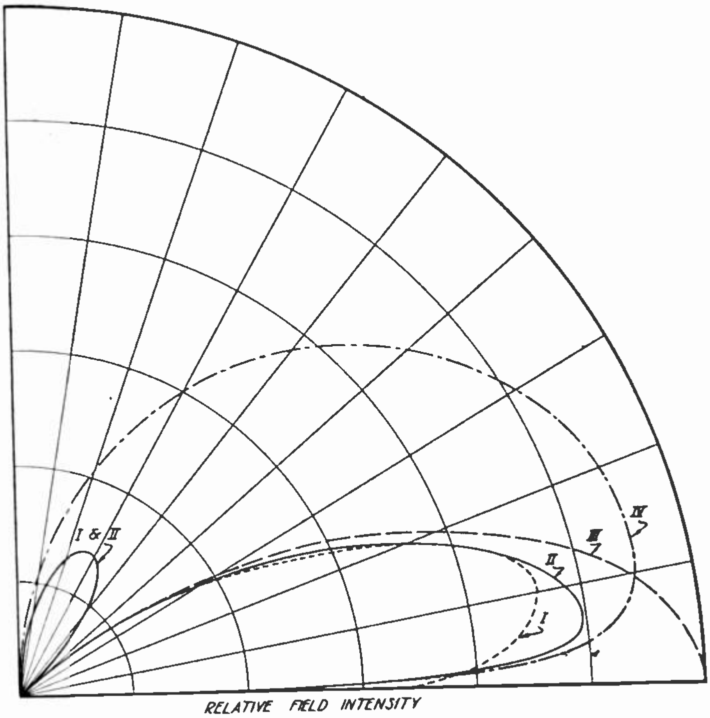

Fig. 19—Theoretical and experimental field intensity characteristics of vertical antenna in the vertical plane.

Field intensity characteristics of vertical antenna.
I—Experimental, $\frac{1}{4}\lambda$ antenna, $\frac{1}{4}\lambda$ above sea water.
II—Theoretical, dipole, $\frac{3}{8}\lambda$ above sea water.
III—Theoretical, dipole, $\frac{3}{8}\lambda$ above perfect earth.
IV—Theoretical, dipole, at surface of sea water.

(three-eighths of a wavelength in this case). Some of the deviation of the computed curve from the observed values in the vicinity of the antenna must be attributed to the finite length of the antenna. The primary importance of the height of the equivalent dipole in determining the radiation pattern is illustrated by the computed curves II and IV of Fig. 19. The height of the dipole gives rise to phase differences between primary and reflected waves and a resulting decrease in effective radiation due to interference.

To show the influence of the finite conductivity of the ground plane curve III, Fig. 19, is computed for the corresponding case of infinite conductivity. The energy dissipated in the ground evidently results in a very rapid attenuation of the field along the surface, but does not appreciably influence the radiation characteristic at high angles.

PART II

Description of the Apparatus

The very special conditions under which the data of the previous section were taken required that the measuring equipment be designed most carefully with respect to ease of adjustment, stability of operation under conditions of severe vibration, and lightness of weight. In the following paragraphs are to be found details of the apparatus used.

Several well-known laboratory methods for measuring field strengths appeared to be ruled out from the start. Substitution methods, wherein the received signal is compared with a known voltage from a local source of the same frequency, were evidently not adapted to the problem in hand on account of the time required for making an observation and the impossibility of designing a local variable voltage source operating at 29 megacycles without violating the restrictions on weight. An attenuation method which reduces the received signal to an arbitrary standard level by means of a calibrated attenuator had to be rejected on account of the time required for operation as well as the difficulty in constructing a suitable attenuating unit. The attenuator might be introduced in the intermediate-frequency amplifier circuit of a superheterodyne receiver, but again weight and time restrictions precluded this possibility.

The measuring device ultimately adopted consisted of a receiver comprising a detector unit with a direct-current galvanometer in the plate circuit preceded by one stage of radio-frequency amplification. The apparatus was calibrated in the laboratory immediately before and after each flight. The calibration was effected by applying to input terminals a variable, known voltage of the same frequency as the antenna excitation and noting the corresponding meter deflections.

The antenna was excited by means of a transmitter consisting of a master oscillator and power amplifier. Two 75-watt tubes in parallel were employed for the oscillator and two 75-watt screen-grid tubes in "push-pull" for the amplifier. The frequency of the oscillator was held constant at 29 megacycles by maintaining zero beat between the transmitted signal and the 290th harmonic of the Round Hill 100-kilocycle standard frequency source. The frequency shift caused by keying amounted to less than 0.002 per cent. The greatest deviation from the nominal value of 29 megacycles throughout the course of the investigation was of the same order of magnitude. The output of the amplifier was led to the antenna through a two-wire feeder system represented in Fig. 1. Equal loading on the amplifier tubes was secured by proper adjustment of the coupling coil and the termination of the feeder of an antenna was determined experimentally such as to eliminate reflections and the resultant standing waves on the line.

The circuit arrangement of the receiver employed in the airship as a field intensity measuring device is shown in Fig. 20. The receiving antenna was a short vertical rod coupled to the grid circuit through a small condenser as indicated. The calibrating voltage applied directly

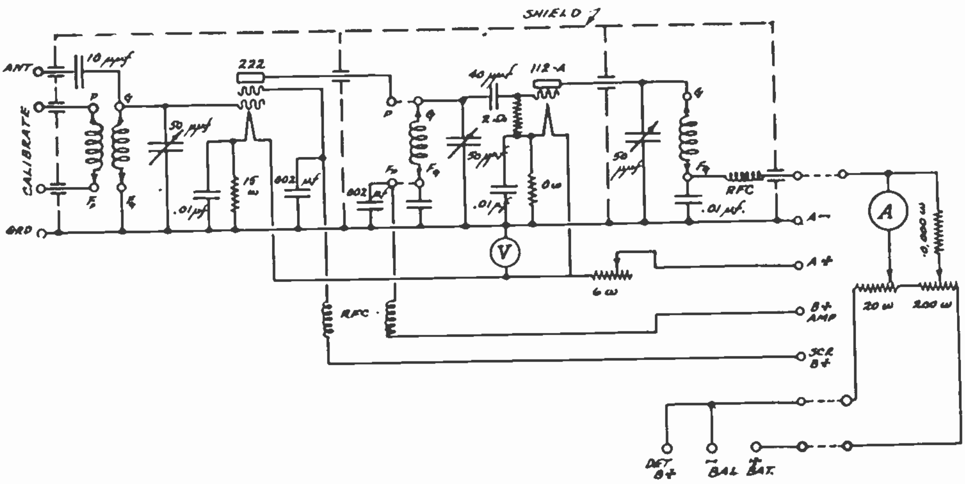

Fig. 20—Wiring diagram of measuring equipment used for determining relative field intensities.

before and after flight was inductively coupled as required by the particular design of the standard signal generator.

In order to obtain sufficient sensitivity grid detection and regeneration by means of the feed-back through plate-grid capacitance of the detector tube were employed. A tuned circuit was introduced into the plate lead of the detector but inductive coupling between this circuit and the grid circuit was reduced to a minimum by isolating the tuned circuit in a shielded compartment. These precautions were found to be necessary if the form of the detector calibration curve was to remain unchanged for varying degrees of regeneration. In operation the regeneration control was held fixed but it was desired that the circuit be of such a nature that small disturbances would not result in any appreciable change in the calibration curve. As long as the plate and grid coils were not in inductive relation it was found that considerable changes in the amount of regeneration resulted only in a parallel displacement of the calibration curve, whereas otherwise the shape itself varied rapidly with the regeneration. The degree of regeneration actually used was small and after an initial warming-up period of an hour or two the calibration could be depended on for hours at a time.

The calibrating voltage for the receiver was obtained from the standard signal generator of Fig. 21. The regeneration is controlled by a variable condenser in the plate circuit, and the grid current passing through the coupling coil contains a rectified direct-current component as well as harmonic components. It has been shown[4] that if the grid-voltage—grid-current characteristic is quadratic there may exist

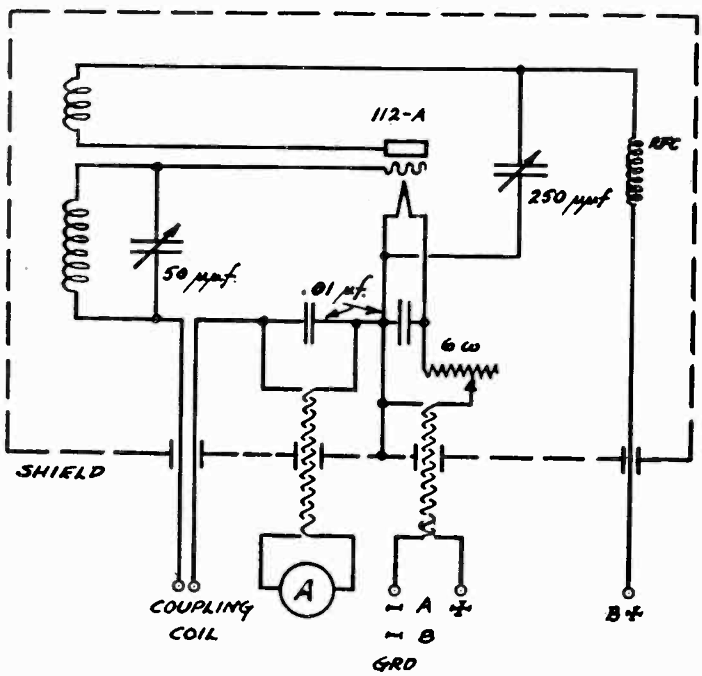

Fig. 21—Wiring diagram of standard signal generator for 29 megacycles.

between second harmonic and rectified components of grid current an almost linear relationship. The rectified current is indicated by the microammeter A, and the second harmonic selected by coupling to a tuned circuit.

In operation a calibration was first obtained with the aid of a vacuum tube voltmeter relating the microammeter reading A to the second harmonic voltage across the coupling coil. A typical calibration curve is illustrated in Fig. 22. Next the generator was coupled to the receiver (the same inductive relationship being maintained between the coils) and the plate meter of the receiver calibrated with respect to the generator grid meter. The advantages of this indirect procedure

[4] W. Van B. Roberts, *Jour. Franklin Inst.*, vol. 20, p. 301, (1926).

are the following. The signal generator operates at 14.5 megacycles rather than at a fundamental of 29 megacycles, with resulting greater ease of construction and stable operation. Second, the necessity of a balancing-out circuit for the grid meter is obviated, thus lessening the time required for measurement. Finally, the sensitivity of a simple type vacuum tube voltmeter is not sufficient to calibrate the receiver over the entire range of radio-frequency voltages to be dealt with. Indica-

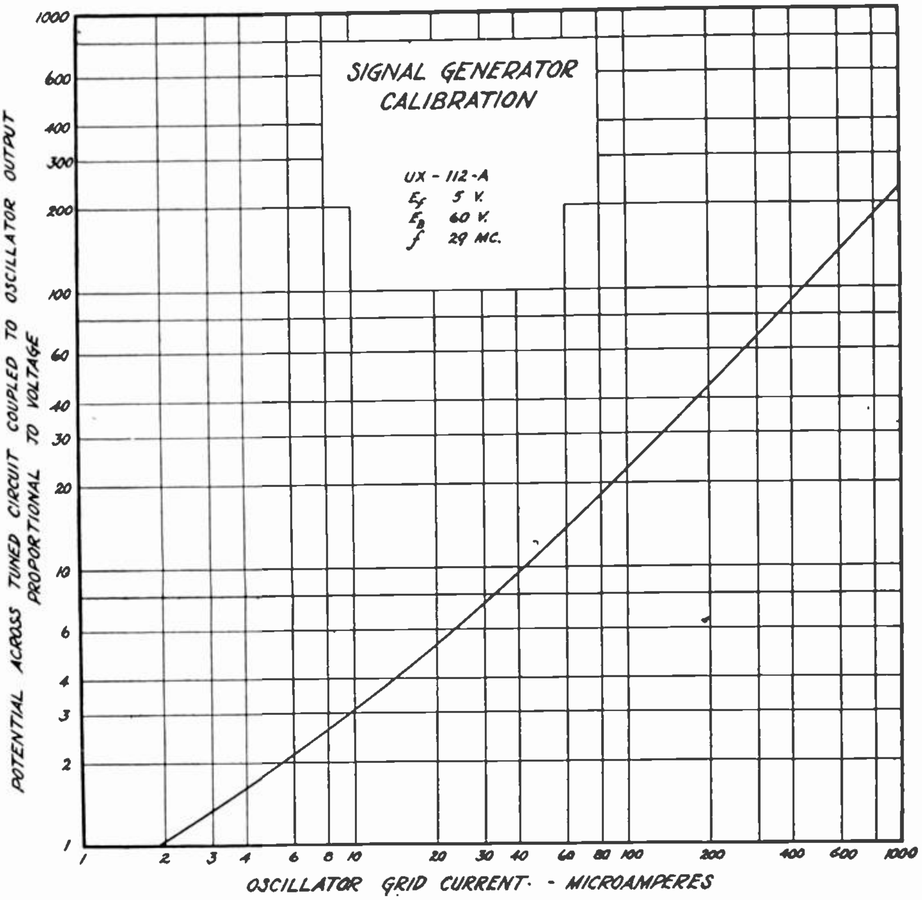

Fig. 22—Typical signal generator calibration curve.

tions corresponding to these very small voltages could easily be observed on the grid-current meter of the generator and the calibration curve extrapolated in virtue of its linearity.

The magnitude of the generated voltage was controlled by the amount of feed-back. A change in regeneration, however, resulted in a change in the fundamental frequency of the oscillator. Rather than elaborate the design of the oscillator it was found simpler to maintain the frequency constant by beating after each change of regeneration with the 145th harmonic of a 100-kilocycle standard frequency source. The power source energizing the antenna was "monitored" against this same frequency standard. The vacuum tube voltmeter circuit is illustrated in Fig. 23. A calibration of the voltmeter was obtained by applying a small voltage of 1000 cycles per second frequency directly to the grid of the tube. Calibration curves were also made at 10 and 100 kilocycles, and as they did not vary in shape it was assumed that the calibration was practically independent of frequency even at very much higher frequencies. No change in the calibration curve was apparent over a period of several months. The ratio of maximum to minimum voltage was well over 100 to 1.

The exact location of the airship at the instant of each observation was determined by triangulation from the terminals of a base line

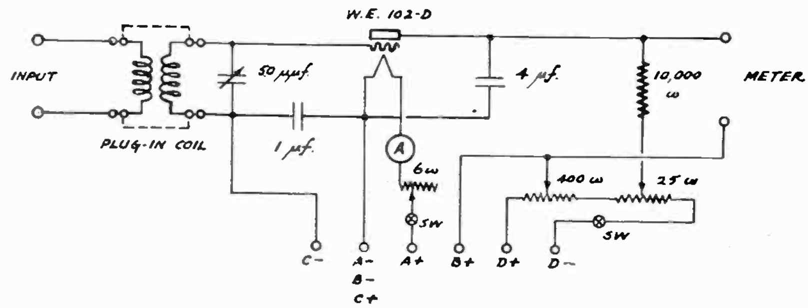

Fig. 23—Wiring diagram of vacuum tube voltmeter used for the calibration of the standard signal generator.

running at right angles to the usual line of flight. The transit observers were equipped with receivers and the instant at which observations were to be made was indicated through a signal from a small transmitter in the airship. With the equipment described it was possible to make observations at 30- to 45-second intervals.

Appendix

For the convenience of the reader the theoretical expressions serving as the basis of the computed field intensities and referred to in the footnotes of the preceding paper are assembled together.

The expression for the Hertzian vector of a field about a vertical dipole located at the surface of the earth is, according to Sommerfeld:

$$\Pi_0 = \int_0^\infty \frac{2k^2}{N} J_0(\lambda r) e^{-\sqrt{\lambda^2 - k_0^2}\, z} \lambda d\lambda$$

where,

Π_0 = the wave potential or Hertzian vector

$N = k^2\sqrt{\lambda^2 - k_0^2} + k_0^2\sqrt{\lambda^2 - k^2}$

$k^2 = (\epsilon\omega^2 + i\sigma\omega)/c^2$

$k_0^2 = \omega^2/c^2$

ϵ = dielectric constant of the medium forming the ground plane (rational electrostatic units)

σ = conductivity of this medium (rational electrostatic units)

$\omega = 2\pi f$

f = frequency in cycles per second

c = velocity of light $\cong 3 \times 10^{10}$ (cms/sec.)

J_0 = zero order Bessel function

z = altitude of the point in question above the ground plane, (cm)

r = horizontal distance to this point (cm)

$i = \sqrt{-1}$

e = Naperian base, 2.718 . . .

λ = variable of integration

Sommerfeld has evaluated this integral approximately for the case where $k^2 \gg k_0^2$ and when the angle made by the radius vector from the dipole to the point of observation with the horizontal is small. If the numerical distance $\rho \cong \dfrac{ik_0^3\, r}{2\, k^2}$ is small, we have

$$\Pi_0 = \frac{2e^{ik_0R}}{R}[1 - 2\sqrt{\rho}\, W - i\sqrt{\rho\pi}e^{-w^2}]$$

where,

$$R = \text{radius vector}$$

and,

$$W = e^{-w^2}\int_0^w e^{u^2} du$$

and,

$$w^2 = ik_0 \frac{(k_0r + kz)^2}{2rk^2}$$

An expansion of the integral valid for small values of w may be obtained

$$W = w\left(1 - \frac{2}{3}w^2 + \frac{2\cdot 2}{3\cdot 5}w^4 - \frac{2\cdot 2\cdot 2}{3\cdot 5\cdot 7}w^6 + \cdots \frac{(-1)^n 2^{2n} n!}{(2n+1)!}w^{2n} + \cdots\right)$$

from which one may calculate Π_0. In the case of the physical conditions considered in this paper, the expression for w reduces to

$$w = \omega\sqrt{\frac{r}{2\sigma c}} + z\sqrt{\frac{\omega}{4rc}}(1 + i)$$

For the case where w is a real number, that is, along the surface of the earth, calculation of Π_0 for various frequencies, various distances and different ground media is most readily accomplished by first plotting a curve of W against w.

From the Hertzian vector Π_0 may be computed the electric and magnetic field intensities through the relations

$$E_0 = k_0^2\Pi_0 + \nabla(\nabla \cdot \Pi_0)$$

$$H_0 = -\frac{ic}{\omega} k_0^2 \nabla \times \Pi_0.$$

It can readily be shown that except in the immediate vicinity of the antenna the electric vector behaves in the same manner as the Hertzian vector, and the plots made of intensities computed from the Sommerfeld expansion are in fact plots of Π_0 multiplied by suitable amplitude factor.

It will be noted that the condition $k^2 \gg k_0^2$ is satisfied even at the high frequency of 29 megacycles on account of the great conductivity of sea water. The same assumption would in general not be valied in the case of similar waves propagated over dry soil.

At even small altitudes the quantity w becomes large because of the presence of the term in z and the series converges so slowly as to be useless for practical calculations. For this case a series in inverse powers of w proved of value, namely:

$$W = \frac{1}{2w}\left[1 + \frac{1}{2w^2} + \frac{1 \cdot 3}{2 \cdot 2w^4} + \frac{1 \cdot 3 \cdot 5}{2 \cdot 2 \cdot 2w^6} + \cdots \frac{(2n-1)!}{2^{2n-1}(n-1)!\,w^{2n}} + \cdots\right].$$

The field intensity curves computed from Strutt's theory are carried in close to the antenna and consequently it is necessary to use the expression for the electric vector itself rather than simply the Hertzian vector. The resultant electric field intensity E is a vector perpendicular to the radius vector R and has the value

$$E = ik_0 \sin\theta\, \Pi_0 e^{i\omega t}$$

where θ is the angle made by the radius vector R with the vertical. The measured values of field intensity corresponded, however, to the *vertical* component of E, or

$$E_z = ik_0 \sin^2\theta\, \Pi_0 e^{i\omega t}.$$

For the approximate value of Π_0 Strutt obtains

$$\Pi_0 = \frac{e^{-ik_0R}}{R}\left[e^{i\delta\cos\theta} + fe^{-i\delta\cos\theta}\right]$$

where $\delta = \frac{2\pi d}{\lambda}$, d being the height of the dipole above the ground plane and λ the wavelength. If the complex index of refraction be

$$n^2 = \epsilon - i\sigma\lambda,$$

$$f = \frac{n^2 \cos\theta - \sqrt{n^2 - 1 + \cos^2\theta}}{n^2 \cos\theta + \sqrt{n^2 - 1 + \cos^2\theta}}.$$

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

A NOTE ON AN AUTOMATIC FIELD STRENGTH AND STATIC RECORDER*

By

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Summary—*A device for making a continuous record of the energy received from a signal or from static is described. Simple modifications are suggested by means of which peak or average voltage may be recorded.*

Many types of instruments have been used to record field intensities, both of signals and static, and the varying requirements have produced many widely different pieces of apparatus. One may desire to study the changes taking place over a period as short as one millisecond, or as long as an eleven-year sun-spot period. Obviously the same instrument would not do for both studies. The

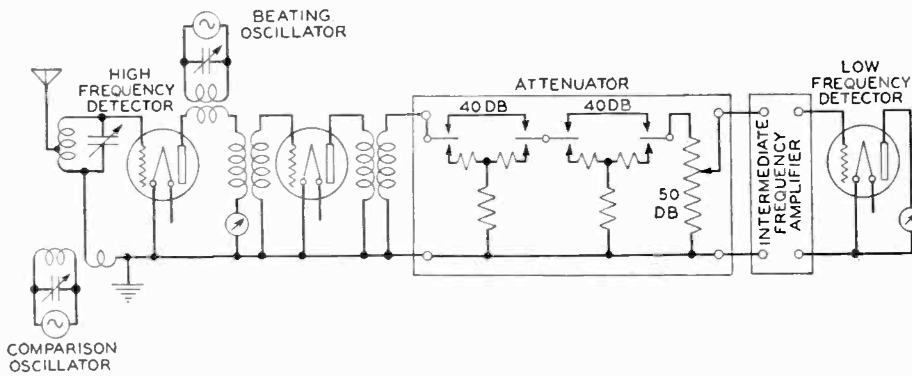

Fig. 1—Schematic diagram of field strength measuring set.

development work on the recorder described here was started some years ago with the aim of producing an instrument capable of recording the energy received from a fading signal during periods of the order of ten seconds.

The method of measuring fields in use when the present work was started has been fully described in an earlier paper.[1] The measurements were made manually using a short wave measuring set of the double detection type, which covered the frequency range from 1 to 30 megacycles. A schematic diagram of the set is shown in Fig. 1. The

* Decimal classification: R270. Original manuscript received by the Institute, May 19, 1932. Presented before U.R.S.I., Washington, D.C., April 29, 1932.

[1] H. T. Friis and E. Bruce, "A radio field strength measuring system," Proc. I.R.E., vol. 14, p. 507; August, (1926).

method of making a measurement is briefly as follows: The set is tuned to the signal to be measured and the attenuator is set to secure a convenient deflection on the low-frequency detector plate current meter. Then the comparison oscillator is turned on and adjusted to the frequency of the signal being measured. The output of the comparison oscillator is adjusted so that the high-frequency detector acting as a tube voltmeter (beating oscillator turned off) shows one volt on its grid and the attenuator (beating oscillator on) is adjusted to give the same output previously obtained from the signal. The attenuator readings and the antenna constants (obtained by comparison with a loop antenna) are sufficient data from which to compute the field strength. The position of the attenuator, early in the intermediate frequency amplifier, prevents overloading of any part of the set at high signal levels and allows a very precise calibration which does not vary with the frequency of the signal. The attenuator contains two 40-db pads and one 0 to 50-db potentiometer. Measurements can be made with an accuracy of plus or minus one-half db on a steady signal. Measured values made manually with this or any other receiver are of necessity but momentary samples, and cannot be made rapidly over long periods. Even a trained observer has difficulty in making significant measurements on a fading signal.

In designing a recorder two schemes of operation are possible. First, the gain of the receiver may be left constant and the variations of the output recorded; or second, the output may be held constant and the resulting changes of gain recorded. Since the operating range of an ordinary receiving vacuum tube is so small compared with the range of variations of field strengths, the choice is necessarily of the constant output system. In the present case the output is not held strictly constant. The gain is changed at short intervals in such a way as to hold the average output constant.

A commercial recorder controller[2] is used to operate the gain control of the measuring set and to record the changes in gain with time. This recorder controller is an instrument containing a sensitive moving coil galvanometer which is actuated by current from some external circuit, in the present case, from the output circuit of the measuring set. A set of jaws closes every two seconds across the arc of swing of the galvanometer needle. The position of the needle when clamped by the jaws determines the amount and direction of rotation to be given to a shaft which is coupled to a control mechanism, in this case, the at-

[2] A detailed description of the mechanism of the Leeds and Northrup recorder used in this work is given by M. F. Béhar, "Industrial temperature instruments," *Instruments*, vol. 3, p. 387; June, (1930).

tenuator potentiometer of the measuring set. The power to operate all of the mechanisms is derived from a small electric motor. This motor also moves a roll of paper continuously at a rate of six inches per hour under a pen which is attached to the shaft controlling the attenuator potentiometer.

The first attempt at combining the recorder with the measuring set was made by running the rectified output current of the receiver together with a constant balancing current through the galvanometer directly (see Fig. 2). Assuming that a steady signal of 1 volt is impressed on the grid of the low-frequency detector and that the battery B is removed, there will be a definite current flowing through the galvanometer in the plate circuit. The voltage of the battery B is adjusted to a value such that the current through the galvanometer is balanced

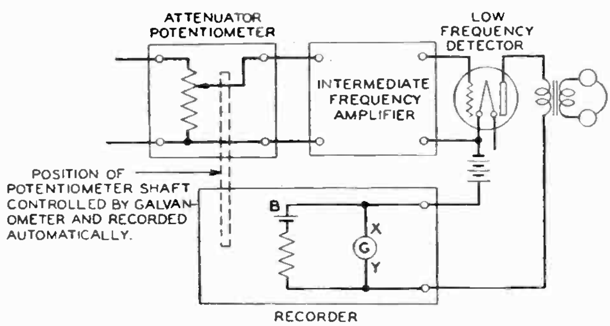

Fig. 2

out. If now the signal voltage is increased, current flows through the galvanometer in the direction X to Y. The recorder mechanism is thus caused to operate, and the shaft of the attenuator potentiometer is rotated in such a way as to decrease the gain of the set. If the signal falls below 1 volt the current in the galvanometer is reversed, and the gain of the set is increased. As was stated before, this adjustment of gain takes place every 2 seconds. The system is so designed that the change in gain is equal to the change in the average signal level, with the limitation that the maximum correction possible at any one time is 3 db. It was found necessary to use a time constant circuit to smooth out the fades. This time constant circuit is made up of a series resistance between the detector plate and the galvanometer, and a large condenser between the plate and filament.

This scheme was not entirely satisfactory, because, first, the time constant circuit made it doubtful just what the results meant, and second, since the recorder changed the gain and plotted a point every 2 seconds, the record line became very broad.

A scheme of recording effective voltages which records the energy[3] received during periods of 9 seconds duration was finaly adopted. It is explained by means of the schematic diagram shown in Fig. 3. An intermediate frequency voltage $e=f(t)$ is impressed on the input of a detector. Assuming that the detector is a square-law device, the current

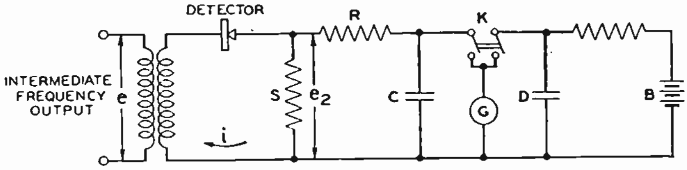

Fig. 3—Schematic diagram of general recorder circuit.

flowing in the detector output circuit will be proportional to the square of the voltage e.

$$i = ke^2 = k[f(t)]^2.$$

The voltage e_2 across S will then be proportional to $[f(t)]^2$.

Circuit theory gives the equation:

$$Ri + \frac{1}{C}\int i\,dt = e_2 = [f(t)]^2.$$

Substituting dq/dt for i:

$$R\frac{dq}{dt} + \frac{q}{C} = [f(t)]^2.$$

Solving for q:

$$q = \frac{1}{R}\epsilon^{-t/RC}\int \epsilon^{t/RC}[f(t)]^2 dt + c\epsilon^{-t/RC}$$

which written in another form is:

$$q_T = Q = \frac{1}{R}\epsilon^{-T/RC}\int_{t_0}^{T} \epsilon^{t/RC}[f(t)]^2 dt + q_0\epsilon^{-(T-t_0)/RC}$$

in terms of the initial conditions. For our case $q_0=0$ when $t_0=0$, and we have:

$$Q = \frac{1}{R}\epsilon^{-T/RC}\int_{0}^{T} \epsilon^{t/RC}[f(t)]^2 dt.$$

We have chosen values for R, C, and T such that t is always small as compared with RC. $\epsilon^{t/RC}$ is then substantially constant, and we have:

[3] An energy type of recorder employing a fluxmeter has been described in a paper by H. T. Friis, *Bell Sys. Tech. Jour.*, vol. 5, p. 282, April, (1926).

$$Q = \frac{1}{R}\int_0^T [f(t)]^2 dt.$$

The charge Q is thus proportional to the integral of the signal voltage squared, or to the energy received from the signal during the period T. It may also be noted that the charge is inversely proportional to R and independent of C. The value of R should be small enough to permit Q to be sufficiently large, and it must be large enough to make the time constant large as compared with T. A value of 300,000 ohms was chosen for R, and 30 seconds was selected as the minimum time constant. C was then 100 microfarads. The time T had previously been set at 9 seconds so that several fading periods might be included in one recorder cycle.

The operation, during one recorder cycle, of the circuit shown in Fig. 3 is then as follows: From $t=0$ to $t=9$ seconds, the condenser C accumulates a charge proportional to the energy in the signal. During the same time the condenser D receives a charge at a steady rate from the battery B. The rate of charging D is such that at the end of 9 seconds its charge is equal to the charge that C would receive from a steady signal of 1 volt on the detector input, but of the opposite polarity. At $t=9$ seconds the condensers C and D are discharged through the galvanometer by the closing of the keys K. These keys are operated by a cam driven through gears by the recorder motor, and their closing is timed so that the jaws of the recorder mechanism close on the galvanometer needle just as it reaches the maximum point of its swing. From $t=9$ to $t=10$ seconds the recorder mechanism corrects and records the gain of the receiver according to the galvanometer deflection. At $t=10$ seconds the condensers are fully discharged, the keys are opened, and another 10-second cycle starts. If the effective signal voltage at the detector input during any 9-second period is greater than 1 volt, the charge on C will not be entirely balanced out by the charge on D and current will flow through the galvanometer. If the signal averages less than 1 volt the current will flow in the opposite direction. The gain corrections during the tenth second of each cycle are made equal to the change in signal level and in a direction to return the receiver output to one volt.

The circuit shown in Fig. 3 may be simplified as shown in Fig. 4 which is the circuit finally used. Here the condenser D and its charging resistance are omitted, and the biasing voltage is supplied across the resistance S. Several recorders employing this circuit have for some time been used with very satisfactory results to record either signals or static. Sample records of short wave signal intensities made with one of these recorders are shown in a paper recently published by Potter and Friis.[4]

The circuit shown in Fig. 3 employs a square law detector and indicates the energy received from the signal. If the resistance S is made

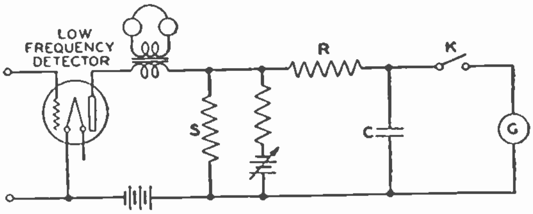

Fig. 4—Final recorder circuit.

large, the detector becomes linear and the recorder then shows the average voltages received. If the resistance S is omitted and R made zero, the system then records peak voltages.

This work was carried out at the Holmdel Station of the Bell Telephone Laboratories under the direction of Mr. H. T. Friis.

[4] R. K. Potter and H. T. Friis, "Some effects of topography and ground on short-wave reception," Proc. I.R.E., vol. 20, p. 699–721; April, (1932).

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

DIRECTIONAL STUDIES OF ATMOSPHERICS AT HIGH FREQUENCIES*

By

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Summary—*A system for recording the direction of arrival and intensity of static on short waves is described. The system consists of a rotating directional antenna array, a double detection receiver and an energy operated automatic recorder. The operation of the system is such that the output of the receiver is kept constant regardless of the intensity of the static.*

Data obtained with this system show the presence of three separate groups of static: Group 1, static from local thunderstorms; Group 2, static from distant thunderstorms, and Group 3, a steady hiss type static of unknown origin.

Curves are given showing the direction of arrival and intensity of static of the first group plotted against time of day and for several different thunderstorms.

Static of the second group was found to correspond to that on long waves in the direction of arrival and is heard only when the long wave static is very strong. The static of this group comes most of the time from directions lying between southeast and southwest as does the long wave static.

Curves are given showing the direction of arrival of static of group three plotted against time of day. The direction varies gradually throughout the day going almost completely around the compass in 24 hours. The evidence indicates that the source of this static is somehow associated with the sun.

Introduction

FOR some time various investigators have made records of one type or another of the direction of arrival of static on the long wavelengths. Watson Watt has made a comprehensive study of the direction of arrival of static in England. Others working under him have used apparatus similar to his in Australia and Africa. Captain Bureau has done considerable work on the study of static in France. In this country, L. W. Austin with E. B. Judson working with him has worked on the long-wave static problem. Harper and Dean, also of this country, have made a study of the direction of arrival of long-wave static in Maine. Very little work, however, has been done on the direction of arrival of short and very short-wave static with the exception of the series of observations made by Mr. Potter as described in his paper on short-wave noise.[1]

* Decimal classification: R114. Original manuscript received by the Institute, May 26, 1932. Presented at the meeting of the American Section of the U.R.S.I. at Washington, D. C., April 29, 1932.

[1] R. K. Potter, "High-frequency atmospheric noise," Proc. I.R.E., vol. 19, p. 1731; October, (1931).

Description of Apparatus

Since the middle of August, 1931, records have been taken at Holmdel, N. J., of the direction of arrival and the intensity of static on 14.6 meters. Fig. 1 shows a schematic diagram of the recording system. It consists of a rotating antenna array, a short-wave measuring set, and a Leeds and Northrup temperature recorder revamped to record field strengths.[2]

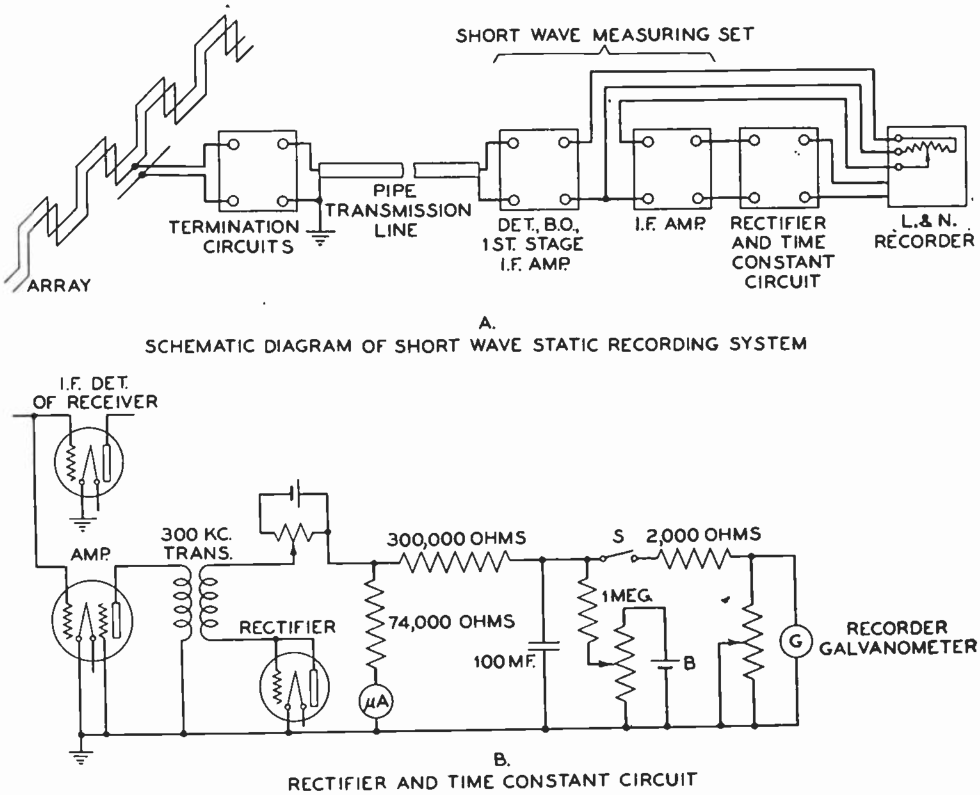

Fig. 1

The rotating antenna, a photograph of which is shown in Fig. 2, is a Bruce type broadside receiving array[3] two wavelengths long made of 3/4-inch brass pipe. The array was designed to operate on a wavelength of 14.5 meters. As shown in the photograph it is mounted on a wooden framework which in turn is mounted on a set of four wheels and a central pivot. The structure is connected by a chain drive to a small synchronous motor geared down so that the array makes a complete rotation once every twenty minutes.

[2] A detailed description of the measuring set and recorder is given in a paper by W. W. Mutch, Proceedings, this issue, pp. 1914–1919.

[3] A. A. Oswald, "Transoceanic telephone service, short wave equipment," *Jour. A.I.E.E.*, vol. 49, p. 267; April, (1930).

Since static on short waves is extremely weak most of the time, the recording system had to be made very sensitive; so sensitive in fact that the first circuit noise of the receiver is recorded.[4] On account of interference which was found on 14.5 meters, it was necessary to operate the system on a wavelength of 14.6 meters. This, however, made

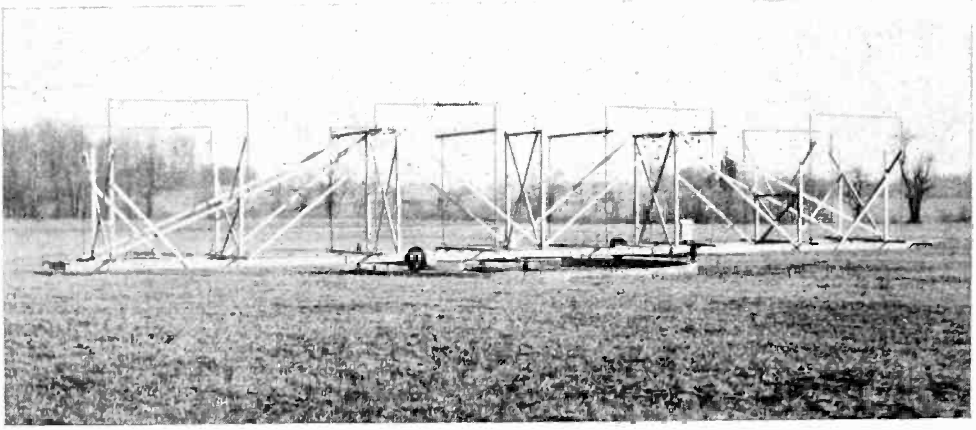

Fig. 2—Short-wave rotating antenna array.

little difference in the directivity of the array, the directional characteristic of which at this wavelength is shown in Fig. 3.

The array termination equipment is housed in a box mounted on the array and is connected to the measuring set in a small house about 275 feet away by means of a 3/8-inch copper concentric pipe transmis-

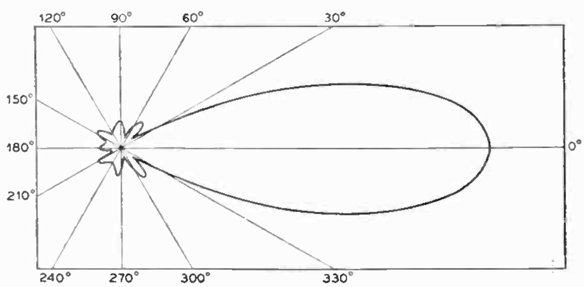

Fig. 3—Directional characteristic of array at 14.6 meters.

sion line buried about 6 inches in the ground. Fig. 4 is a schematic diagram of the array, the termination equipment and the copper pipe transmission line.

Fig. 5 is a photograph of the inside of the house, showing two receivers with their associated recorders. The apparatus on the right

[4] F. B. Llewellyn, "A study of noise in vacuum tubes and attached circuits," PROC. I.R.E., vol. 18, p. 243; February, (1930).

the short-wave recording system. That on the left is a long-wave recording system, the records of which were used to compare with those

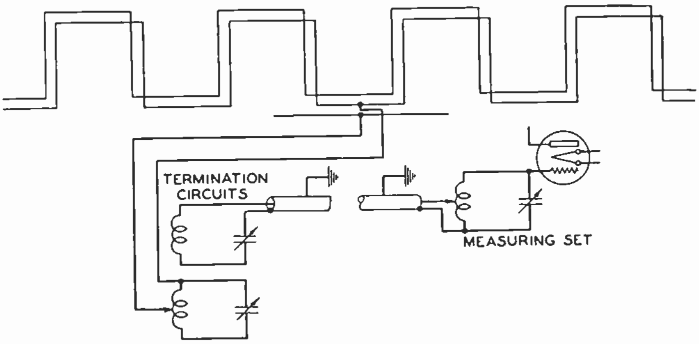

Fig. 4—Schematic diagram of array, termination, and pipe transmission line.

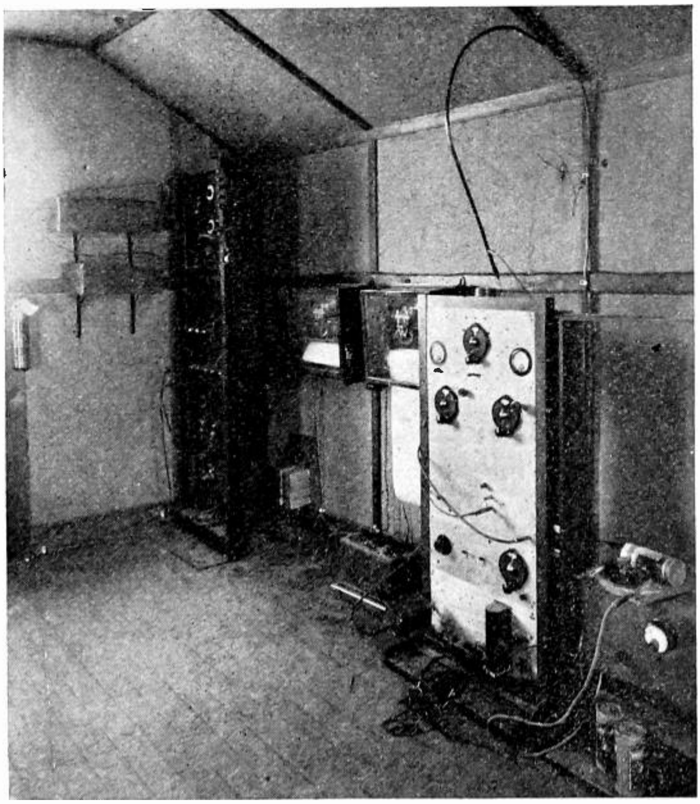

Fig. 5—Long- and short-wave static recording systems.

of the short-wave system. The long-wave antenna system consists of a rotating loop and an *L* type stationary antenna giving the familiar cardioid-shaped directional characteristic.

The receiver used is a short-wave field strength measuring set of the double detection type which was described some time ago.[5]

The output of this receiver is connected through a circuit with a long time constant to the Leeds and Northrup recorder the operation of which is discontinuous.[2] It automatically changes the gain of the receiver at the end of 10-second intervals in such a way that the output of the receiver is kept constant. The gain is changed by means of a noninductive potentiometer inserted in the intermediate frequency amplifier. This potentiometer replaces the slide wire found on the standard temperature recorders. The pen makes a continuous record of the position of the potentiometer arm and this record can be calibrated to give the field strength directly.

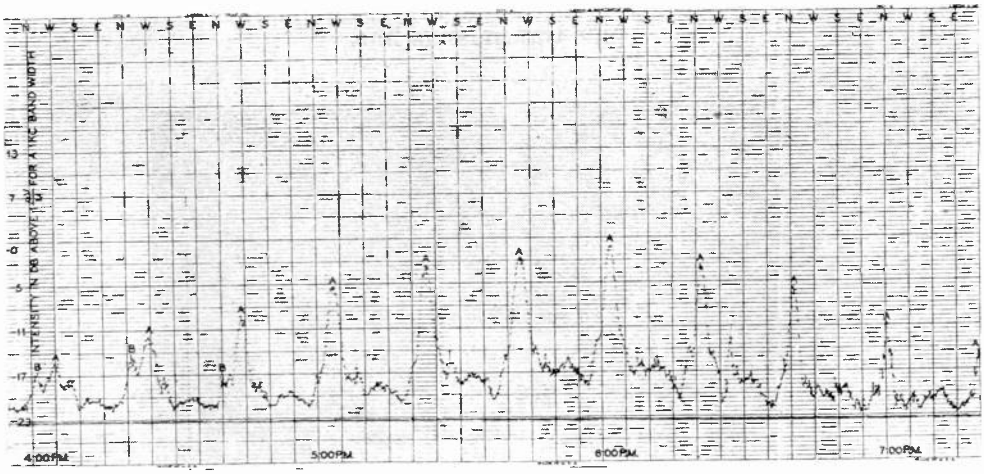

Fig. 6—Sample record of local thunderstorm static on short waves. August 27, 1931.

The operation of the recorder is as follows: For a period of 9 seconds the rectified output from the set charges the 100-microfarad condenser through the 300,000-ohm resistance, see Fig. 1B, the charge being proportional to the energy received from the static during the 9 seconds providing the rectifier is a square law device. During the same time the battery B charges the condenser in the opposite sense to the static. The battery B and associated resistance are adjusted so that if there is no change in the average static over the 9-second period the resulting charge on the condenser is zero. At the end of the interval the switch S is closed by a cam on the recorder shaft and the condenser is discharged through the recorder galvanometer. If the static level has not changed during the interval there will be no charge on the condenser

[5] H. T. Friis and E. Bruce, "A radio field strength measuring system for frequencies up to forty megacycles," Proc. I.R.E., vol. 14, p. 507; August, (1926).

and, hence the galvanometer will not be deflected and the gain of the receiver will remain unchanged. If the static level has increased or decreased the galvanometer will show a corresponding deflection and the recorder mechanism will decrease or increase the gain of the set accordingly.

In the system used the rectifier is not exactly a "square law" device being a two element rectifier in series with a resistance; however, as it was operated with a very small current (5×10^{-6} amperes) it approximated the square law sufficiently accurate for the present purpose.

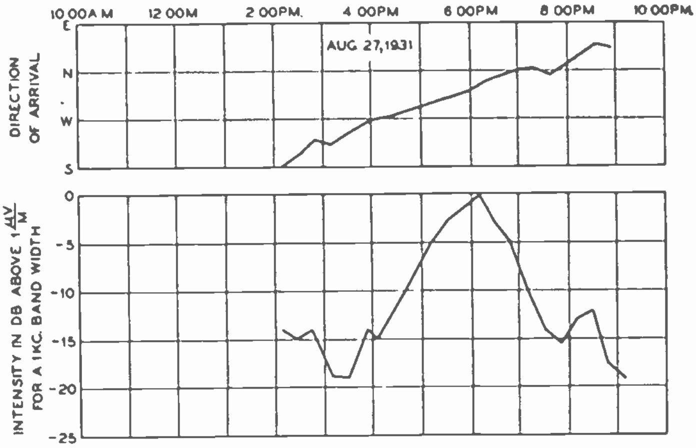

Fig. 7—Direction of arrival and intensity of local storm type static on 14.6 meters.

Results

From the data obtained it is found that three distinct groups of static are recorded. The first group is composed of the static received from local thunderstorms and storm centers. Static in this group is nearly always of the crash type. It is very intermittent, but the crashes often have very high peak voltages. The second group is composed of very steady weak static coming probably by Heaviside layer refractions from thunderstorms some distance away. The third group is composed of a very steady hiss type static the origin of which is not yet known.

During the time that records have been taken, static of the first group arising from several local thunderstorms has been recorded and studied. The data from a few typical records of these storms have been replotted and are shown in Figs. 7, 9, 10, 11, and 12. In these figures the upper curve shows the direction of arrival of the main stream or streams of static plotted against time and the lower curve shows the intensity of these streams at the corresponding times.[6] In addition to the main streams shown there were usually other minor streams, but these are difficult to follow in detail due to interference from random static from local squalls which are generally present during these periods. Fig. 6 is a section of a typical record of this type of static. It is the record for August 27 of which Fig. 7 is the replot. The peaks marked *A* indicate the position of the main storm. Those marked *B* show the position of one of the minor storms.

Fig. 7 shows the data obtained from this record. It represents a severe electrical storm that passed Holmdel early in the evening. During the early afternoon hours the storm was preceded by several thunder squalls. The static from these squalls was recorded, but there were so many of them and the direction of each changed so fast (as could be observed visually) that it was not possible to follow them on the records. During the late afternoon and early evening hours the static from the south grew stronger than that from the local squalls indicating that a definite storm center was forming there or approaching within range of the receiver from that direction. From then on this storm center did not follow a straight path but, as shown by the records, circled around the receiver and disappeared in the northeast. The manner in which the intensity increased and decreased as the storm passed is clearly shown on the lower curve of the figure.

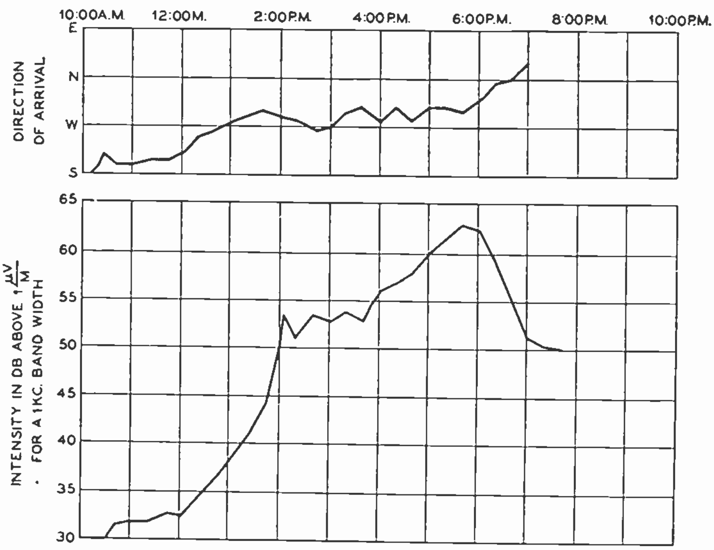

Fig. 8—Direction of arrival and intensity of local storm type static on 6936 meters. August 27, 1931.

[6] The band width of the receiver used was 26 kc but before plotting, the data were reduced to the case of a receiver having a band width of 1 kc, i.e., the intensity values were reduced by a factor of $\sqrt{26}$.

For the purpose of comparison, Fig. 8 shows the replot of the long-wave record for the same day.[7] Note that the ratio of the intensity of the long-wave static in microvolts per meter for a 1-kilocycle band width to that of the short-wave static was 63 db when the storm was

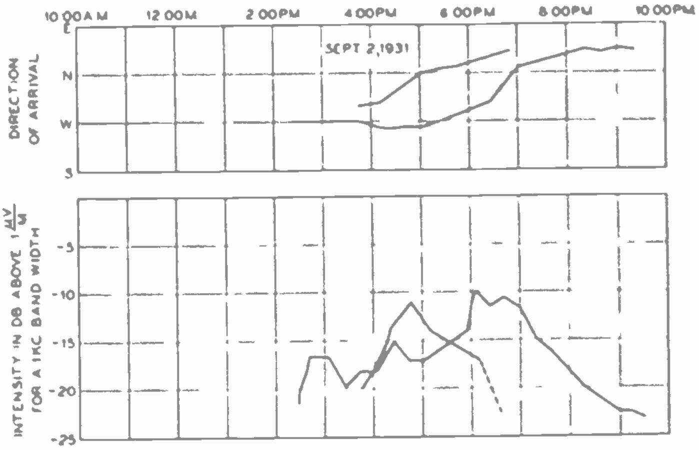

Fig. 9—Direction of arrival and intensity of local storm type static on 14.6 meters.

the severest. This ratio is probably a little too high because the rectifier device was not truly "square law." If we assume the inverse frequency law for the intensity of static this ratio should have been 53.5 db.

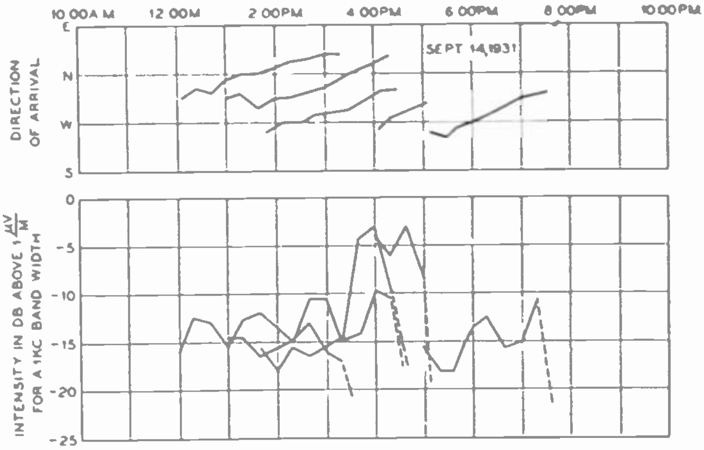

Fig. 10—Direction of arrival and intensity of local storm type static on 14.6 meters.

Fig. 9 shows the data obtained from the record of a well defined storm center that traveled in a straight or nearly straight line towards

[7] The long-wave data mentioned in this paper are all taken on a wavelength of 6936 meters.

the receiver. The static came from the west early in the afternoon, continued to come from that direction as the storm approached, and then as the storm passed Holmdel the direction shifted rapidly from the west through northwest and north to the northeast where it remained as the storm receded until the static no longer was strong enough to record. A minor storm preceded this main one by about an hour as is shown by the short curve preceding the main one. The main storm could clearly be seen passing Holmdel along the northern horizon, but at no time did it approach closer than 15 miles.

Fig. 10 shows the data obtained from the record of several small, but well defined storm centers that followed each other in rapid succession. On this day several small thunder squalls could be seen passing along the northern horizon.

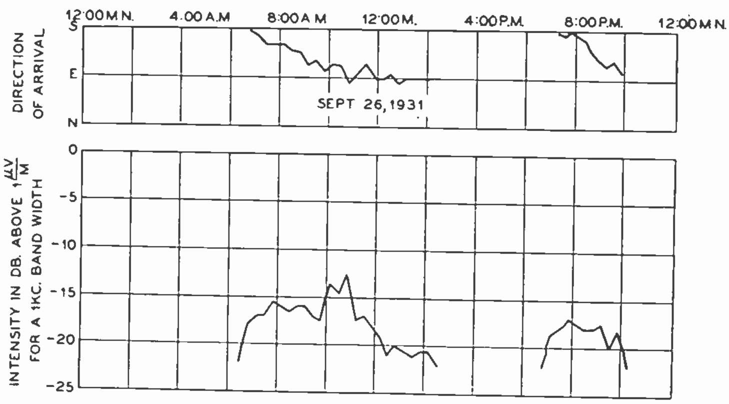

Fig. 11—Direction of arrival and intensity of local storm type static on 14.6 meters.

So far all of the records discussed have been of storms that approached from the southwest or west and passed northwest of the receiver. Fig. 11, on the other hand, shows the data from the record of two storms occurring the same day that approached from the south and passed the receiver on the southeast.

Finally Fig. 12 shows the data from a record of a storm that approached the receiver from the west and split, part of it passing to the north and part to the south of the receiver.

From these figures it is evident that on the average the thunderstorms were audible for four hours before and four hours after they reached Holmdel. Taking 35 miles an hour as the average velocity of a thunderstorm[8] this gives a distance of 140 miles that the storm centers were distant from Holmdel when the static could still be heard.

[8] *See* W. J. Humphreys, "Physics of the Air," p. 365. Also Ward, "The Climates of the United States," p. 322.

It is also worthy of note that by far the majority of storms came from the southwest and west and passed north of the receiver with only an occasional one passing south and southeast. The directions lying between southeast and northeast appear to be substantially free of this type of static at Holmdel and directional antennas built there to receive from those directions on short waves should be troubled with static only infrequently. Of course, this would not necessarily hold for other receiving locations. Locations in some sections, for example, would probably receive an equal amount of this type of static from all directions.

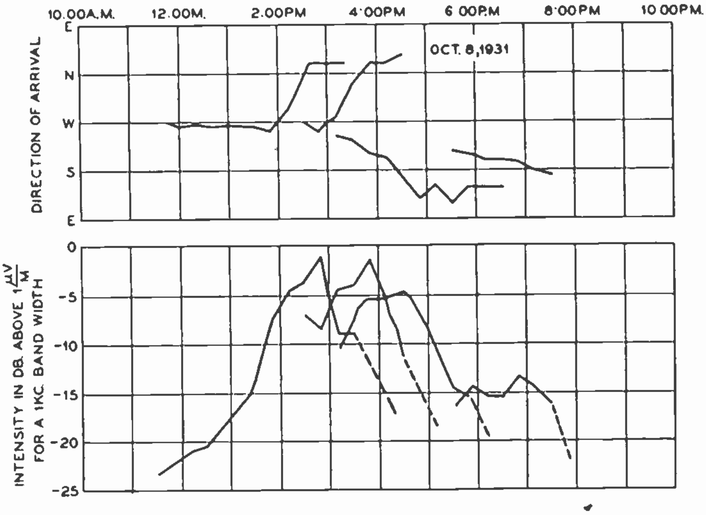

Fig. 12—Direction of arrival and intensity of local storm type static on 14.6 meters.

The static from the second group, which probably originates at long distances, is usually very weak on 14.6 meters. In fact, only occasionally is it strong enough to actuate the recorder. Because of this very few satisfactory records have been obtained of it. From the records that have been obtained, however, and from aural observations it has been determined that this static is of the crash and rumble type; its direction of arrival follows very closely that of the long wave static; and finally it is heard only when the long wave static coming from distant thunderstorms is very strong. It, therefore, probably comes from thunderstorms located some distance from the receiver. The most common directions of arrival of this static, as for the long wave static, are those directions lying between southeast and southwest.

On March 1, 1932, this kind of static was recorded by the short wave recorder from 2:30 P.M. to 3:50 P.M. The data obtained are shown and compared with those obtained on long waves in Table I. The direction of arrival for both the long and short wave static on this day was southeast. As shown in the table the difference between the intensity of the long and short wave static varied between 56 and 62 db. These values should also probably be somewhat lower because the rectifier is not a "square-law" device.

TABLE 1

Time	Intensity of static in db above 1 (microvolt per meter) For a 1—kc band width		Difference
	Long-Wave	Short-Wave	
2:30 P.M.	34.0	−22.0	56.0
2:50	37.5	−24.0	61.5
3:10	37.0	−22.5	59.5
3:30	35.5	−24.0	59.5
3:50	37.0	−25.0	62.0

Since this static is so weak that it cannot be recorded much of the time, the crash method[1] of measuring static as used by Potter could probably be used to great advantage to measure it.

The static of the third group is also very weak. It is, however, very steady, causing a hiss in the phones that can hardly be distinguished from the hiss caused by set noise. It is readily distinguished from ordinary static and probably does not originate in thunderstorm areas. The direction of arrival of this static changes gradually throughout the day going almost completely around the compass in twenty-four hours. It does not quite complete the cricuit, but in the middle of the night when it reaches the northwest, it begins to die out and at the same time static from the northeast begins to appear on the record. This new static then gradually shifts in direction throughout the day and dies out in the northwest also and the process is repeated day after day. Fig. 13 shows the direction of arrival of this static for three different days plotted against time of day. Curve 1 is for January 2, 1932, curve 2 is for January 26, 1932, and curve 3 is for February 24, 1932. Fig. 14 is a photograph of a section of one of the records.

This type of static was first definitely recognized only this last January. Previous to this time it had been considered merely as interference from some unmodulated carrier. Now, however, that it has been detected it is possible to go back to the old records and trace its position on them.

During the latter part of December and the first part of January the direction of arrival of this static coincided, for most of the daylight hours, with the direction of the sun from the receiver. (See curve 1, Fig. 13.) However, during January and February the direction has gradually shifted so that now (March 1) it precedes in time the direction of the sun by as much as an hour. It will be noticed that the curves

2 and 3 of Fig. 13 have shifted to the left.[9] Since December 21, the sun's rays have been getting more and more perpendicular at the receiving location causing sunrise to occur at the receiver earlier and earlier each day. It would appear that the change in the latitude of

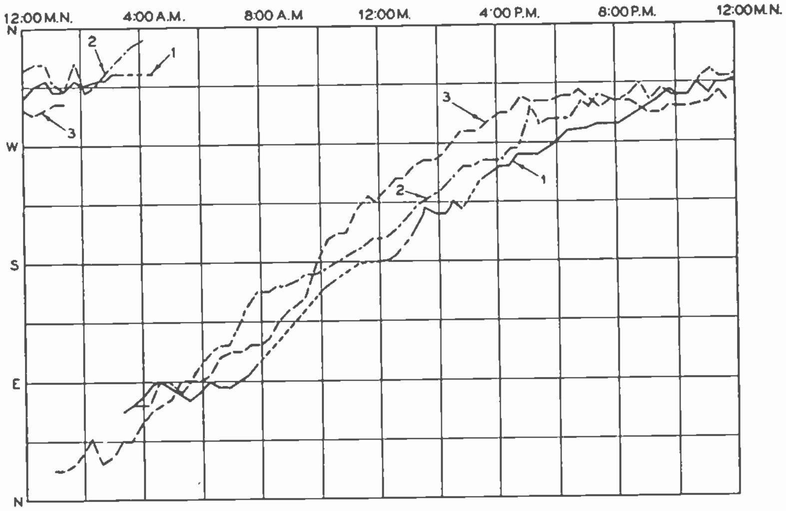

Fig. 13.—Direction of arrival of hiss type static on 14.6 meters.

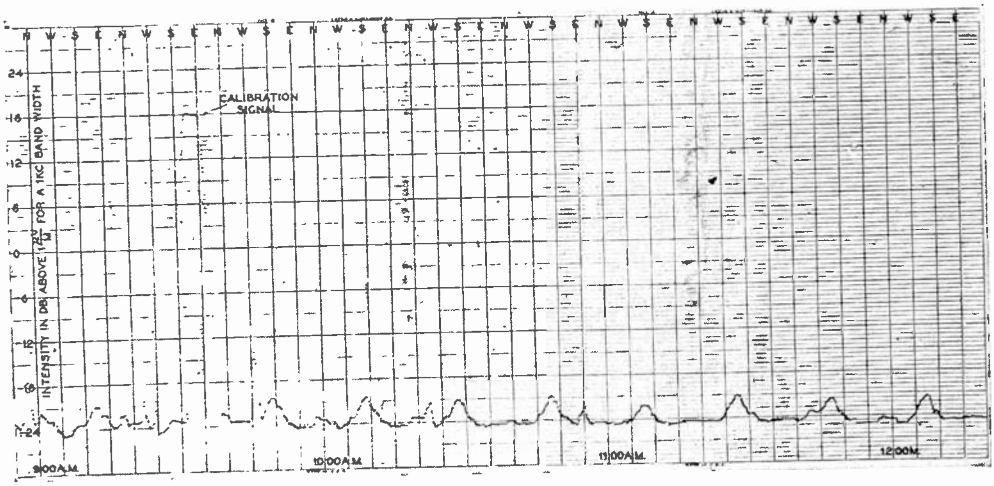

Fig. 14—Sample record of short-wave hiss type static. February 24, 1932.

the sun is connected with the changing position of the curves. However, the data as yet only cover observations taken over a few months and more observations are necessary before any hard and fast deductions can be drawn.

The fact that the direction of arrival changes almost 360 degrees

[9] Since this paper was written the curve has shifted much further to the left. Now (May 25) it crosses south at 4:30 A.M.

during twenty-four hours and that the shift in the position of the curve observed during the three months over which data has been taken corresponds to the change in latitude of the sun affords definite indication that the source of this static is somehow associated with the position of the sun. It may be that the static comes directly from the sun or, more likely, it may come from the subsolar point on the earth.

The intensity of this static is never very high. At no time during the period that records have been taken has it exceeded 0.39 microvolts per meter for 1-kilocycle band width. As will be noticed from the record (Fig. 14), however, its presence during otherwise quiet periods is unmistakable.

The experiments which have been described in this paper were carried out at Holmdel, New Jersey. The writer wishes to acknowledge his indebtedness to Mr. Friis for his many helpful suggestions.

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

THE IONIZING EFFECT OF METEORS IN RELATION TO RADIO PROPAGATION*

BY

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Summary—From a study of available meteor data it is concluded: (1) that meteors expend the larger part of their energy in the Kennelly-Heaviside regions, that is, in the regions of the upper atmosphere which control the propagation of all long-distance radio waves; (2) that the major portion of a meteor's energy goes into ionization of the gases around its path; (3) that this ionization extends to a considerable distance from the actual path,—in some cases several kilometers or more—and lasts for some minutes after the meteor has passed; (4) meteor trains are produced only in the lower Kennelly-Heaviside layer.

A table of the various sources of ionization of the upper atmosphere is given with values for each in ergs cm^{-2} sec^{-1}. These include sunlight, moonlight, starlight, cosmic rays, and meteors. During meteoric showers the ionizing effect does not appear to be negligible compared with that due to other ionizing agencies occurring at night.

A meteor of one-gram mass or greater will produce, on the above assumptions, sufficient ionization to affect propagation. One explanation of the general turbulent condition of the ionized layers may be provided by the continuous bombardment of meteors.

DURING the past decade the study of the properties and conditions of the upper atmosphere has become highly important not only from an academic but also from a commercial standpoint. This ensues from the fact that the upper atmosphere is used every day in long-distance radio work. Long and short waves alike depend on it to provide a means of guidance around the curvature of the earth. It has been generally recognized that it is of great importance to consider the possible sources of disturbance of the ionization in this region. One such possible source is the ionizing effect of meteors, and on reviewing the available data concerning meteors it becomes apparent that they might be expected to have an appreciable effect on short-wave transmission. A brief review of the more pertinent results follows.

In the first place, it is found that the actual paths of meteors lie in just those regions occupied by the Kennelly-Heaviside layers. For instance, from observations of 107 meteoric bodies, W. F. Denning[1] arrives at an average value of appearance of 118.5 kilometers and of dis-

* Decimal classification: R113.5. Original manuscript received by the Institute, September 29, 1932.
[1] Nature, vol. 57, p. 540, (1898).

appearance, 72.9 kilometers. The average velocity was 43.3 kilometers per second. These figures refer to objects visible to the naked eye. From telescopic observations it is apparent that meteors also occur at much greater heights. The ionized region lies above about 80 kilometers, with maxima of ionization in the neighborhood of 90 kilometers, and 200–300 kilometers, roughly; these values varying with the hour and season.

This coincidence between the height of meteor paths and the Kennelly-Heaviside region is probably not one of pure chance, for on the

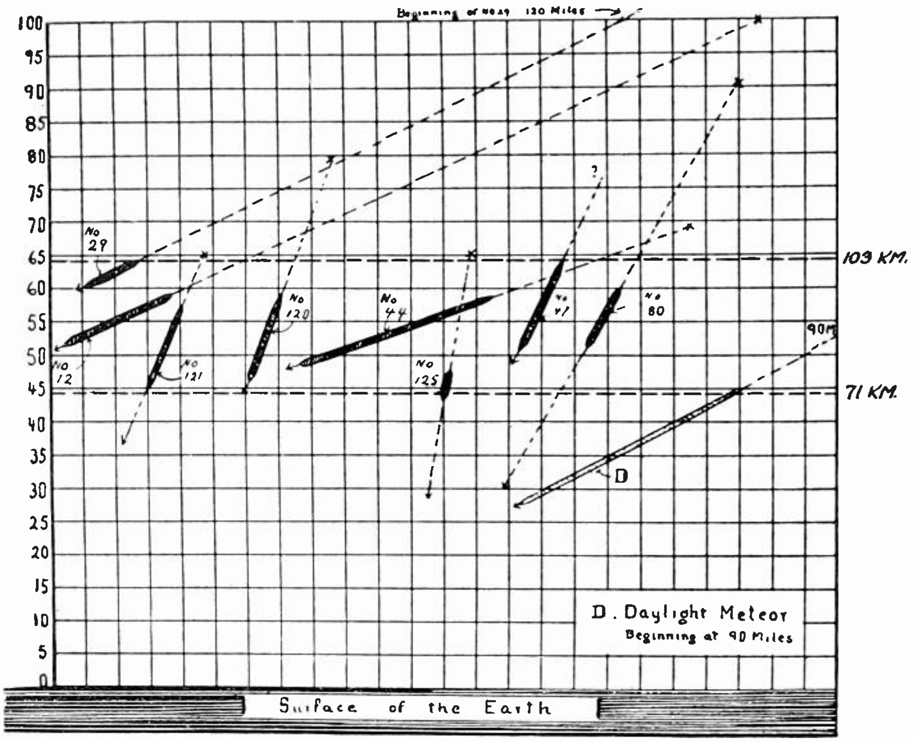

Fig. 1—Chart giving the altitude of eight self-luminous meteor trains and the corresponding lengths of meteor tracks.

(Republished from the Astrophysical Journal of 1907 by permission of the University of Chicago Press.)

assumption that the visibility of the meteor is largely associated with ionization, it is evident that such trails will most often be found in those regions of the atmosphere favorable for ionization. The few spectra that have been obtained of the light of meteors[2] are bright line spectra; i.e., spectra of ionized gas with little or no continuous emission. H. B. Maris[3] concludes that the energy of the light emitted by a meteor cannot be explained as due to the temperature of the meteor and an

[2] P. M. Millman, Publication of the American Astronomical Society, vol. 7, no. 4, p. 94.
[3] *Terr. Mag. and Atmos. Elec.*, vol. 34, no. 4, p. 309; December, (1929).

associated air cap on any of the usual assumptions regarding material, density of air, kinetic energy, etc. In the light of modern knowledge it seems more reasonable to assume that the visibility of the meteor is due to the ionization of the gas around its path. This gas will be composed not only of the air molecules but also of the volatilized constituents of the meteor itself.

In view of the fact that it has not as yet been possible to reproduce experimentally conditions which are present during the passage of a meteor through the upper atmosphere, we can attack the problem only on a theoretical basis, being guided by such data as we have gleaned from observations of the meteors and their trains. We know that the energy of impact of the atmospheric molecules is more than sufficient for ionization—in fact it is of the order of magnitude of the energy of a quantum in the far ultra-violet or soft X-ray region, wavelengths which ionize air very readily.

Furthermore, we know that only a small part of the kinetic energy of the meteor can reasonably be accounted for in the heating of the meteor and the air through which it travels. It has been concluded by other investigators[4] from a more detailed theoretical attack, that less than 2 per cent of a meteor's energy is expended in this way, and that 98 per cent goes into ionization and excitation of the air around its path.

In 1907 an article by C. C. Trowbridge[5] appeared in the *Astrophysical Journal* in which it was shown that the trains sometimes left by meteors were definitely restricted to a certain region. Fig. 1 is a reproduction taken from this article. It may be seen that the meteors are sometimes visible both before and after leaving the train, but that the train is left only in the particular region shown. These trains are glowing columns of gas surrounding the path of the meteor. They sometimes persist for a half hour or longer and are often several kilometers in diameter. It is obviously impossible to account for this phenomenon on any ordinary basis of high temperature.† The measurements of a number of trains give 87 kilometers as the mean altitude of this region, which may be described as being so favorable for producing and sustaining ionization that a meteor on passing through it may leave a glowing train of ionized gas visible for many miles and persisting for

[4] F. A. Lindeman and G. B. Dobson, *Proc. Royal Soc.* (London), vol. 411, p. 102, (1923).

[5] Astrophys. Jour., vol. 26, p. 95, (1907).

† It seems probable that these trains are similar in nature to the afterglow in nitrogen which under certain conditions has been made to persist for as long as 187 minutes after excitation. (Charles T. Knipp, "Duration of afterglow in nitrogen," paper presented at meeting of American Physical Society, Chicago, November 27, (1931).

many minutes. Since this is also the height of the lower Kennelly-Heaviside layer as found by radio measurements, we are thus led to the conclusion that meteor trains are definite Kennelly-Heaviside lower-layer phenomena.

The variation in height of the different trains shown in the figure is not inconsistent with the variation of the layer height as observed by radio. Each of these trains was observed by at least two observers at different stations, and since all of the trains lasted several minutes the measured altitudes are probably reliable. If the train is taken as defining the position of the lower ionized layer, such measurements are possibly of greater accuracy than those obtained by radio methods since the latter give only virtual heights.

From radio observations, it is fairly well established that there is another layer at more than twice the height of the lower one which also shows high ionization. One might expect, therefore, that in this higher region also, meteors would leave a visible train. However no trains were observed outside of the particular region cited.

Let us estimate the ionization which would be produced by an individual meteor and compare it with the ionic concentration which is generally assumed in order to explain short-wave radio phenomena. If the mass of a meteor is taken as one gram, its velocity as 40 kilometers per second, its length of path as 200 kilometers, and the range of ionization around the path as one-half kilometer, the concentration of ionization on the above assumptions would be of the order of 10^6 ions per cubic centimeter. The maximum ionization deduced from radio data is also of the order of 10^6 electrons per cubic centimeter.

The various possible sources of ionization of the upper atmosphere may be taken to be: (1) the ultra-violet light from the sun, (2) from the moon, and (3) from the stars, (4) cosmic rays, and (5) meteors. To these may be added ions and electrons or neutral particles from the sun for which however we have no direct data.

In the following table values for the energy received from each of these sources are given.

Sources of Ionization	*Energy Received by the Earth in Ergs cm^{-2} $sec.^{-1}$*
Ultra-violet light from the sun	28.35
" " " " full moon	0.000044
" " " " stars (Approx.)	0.014
Cosmic rays	0.00031
Meteors—Average normal day A.M.	0.00024
Meteors—Average normal day P.M.	0.00012
Meteors during meteoric shower (A.M.) up to	2.4

The energy of the ultra-violet light up to 1350Å, assuming a black body temperature of 6000° K. was taken as being the part of the total radiant energy of the sun active in producing the ionization of the atmosphere. The value of 1350Å has been given as the probable upper limit of wavelength for the ionization of air by A. L. Hughes.[6]

The photographic ratio of the intensities of sunlight and light of the full moon is 650,000. This value was used in obtaining the ultra-violet energy from the full moon. This energy value is probably too high since the visual ratio of sunlight to moonlight is only 375,000, indicating that the surface of the moon is yellowish. Thus it seems that the effects to be expected from moonlight must be small.

The value for starlight is that worked out by P. O. Pedersen[7] from Eddington's figures, divided by two since only half of the energy from all of the stars can be compared to that of sunlight.

The value of the energy from cosmic rays is due to R. A. Millikan and G. H. Cameron.[8]

H. Shapley[9] gives as a conservative estimate based on telescopic meteors, 10^9 meteors striking the earth each day. This number is increased, sometimes enormously, at times of meteoric showers. There is no accurate estimate of the mass of an average sized meteor, such values as are usually given being based on calculations from the brightness of the train. They range from a few milligrams, or a fraction thereof, to about 14 kilograms (for a 3rd magnitude meteor) depending upon the assumptions used in obtaining them. W. H. Pickering[10] states that the small mass usually derived for a meteor is based on "some very doubtful assumptions with regard to the energy converted into light by a candle and the amount of energy similarly converted by a meteor." He further points out[11] that it is difficult to believe that a body weighing a few grains could excite a cylinder of space, which may include several cubic miles, in the manner described. C. P. Olivier[12] concludes that "certainly a priori larger values would seem more probable, but most men who have attacked the problem find them smaller."

If for our purposes, we assume the conservative value of 10 milligrams for the mass, we arrive at a value for the average energy of about 0.002 that of a first magnitude meteor as calculated by Lindeman and Dobson.[4]

[6] A. L. Hughes, "Report on Photo-Electricity," *Nat. Res. Council Bull.*, vol. 2, p. 86, (1921).
[7] P. O. Pedersen, "Propagation of Radio Waves," p. 74.
[8] *Phys. Rev.*, vol. 31, p. 921, (1928).
[9] Harvard Circular, No. 317, May, (1928).
[10] *Astrophys. Jour.*, vol. 29, p. 365, (1909).
[11] *Ann. Harvard Coll. Obs.* vol. 41, p. 40.
[12] Olivier, "Meteors", p. 143.

A mass of 10 milligrams and a velocity of 40 kilometers sec^{-1} for an average meteor gives for the kinetic energy 8×10^{10} ergs. 10^9 meteors for 24 hours is 1.16×10^4 per second. Thus $8 \times 10^{10} \times 1.16 \times 10^4 = 10^{15}$ ergs per second (approx.). The area of the earth in square centimeters is

$$5.1 \times 10^{18}.$$

Therefore, we have,

$$\frac{10^{15}}{5.1 \times 10^{18}} = 2 \times 10^{-4} \text{ ergs cm}^{-2} \text{ sec}^{-1} \text{ (approx.)}.$$

However, the number of meteors per hour varies during the 24 hours and during the year. Olivier[13] gives tables which show that at least twice as many meteors fall after midnight as before and twice as many are seen in the latter half of the year as are observed during the first six months. This would have the effect of causing a maximum number after midnight and during the fall of the year. From one of these tables due to Coulvier and Gravier, the diurnal maximum occurs between the hours of 2 and 3 A.M. Thus four-thirds of the figure above has been taken as the A.M., and two-thirds as the P.M. value.

The table does not take into account the relative efficiencies of the various radiations in producing ionization of the upper atmosphere and more particularly in the Heaviside layer. We can at best form only a very rough estimate for each type of energy. Since no ultra-violet radiation in the indicated region can be measured at the surface of the earth, the efficiency of the ultra-violet sunlight may be taken as 100 per cent. This efficiency is taken as the ratio of the energy absorbed by the atmosphere to the energy incident at the outside of the atmosphere. The efficiency above 75 kilometers is possibly less than this but probably not much less. For moonlight and starlight the same will be true. For cosmic rays, however, in view of their variation in intensity up to 20 kilometers, the ionizing efficiency above 50 kilometers must be negligible. The energy transfer of the meteors takes place in the atmosphere above 50 kilometers with probably only one exception in a few million or more, so that the efficiency, if all of the energy were used up in ionization, would be approximately 100 per cent. This condition, of course, is not strictly true, some of the energy evidently going into light and heat.

The value given in the table for a meteoric shower of large proportion is based on several estimates[14] of 200,000 meteors seen per hour during the Leonid shower of November 12, 1833. That the ionization

[13] Olivier, "Meteors", p. 182.
[14] Russell, Dugan, and Stewart, "Astronomy", vol. I, p. 457.

must be high during such showers is suggested by the fact that an aurora[15] was observed "throughout the heavens" during the shower of November 13, 1866, although the earth's magnetic field was unusually quiet. The aurora observed was of the same color as that seen during magnetic storms but was devoid of streamers.

In view of the above it seems fair to conclude that the amount of ionizing energy received from meteors and spent in the Kennelly-Heaviside regions cannot be neglected in studies of the various ionizing agencies. On nights of meteoric showers, it seems likely that meteors may provide the largest source of ionization unless there is also bombardment by particles from the sun. This possibility does not seem to have been considered in detail heretofore. H. Nagaoka,[16] considering the possible effects of meteors on radio transmission, has concluded that the passage of a meteor would result in an increase in the refractive index owing to a scarcity of electrons; i.e., a sort of electron clean-up effect caused by meteoric dust. This view is the opposite of that presented in the present paper.

It is evident from radio measurements that a certain degree of turbulence exists in the upper atmosphere. Signals vary in strength, not only from day to night but from hour to hour and in the case of short waves even from second to second. This is not consistent with a strict interpretation of the classical idea according to which the upper atmosphere exhibits isothermal equilibrium. One of the agencies contributing to this turbulence may well be meteors or meteoric dust. It is known that the earth, in its travel through space, encounters at unpredicted times, in addition to a normal number of meteors of random direction, denser clouds of varying size of meteoric matter.

During the past year meteors have been observed in Arizona by members of an expedition organized by the Harvard College Observatory.[17] They have found meteors in much greater numbers than had been previously expected. They also found that the velocities were very high—so high in fact as to leave no doubt that they had come from interstellar space. These new data increase the estimate of the number of meteors which hit the earth per day by a considerable amount, and also give them a much greater average velocity.

The general conclusions in relation to radio transmission have been suggested in an earlier paper.[18] If densities of the order of 10^6 electrons per cubic centimeter can be produced it seems likely that effects of various kinds might be expected. Small ionization due to meteors might

[15] James Challis, *Roy. Astron. Soc. Month. Not.*, vol. 27. p. 75, (1867).
[16] Inst. of Phys. and Chem. Res. (Tokyo), Sci. Paper 297, (1931).
[17] S. L. Boothroyd, Paper presented at meeting of A.A.A.S., June 22, (1932).
[18] Skellett, *Phys. Rev.*, vol. 37, no. 12, p. 1668; June 15, (1931).

provide the increase necessary under certain conditions in order to return a wave which would otherwise not be reflected back to earth. The haphazard bombardment might contribute a degree of turbulence to the layer and help to produce fluctuations or fading in the signal. If such effects occur one would expect them to be especially marked during meteoric showers. Measurements were accordingly made by J. P. Schafer and W. M. Goodall during the Perseid and Leonid showers of 1931. Their results are reported in the following paper.

G. W. Pickard[19] has made a statistical study of radio transmission during meteor showers. While his results are not conclusive, he interprets them as indicating a correlation.

[19] Proc. I.R.E., vol. 19, p. 1166; July, (1931).

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

OBSERVATIONS OF KENNELLY-HEAVISIDE LAYER HEIGHTS DURING THE LEONID METEOR SHOWER OF NOVEMBER, 1931*

By

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Summary—*This paper describes the results of radio measurements of the virtual heights of the Kennelly-Heaviside layer during the Leonid meteor shower of November, 1931. While the results are not conclusive, due to the fact that a moderate magnetic disturbance occurred during this same period, there is some reason to believe that the presence of meteors in unusual numbers causes increased ionization of an intermittent nature in the region of the lower layer.*

Reasons have been given by A. M. Skellett[1] of these laboratories for believing that meteors may cause sufficient ionization in the upper atmosphere to affect radio-wave propagation. In order to discover possible effects of this sort, radio measurements of the virtual heights of the Kennelly-Heaviside layers were made on the three nights of the 1931 Leonid shower, November 15–16, 16–17, and 17–18. We are indebted to Mr. Skellett for the suggestion to make these tests.

The observations were made with a recently developed system for virtual height measurements.[2] This system uses a cathode ray oscillograph employing a sinusoidal timing wave. Observations are made visually. The transmitter and receiver are separated by a distance of one kilometer. Three frequencies, 2398, 3256, and 4795 kilocycles were used in these tests.

Several unusual phenomena were found which may have been due to the presence of meteors. Unfortunately, however, a magnetic disturbance of moderate intensity occurred during this meteor shower, and therefore definite conclusions regarding the effect of meteors cannot be drawn at this time.[3] In view of the growing interest in phenom-

* Decimal classification: R113.5×R113.61. Original manuscript received by the Institute, September 29, 1932.

[1] A. M. Skellett, Proc. I.R.E., this issue pp. 1933–1940, and *Phys. Rev.*, vol. 37, no. 12, p. 1668; June 15, (1931).

[2] J. P. Schafer and W. M. Goodall, Proc. I.R.E., vol. 20, pp. 1131–1149; July, (1932).

[3] If magnetic disturbances can be caused by the arrival of charged particles from the sun in unusual numbers, perhaps they can also be produced by the generation of ions due to unusual quantities of meteors or meteoric dust. A preliminary study of magnetic data, earth currents, and solar activity taken together with the virtual height measurements indicate that this particular magnetic disturbance might well have been due to meteoric rather than solar causes.

ena related to the upper atmosphere, it is believed to be worth while to record the unusual features of the results obtained and to discuss briefly their possible significance.

Intermittent reflections corresponding to virtual heights (h_v) of 100 to 200 kilometers for the highest frequency (4795 kilocycles) were obtained throughout the three nights. The reflections occurred for short periods of several seconds on the first and third night, and appeared and disappeared suddenly. On the second night these reflections were present a much greater proportion of the time than on the other two. Intermittent reflections of this type are not normally found.

Fig. 1 illustrates the variations in virtual height which were observed on the second night (the night of maximum meteor activity). At about 11:40 P.M. weak lower-layer reflections (h_v about 130 kilometers) and stronger upper-layer reflections (h_v=370 to 400 kilometers) were obtained for 2398 and 3256 kilocycles. No reflections were obtained for 4795 kilocycles at the same time. This condition is about normal for an undistrubed night. Within the next half hour, however, the lower-layer reflections gradually increased in intensity and the virtual heights became lower. The upper-layer reflections became weaker and actually disappeared at about midnight, due probably to the shielding effects of the lower layer. The ionic gradient in the lower layer seems at this time to have increased to such a point that the virtual heights for all three frequencies were of practically the same value (h_v 107 kilometers) and as many as four strong multiples from this layer were obtained. For a short time pulses were also transmitted on a still higher frequency of 6425 kilocycles during the time when strong multiple reflections from the lower layer were received on the other frequencies. No reflections were found on this frequency. This means that the effective electron density in the lower layer must have increased to approximately 5 x 10^5 electrons per cubic centimeter as determined from calculations for the two frequencies of 4795 and 6425 kilocycles.

Shortly after 1:00 A.M. the lower-layer reflections became weaker, the multiples disappeared, and upper-layer reflections appeared again and became stronger for the two lower frequencies. Upper-layer reflections were not observed for 4795 kilocycles until sunrise. Indications of two other periods of maximum ionization of the lower layer were observed at approximately 2:45 and 4:30 A.M., for the three lower frequencies. These maxima were less pronounced than the one at midnight.

However, previous records have shown that all meteor showers are not accompanied by magnetic disturbances, and even an extensive study of the data might not be conclusive since the cause of magnetic disturbances is still in doubt.

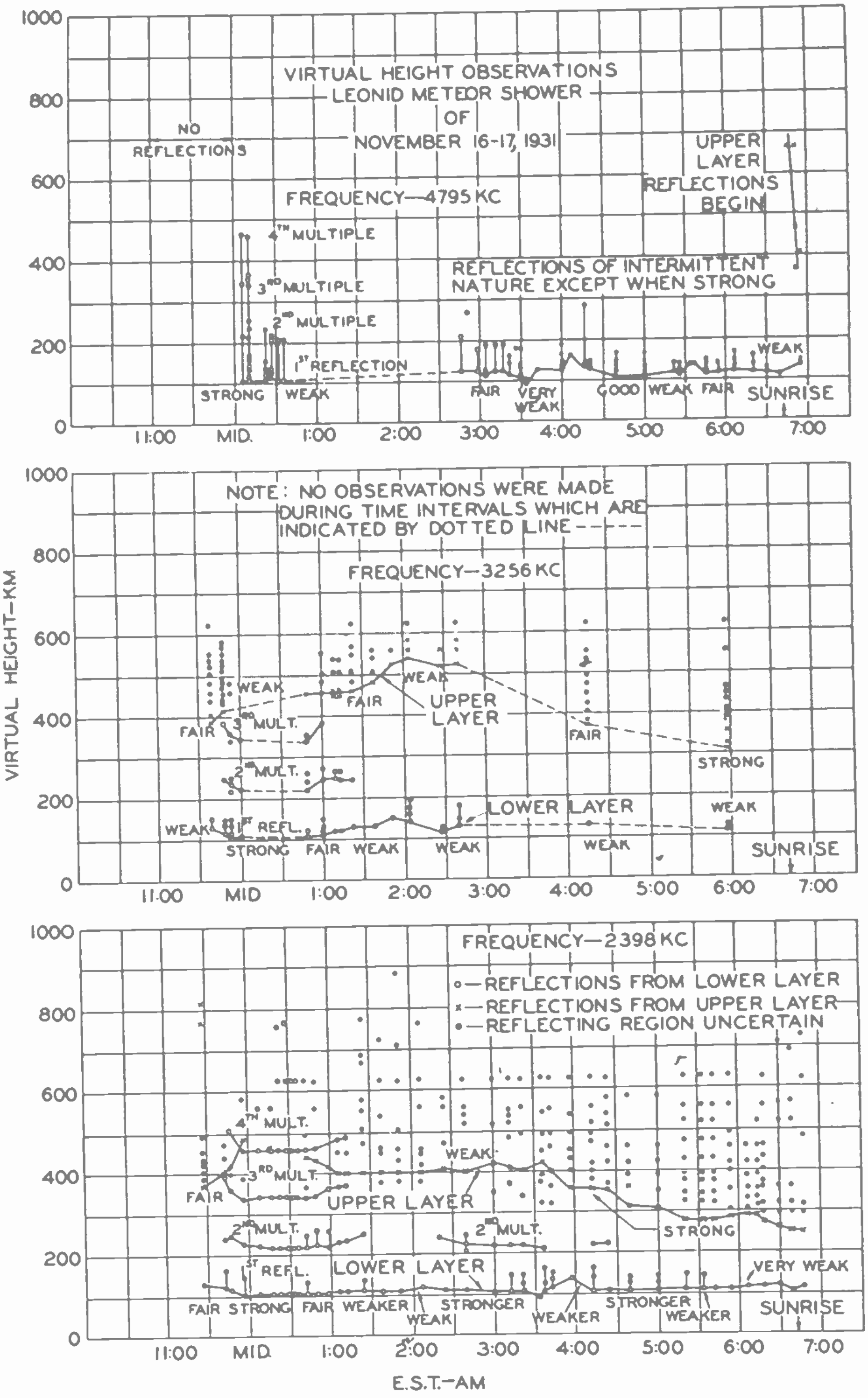

Fig. 1—Virtual height variations during the night of November 16–17, 1931, for frequencies of 2398, 3256, and 4795 kilocycles. Also note the variations in the intensity of reflections. From the behavior of the reflections from the lower layer it appears that there was a large increase in the effective ionization of the lower layer near midnight, and minor increases at about 2:45 and 4:30 A.M.

Two similar maxima were observed on the third night; at midnight and at 4:00 A.M., but neither one was as pronounced as the first one of the previous night.

These observations indicate unusually disturbed conditions of the lower Kennelly-Heaviside layer and would seem to indicate that the meteors may have been a source of intermittent ionization in this region. The large maxima of ionization near midnight on the second night might be due to particularly large single meteors or to groups of meteors.

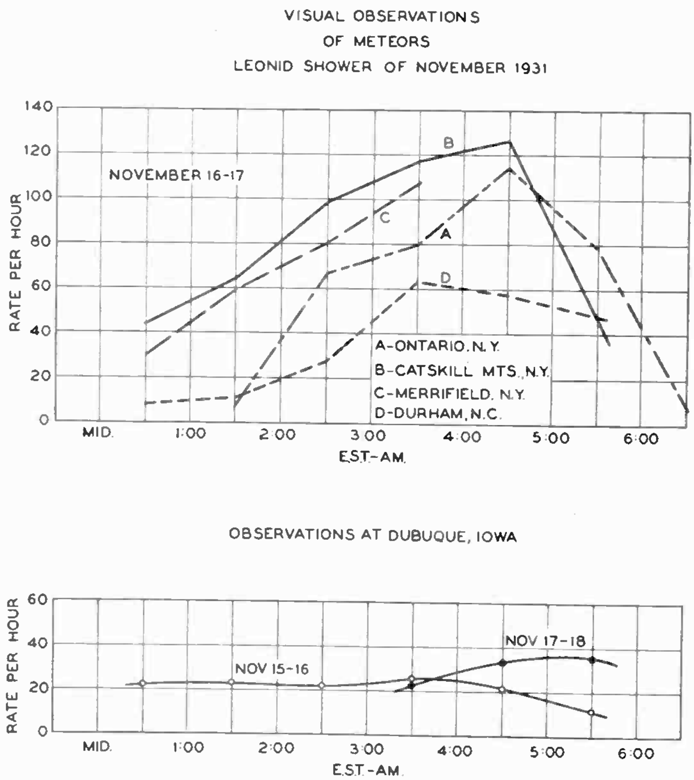

Fig. 2—Curves showing the variation in the observed rates of meteors during the Leonid shower of November, 1931. Note that the greatest rate was observed about 4:30 A.M. on the morning of November 17. The actual number of meteors was probably much greater than those indicated as all curves except *D* are for the average value of a single observer.

No local visual observations of meteors could be made on the nights in question, due to the stormy weather, but observers at other points in the United States have reported this Leonid shower to be the most active shower of any description since 1866. The curves of Fig. 2 were drawn from data published by Charles P. Olivier[4] and show that there was a pronounced maximum in the number of meteors on the night of November 16–17 as compared with the nights before and the night

[4] Charles P. Olivier, *Popular Astronomy*, p. 46, January, (1932).

after. The upper set of curves show that the maximum number of meteors occurred between 4:00 and 5:00 A.M. on the morning of the 17th. This time corresponds to the time of one of the minor increases in apparent ionization of the lower layer. (4:30 A.M.) No reason for the large maxima of ionization near midnight is found from these charts, but Olivier mentions the fact that during the night a number of large meteors left visible trains, two of which lasted for twelve minutes and several for five minutes. It is conceivable that a meteor of this description could be responsible for the increase in ionization which was found.

Somewhat similar phenomena to those found during the Leonid shower were observed during the Perseid shower of August 11 to 13. Although they were not of such a pronounced nature their occurrence may be more significant than those accompanying the Leonid shower since no magnetic disturbance of any appreciable value seems to have been reported for this shower, and earth current records showed only very small variations.

It should also be mentioned that similar though less pronounced increases in ionization have been found at various times during nights when there has been no evidence of meteoric or magnetic disturbances. This is not necessarily inconsistent with the meteoric hypothesis since the earth while traveling in its orbit may occasionally encounter clouds of meteoric dust which is too fine to be visible as meteors but sufficient in the aggregate to produce appreciable ionization.

It will be of interest to follow this investigation through future meteoric showers, especially during the Leonid shower of 1932 when the number of meteors should be at the peak of the 33-year cycle.

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

SOME NOTES ON DEMODULATION*

By

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Summary—*The audio output of a detector depends upon two magnitudes which are independent each from the other. These magnitudes are the radio-frequency envelope of the input and the rectification characteristic of the detector. In problems dealing with the distortions caused by selective circuits or by the superposition of several modulated signals it becomes necessary to treat both magnitudes separately.*

A new method to find graphically the radio-frequency envelope for the "general modulated signal," is given.

An analysis is made showing how to find the detector output if the input radio-frequency envelope and the rectification characteristic of the detector are known.

I. Introduction

In electrical communication two different principles are utilized to transmit a message between two distant points. The first and older method is to send the low-frequency currents which are generated by the microphone or the telegraph key to the distant point over wires. The other method employs a "carrier" frequency on which the "message" frequency is superimposed. This latter system is applicable to both wire and wireless communication circuits.

In the case of a "carrier frequency," two problems immediately present themselves. First, we have to superimpose the "message frequency" upon the carrier. At the receiver, we have in turn to eliminate the carrier from the message frequency. We call these procedures modulation and demodulation, respectively.

Confining ourselves to radio communication we see that *principally* various modes of modulation are available. We may use amplitude, phase, or frequency modulation and combinations of these three modes. A great number of electrical arrangements for performing these types of modulation is known, especially for amplitude modulation. On the other hand, when considering the problem of demodulation we find that only *one* principle can be used: rectification. With our present-day knowledge, no other means are available to separate carrier and message frequency.

This fact defines the type of modulation which most advantageously may be used. If we apply a radio-frequency voltage of constant amplitude to the input terminals of the rectifying detector, the out-

* Decimal classification: R148. Original manuscript received by the Institute, July 27, 1932.

put current will be a steady direct current without any superimposed audio-frequency components. But with an input radio-frequency voltage of periodically *variable amplitude* these amplitude variations will appear as audio-frequency components in the output current. In general, the output audio frequency will be different to a certain extent from the envelope of the radio-frequency input, this difference being due to the rectification characteristic of the detector. It follows from these considerations:

1. The detector input radio-frequency voltage must show *amplitude variations* in order to get any audio output.
2. The audio output of the detector depends upon two magnitudes, *the envelope of the input radio-frequency voltage* and the *rectification characteristic of the detector.*

This physical fact makes it necessary to treat the two magnitudes, envelope and rectification characteristic, *separately.*

II. Envelope of the Modulated Signal

A sinusoidal alternating current is usually represented by the projection of a rotating radius vector into a projection axis, (Fig. 1). We

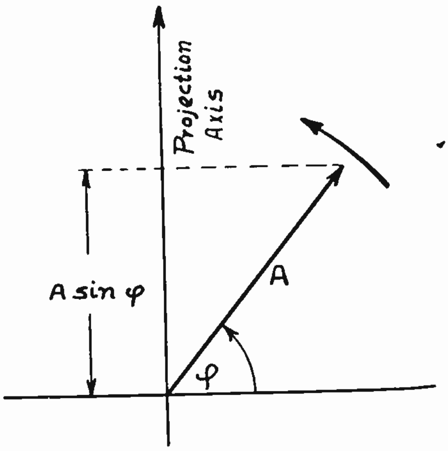

Fig. 1

may write

$$i = A \sin \varphi, \tag{1}$$

where φ is connected with the angular velocity ω by the relation

$$\omega = 2\pi f_0 = \frac{d\varphi}{dt} \cdot \tag{2}$$

Each of the magnitudes, amplitude, phase, or frequency can be subjected to a periodical change at audio rate, so rendering amplitude, phase, or frequency modulation, respectively. It has been previously shown[1] that each of these types of modulation and combinations of them will produce a carrier frequency and a set of side band frequencies which are evenly distributed on both sides of the carrier. These results have been derived in assuming a sinusoidal audio frequency, but, from the mathematical expressions given in the paper mentioned above, carrier and side bands may be readily calculated in case the audio frequency is a nonsinusoidal function. Expanding the audio function into a Fourier series it is seen that simply the number of side band frequencies is increased and their amplitudes are changed.

The modulated radio-frequency signal which is generated in the modulated stage has to pass the amplifier stages of the transmitter, is radiated by the antenna, propagated through space, picked up by the receiving antenna, amplified again and finally supplied to the input terminals of the detector. On its way from the modulated stage to the detector, its components are subjected to certain changes. Selective circuits and nonlinear amplification both at the transmitter and receiver will affect the amplitudes of the components, while in space due to selective absorption and reflection both their amplitudes and phases may be changed. We see that the components of a signal arriving at the input terminals of the detector in the receiver, will differ more or less from those leaving the modulated stage. We write for this *detector input signal*

$$i = A\left[\sin(\omega t + \varphi) + n\sum_{n=1}^{n=N}\left[a_n \sin((\omega + n\mu)t + \alpha_n) + b_n \sin((\omega - n\mu)t - \beta_n)\right]\right]. \tag{3}$$

Abbreviations:

ω radio radian frequency
φ phase angle for radio frequency
μ fundamental audio radian frequency
$n\mu$ radian frequency of the nth audio harmonic
N total number of side band pairs present
A amplitude of the carrier
$\left.\begin{matrix} Aa_n \\ Ab_n \end{matrix}\right\}$ amplitudes of the nth side bands
$\left.\begin{matrix} \alpha_n \\ \beta_n \end{matrix}\right\}$ phase shift with respect to the corresponding *input* component

Since the items α_n, β_n, a_n, and b_n are entirely arbitrary, (3) represents the most general case of modulation. As may readily be seen by substituting suitable values for a_n, b_n, α_n, and β_n, equation (3) can be transferred into the expressions for amplitude, phase, or frequency modulation.[1] Therefore, we call the expression given by (3) "*the general modulated signal.*" This equation also includes the cases in which two different signals are picked up by the receiving antenna, the carriers of which are not sufficiently spaced as to be separated by selective radio-frequency amplifier stages. It consists of the carrier

$$A \sin(\omega t + \varphi) = C \tag{4}$$

and the side bands

$$\begin{aligned} A \sum_{n=1}^{n=N} [a_n \sin((\omega + n\mu)t + \alpha_n) + b_n \sin((\omega - n\mu)t - \beta_n)] \\ = A \sum_{n=1}^{n=N} M_n = M. \end{aligned} \tag{5}$$

As we shall see later, the term M can be represented by a radio-frequency vector of the angular velocity ω. We call it "*modulation vector.*"

This signal is to be rectified in the detector. In order to find the detector output current we have to know the radio-frequency envelope of the expression given in (3). For this purpose we investigate the magnitude M_n which represents the nth side band.

1. *Analytical Expression for the Envelope*

Transforming (5) into

$$\begin{aligned} M_n &= \sin \omega t[- s_s \sin n\mu t + s_c \cos n\mu t] \\ &\quad + \cos \omega t[d_c \sin n\mu t + d_s \cos n\mu t] \end{aligned} \tag{6}$$

where,

$$\left.\begin{aligned} s_s &= \text{sum} \\ d_s &= \text{difference} \end{aligned}\right\} \text{of sines} = a_n \sin \alpha_n \pm b_n \sin \beta_n$$

$$\left.\begin{aligned} s_c &= \text{sum} \\ d_c &= \text{difference} \end{aligned}\right\} \text{of cosines} = a_n \cos \alpha_n \pm b_n \cos \beta_n$$

we find that M_n consists of two radio-frequency terms. For reasons of abbreviation, the bracketed terms in (6) are put equal to S_n and

[1] H. Roder, "Amplitude, phase, and frequency modulation," Proc. I.R.E., vol. 19, p. 2145; December, (1931).

D_n, respectively, so getting

$$M_n = S_n \sin \omega t + D_n \cos \omega t. \tag{7}$$

This, when substituted into (3) yields

$$i = A(t) \sin (\omega t + \phi(t)) \tag{8}$$

where,

$$\phi(t) = \arctan \frac{\sin \varphi + \sum_{n=1}^{n=N} D_n}{\cos \varphi + \sum_{n=1}^{n=N} S_n} \tag{9}$$

and,

$$A(t) = \text{envelope} = A\sqrt{\left(\cos \varphi + \sum_{n=1}^{n=N} S_n\right)^2 + \left(\sin \varphi + \sum_{n=1}^{n=N} D_n\right)^2}. \tag{10}$$

Thus, the problem of finding the radio-frequency envelope is solved.

Equation (10) lends itself very advantageously to investigating the detector output in case a pure square-law detector is used. In this case, the expression in the root is directly proportional to the output current. But in the case of a linear detector it would be quite a laborious task to evaluate the expression given in (10) if the problem is to be worked out numerically under various conditions. For this reason we shall attempt to find the envelope by a graphical method.

2. *Graphical Method for Finding the Envelope*

It is conventional in alternating-current theory to replace a magnitude which varies sinusoidally with time by the projection of a radius vector into a projection axis, whereby we may either assume that the projection axis is standing still with the radius vector rotating counterclockwise or that the projection axis is rotating clockwise with the radius vector standing still. We prefer the latter assumption and fix the relative position of the projection (i.e., time) axis such that, for $t=0$, it coincides with the y-axis. This necessitates drawing $S_n \sin \omega t$ as a horizontal vector of the magnitude S_n and $D_n \cos \omega t$ as a vertical vector of the magnitude D_n. By this trick, we eliminate the radio frequency, ω. We thus obtain Fig. 2 as a graphical interpretation of (7).

The terms S_n and D_n in that equation, however, are magnitudes which vary with time at audio-frequency rate. They contain sine and cosine components and, consequently, they can be represented by vectors having the angular velocity $n\mu$. But, in this present case we preferably choose the assumption that the projection axis is standing still while the vectors are rotating with the angular velocity $n\mu$. For the term

$$S_n = - s_s \sin n\mu t + s_c \cos n\mu t \tag{11}$$

the horizontal axis becomes the projection axis. With reference to Fig. 1, it follows that s_s and s_c must be drawn as shown in Fig. 3, thus

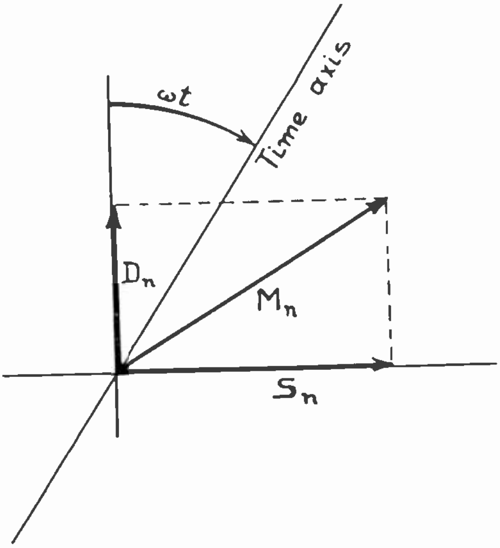

Fig. 2

resulting in the time vector S_{no}. Similarly, the term

$$D_n = d_c \sin n\mu t + d_s \cos n\mu t \tag{12}$$

must be referred to the vertical axis and renders the time vector D_{no}. Both S_{no} and D_{no} rotate with the constant angular velocity $n\mu$. The vector sum of the *horizontal component* of S_{no} and of the *vertical component* of D_{no}, gives the vector M_n as a function of audio frequency.

This procedure suggests making use of the well-known complex symbols as is commonly done in alternating-current theory. We may write (12) in the following form

$$D_n = \mathbf{J}_{n\mu} D_{no} = \mathbf{J}_{n\mu}(d_c + jd_s) \tag{13}$$

the symbol $\mathbf{J}_{n\mu}$ indicating that only the *j-component* of the vector is to be taken. A corresponding expression is obtained for S_n from (11). However, because S_{no} is to be projected into the horizontal axis we have to shift the S_n plane by -90 degrees. We do so by writing symbolically:

$$S_n = -j\,\mathbf{R}_{n\mu}S_{no} = -j\mathbf{R}_{n\mu}(-s_s + js_c) \tag{14}$$

thus indicating by the symbol $\mathbf{R}_{n\mu}$ that only the *real* component is to be used. With these symbols, (7) yields—

$$M_n = \mathbf{R}_{n\mu}[+s_c + js_s] + \mathbf{J}_{n\mu}[d_c + jd_s]. \tag{15}$$

Substituting for s_s, s_c, d_s, d_c their respective values ((5) and (6)) we finally get the simple symbolic expression:

$$Mn = \mathbf{R}_{n\mu}S_{no} + \mathbf{J}_{n\mu}D_{no} \tag{16}$$

where,

$$\left.\begin{aligned} S_{no} &= a_n\epsilon^{j\alpha_n} + b_n\epsilon^{j\beta_n} \\ D_{no} &= a_n\epsilon^{j\alpha_n} - n_n\epsilon^{j\beta_n} \end{aligned}\right\} \tag{17}$$

The time vectors S_{no} and D_{no} can be found in the most simple manner (Fig. 4). The addition of their proper components gives the vector M_n. Inspection shows that the diagram corresponding to (16) is equivalent to that obtained above (Fig. 2).

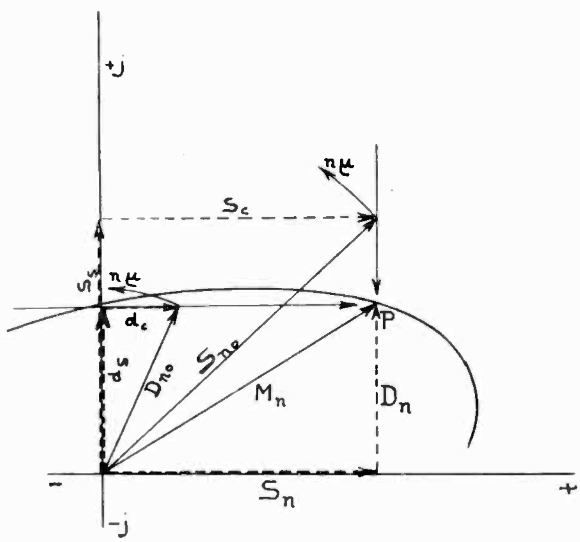

Fig. 3

When S_{no} and D_{no} are rotated with the constant angular velocity $n\mu$, the end-point, P, of M_n describes an ellipse.[2] (Fig. 5.) We may draw this ellipse either point by point or we may construct it from its axes. To find these we first have to know two conjugated diameters, which we may get readily by shifting S_{no} and D_{no} by ± 90 degrees (point P_1). As can easily be shown[3] the diameter P_1P_1', is conjugated to the diameter PP'. With two conjugated diameters being known, the axes

[2] For proof see Appendix 1.
[3] See Appendix 2.

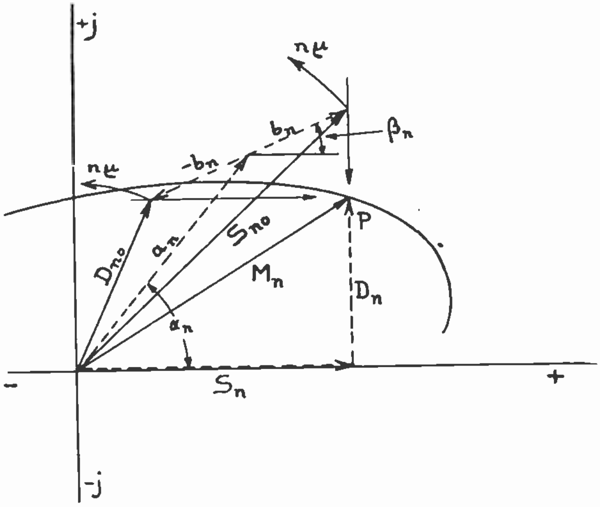
+j
$n\mu$
b_n
β_n
$-b_n$
$n\mu$
P
D_{no}
a_n
S_{no}
M_n
D_n
α_n
S_n
-
+
-j

Fig. 4

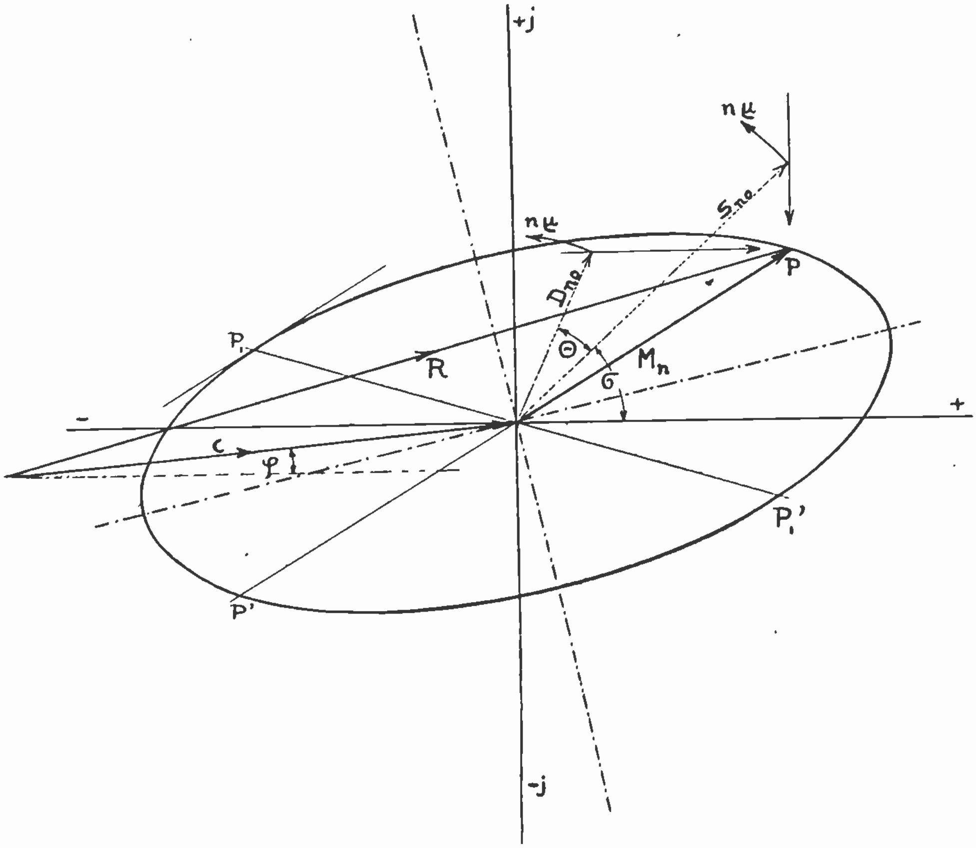
+j
$n\mu$
S_{no}
$n\mu$
P
D_{no}
P_1
R
Θ
M_n
σ
-
+
c
φ
P_1'
P'
-j

Fig. 5

of the ellipse and the ellipse itself may be found by well-known graphical methods.

In certain cases, the ellipse will degenerate into a circle or a straight line. We have:

(1) for $a_n = 0$ or $b_n = 0$: the ellipse changes to a circle.

(2) for $a_n = b_n$: the angle between D_{no} and S_{no} becomes equal to 90 degrees. Instead of the ellipse, a straight line is obtained which includes an angle of $\frac{1}{2}(\alpha_n - \beta_n)$ with the horizontal axis.

(3) For $|\alpha_n| = |\beta_n|$ the axes of the ellipse do coincide with the axes of the coördinate system.

We have thus found a simple graphical method by means of which we are able to replace each pair of corresponding side bands by a radio-frequency vector M_n rotating with a frequency of $n\mu$. The angular velocity of the vector M_n, however, is not constant.

Now, when returning to (5), from which we started, we can represent the bracketed term by a vector M_n, while the arithmetical summation becomes a geometrical summation. The diagram becomes complete, if we add the vector of the carrier, for which we have

$$\text{Carrier} = \dot{C} \cos \varphi + j \sin \varphi .$$

Then,

$$\dot{M} = \sum M_n$$

and,

$$\dot{R} = \dot{C} + \dot{M} .$$

R is the instantaneous magnitude of the radio-frequency envelope. If the diagram is drawn for a number of subsequent values of μt, Fig. 6, then the end-point of R, P_0, will trace a curve ϕ. This curve when plotted in rectangular coördinates with R as ordinate and μt as abscissa, is the desired envelope of the radio frequency. The angle ϑ in Fig. 6 is the maximum phase shift to which the radio frequency is subjected during the modulation cycle.

Vector diagrams of this type have already been used formerly to represent phase modulation and amplitude plus phase modulation.[4]

In order to summarize the result of this section the following rule may be given for the graphical treatment of modulation problems. In the analytical work the modulated radio frequency will usually be obtained in a form corresponding to (3) or (4) and (5). These expressions are first separated into carrier frequency and into corresponding pairs of side band frequencies. The trigonometric functions containing sums and differences of angles are transformed into products of trig-

[4] See footnote 1, Figs. 10 and 12 of the paper referred to.

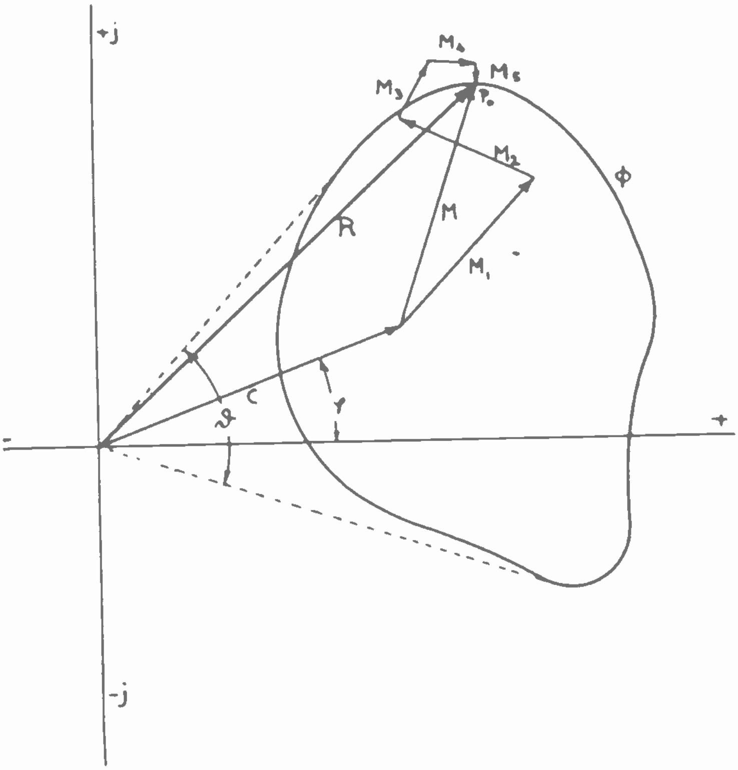

Fig. 6

onometric functions by simple trigonometric transformations. The result so obtained can immediately be written in terms of vectors. We put in the expression for the carrier

$$\sin \omega t = +1$$
$$\cos \omega t = +j,$$

and in the expression for each pair of side bands

$$\sin \omega t = -j\mathbf{R}_{n\mu}$$
$$\cos \omega t = +\mathbf{J}_{n\mu}$$
$$\sin \mu t = +1$$
$$\cos \mu t = +j$$

whereby we indicate

by the symbol **R** . . . only the *real* component is to be used
by the symbol **J** . . . only the *imaginary* component is to be used
by the subscript $n\mu$ . . . the vector rotates with the constant angular velocity $n\mu$.

If the vector equation as obtained by this procedure is represented graphically, then for each pair of side band frequencies a vector M_n is found. The graphical addition of all vectors M_n resolves into the "modulation vector" M. When adding the modulation vector and the vector obtained for the carrier, the instantaneous value of the radio-frequency envelope will result.

III. Procedure of Demodulation

It can be shown generally in a very simple manner how the envelope of the radio frequency and the rectification characteristic of the detector define the audio output current. According to (8), the input signal voltage which is a radio frequency can always be written in the following form (8)

$$e = A(t) \sin (\omega t + \phi(t)). \tag{18}$$

In this equation, $A(t)$ represents the envelope of the radio frequency which can be found by the methods given in the preceding section. We

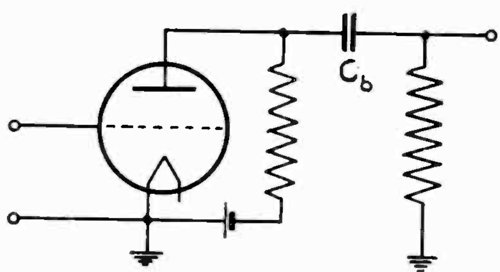

Fig. 7

assume $A(t)$ to be a periodic function of audio frequency having the period T_a. $\phi(t)$ represents a phase angle with respect to a convenient reference time. It varies at an audio rate as is well known for phase or frequency modulation. The voltage, e, Fig. 8b, is applied to a detector, the rectification characteristic of which (Fig. 8a) can always be represented by the following power series

$$i = f(e) = u_1 e + u_2 e^2 + u_3 e^3 + u_4 e^4 + \cdots . \tag{19}$$

where,

i is the output current (rectified current)
$u_1, u_2 \ldots\ldots$ are constants which characterize the detector, and
e is the input voltage.

We confine this investigation to ideal conditions, viz., (Fig. 7): no grid current and pure resistive load in the plate circuit, (i.e., C_b very large). In the majority of applications, these conditions are very well approached. If, however, the plate load has a considerable reactive component, our simple treatment is not applicable.[5]

The output current, $i=f(t)$, which is due to the voltage e, is shown

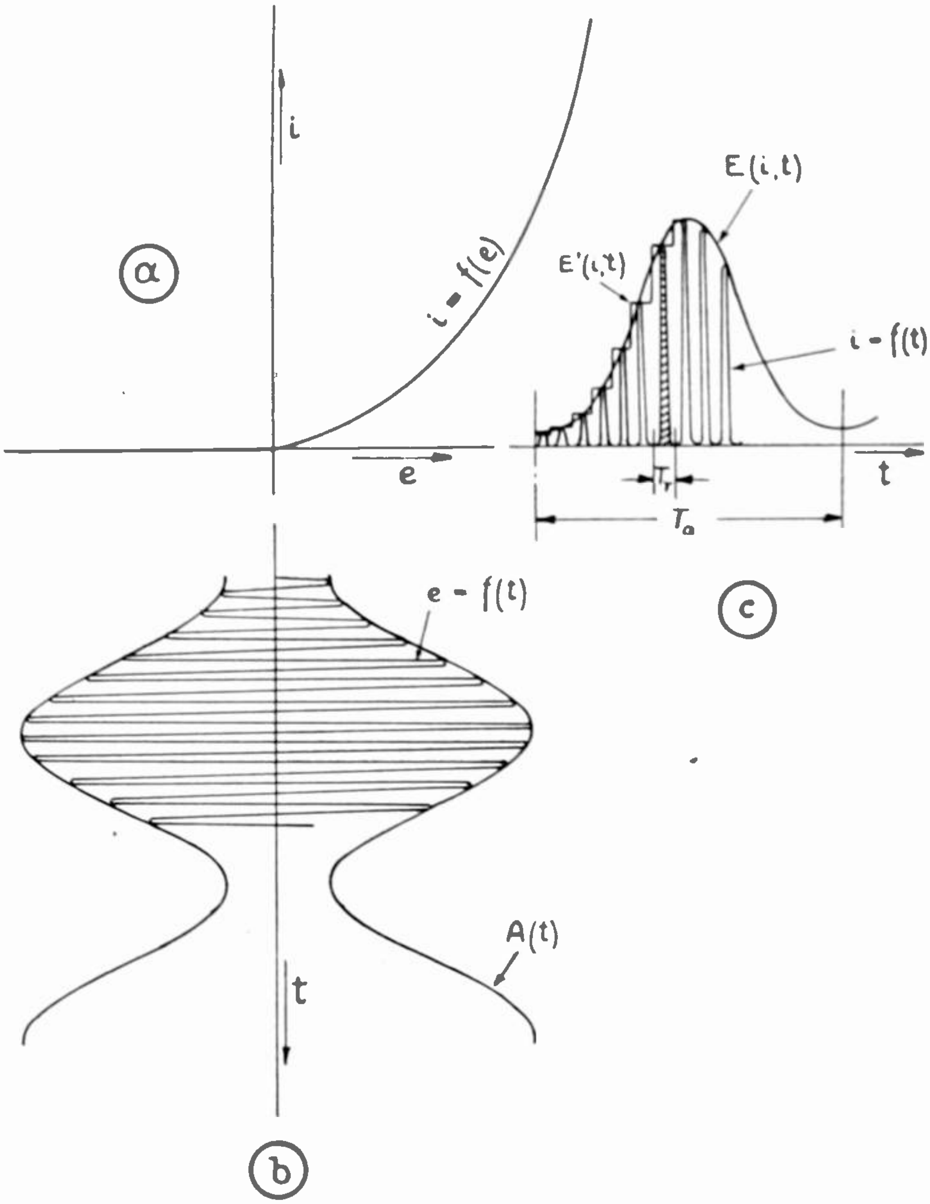

Fig. 8

in Fig. 8c. It is seen that i consists of radio-frequency components and audio-frequency components. The membrane of a loud speaker or of a

[5] H. Barkhausen, "Elektronenröhren," vol. 3, pp. 146 ff., Leipzig, (1929); S. Ballantine, "Detection at high signal voltages," Proc. I.R.E., vol. 17, p. 1154; July, (1929).

headphone, or the mirror loop of an oscilloscope will follow the audio components only. In each instant, the deflection will be proportional to the low-frequency current which is found to be

$$i_a = \frac{1}{T_r}\int_0^{T_r} i\,dt, \tag{20}$$

T_r being the period of the radio frequency. Substituting (18) and (19) into (20) we get

$$i_a=\frac{1}{T_r}\int_0^{T_r}\left[u_1A(t)\sin(\omega t+\phi(t))+u_2(A(t)\sin(\omega t+\phi(t)))^2+\ldots\right]dt. \tag{21}$$

The variation of $A(t)$ in the time interval T_r is very small, since

$$T_r \ll T_a.$$

Thus, $A(t)$ can be considered as being constant in the interval T_r, or, the function $E(i, t)$ in Fig. 8c can be replaced by the steps $E'(i, t)$ and we get

$$i_a = \sum_{n=1}^{n=\infty} u_n(A)(t))^n \,\frac{1}{T_r}\int_0^{T_r} \sin^n(\omega t + \phi(t))dt. \tag{22}$$

The values of the factors

$$\frac{1}{T_r}\int_0^{T_r} \sin^n(\omega t + \phi(t))dt \tag{23}$$

are plain numbers which are independent of T_r. This holds true also in the case of frequency or phase modulation, since in this case the integration interval T_r is varied accordingly. The evaluation of (22) yields

$$\begin{aligned} i_a = {} & \frac{1}{\pi}u_1A(t) + \frac{1}{4}u_2(A(t))^2 + \frac{2}{3}\cdot\frac{1}{\pi}u_3(A(t))^3 \\ & + \frac{3}{16}u_4(A(t))^4 + \frac{8}{15}\cdot\frac{1}{\pi}u_5(A(t))^5 \\ & + \frac{5}{32}u_6(A(t))^6 + \cdots. \end{aligned} \tag{24}$$

This result has been derived for a "perfect" detector; i.e., a detector which has zero conductivity in one direction. It may, however, be applied also to an "imperfect" detector which passes current in both directions (branches i_1 and i_2 in Fig. 9). In this case, as can be simply shown, the output obtained is equivalent to the output of a "perfect" detector which has the characteristic $i_1 - i_2'$; i_2' being the image of the branch i_2. Equation (24) shows that, in general, the audio output cur-

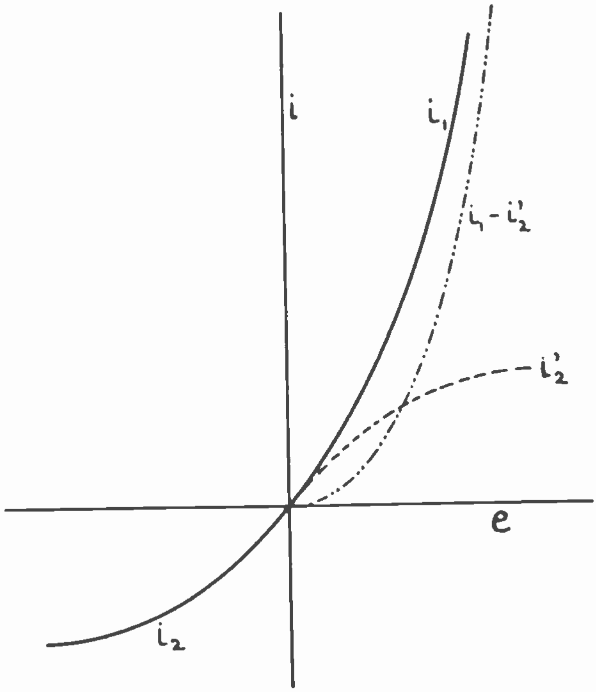

Fig. 9

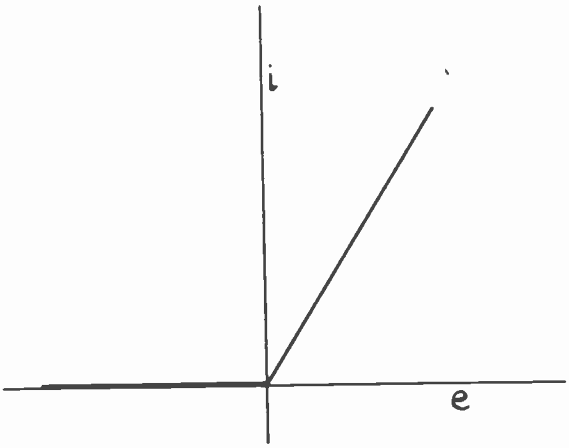

Fig. 10

rent of the detector will differ more or less from the envelope of the input radio-frequency voltage. Only for the "linear detector" (Fig. 10) for which $u_2, u_3, u_4 \cdots = 0$, the audio output current will be congruent to the input radio-frequency envelope.

IV. Conclusion

The two magnitudes, detector characteristic and radio-frequency envelope, are independent each from the other. A very great variety of detector characteristics may be used by properly choosing the characteristic and the load of the rectifier tube. The radio-frequency envelope, on the other hand, is defined by the modulation system applied at the transmitter, and the "transmission system" which extends from the modulated stage at the transmitter to the input terminals of the detector at the receiver. The "transmission system" thus defined contains the amplifier and output stages of the transmitter, the antenna circuit, the propagation medium, receiving antenna and the radio-frequency amplifier stages of the receiver. In opposition to the detector characteristic, it is obvious that with a given modulation system the radio-frequency envelope does not lend itself very well to arbitrary adjustment. For this reason, radio-frequency envelope and detector characteristic are to be treated separately. If the radio-frequency envelope is known, it may be applied to a suitable detector thus making it possible to distinguish properly between the distortions due to modulation and the transmission system on the one side and the procedure of demodulation on the other side.

It may be objected that the preceding considerations, being rather simple and self-evident, do not need to be discussed in such detail as has been done in Sections 1 and 3. But the author felt it justified when outlining these facts, since numerous publications on these problems do not consider that distortions in the audio output are due to *two independent sources,* one of which is arbitrarily adjustable to a much higher extent than the other. The procedure of taking into account only the distortions, which are contained in the output of the detector, does not give a check on the performance of the modulation or transmission system considered.[6]

[6] An example: In a paper by Mr. G. D. Gillet on the problem of common frequency broadcasting, a figure is given (Proc. I.R.E., vol. 19, p. 1347; August, (1931); Fig. 12, on page 1364), in which are plotted the distortion products, $\frac{\text{second harmonic}}{\text{fundamental}}$ obtained at a point equidistant from the two stations. For equal field strength, equal percentage modulation and with audio and radio phase angle = 0 the diagram shows the rather high second harmonic components of −12 db (25 per cent) and −18 db (12.5 per cent) for 100 per cent and 50 per cent modulation, respectively. At first glance one might think that this distortion was obtained as a consequence of the superposition of the two modulated signals, but closer inspection shows that the radio-frequency envelope of the resulting signal is a pure sinusoidal function. The distortion is simply caused by the square-law detector, which, as is well known, gives $\frac{1}{4}$ K per cent second harmonic distortion if the input signal is K per cent sinusoidally modulated. In the above case, a linear detector would show zero distortion.

Appendix 1

It can be simply proved that (15) represents an ellipse. We write with reference to Fig. 5:

x and y = coördinates of the point P,

σ = the angle between the horizontal axis and S_{n0},

θ = the angle between S_{n0} and D_{n0}.

Then,

$$x = S_{no} \cos \sigma$$

$$y = D_{no} \sin (\sigma + \theta).$$

Elimination of σ yields a second-degree equation which is shown in elementary analysis to be an ellipse.

Appendix 2

Point P_1 is obtained by shifting S_{no} and D_{no} by $\pm\frac{1}{2}\pi$. Solving for the direction of the tangent to the ellipse in point P_1 we find:

$$\left(\frac{dy}{dx}\right)_{\sigma+90°} = \frac{D_{no}}{S_{no}} \cdot \frac{\sin (\sigma + \theta)}{\cos \sigma}.$$

The direction of the diameter PP' is

$$\frac{y}{x} = \frac{D_{no}}{S_{no}} \frac{\sin (\sigma + \theta)}{\cos \sigma}.$$

Thus, the tangent and the diameter PP' are parallel. Consequently, the diameter PP' and the diameter P_1P_1' are conjugated.

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

SUPERPOSITION OF TWO MODULATED RADIO FREQUENCIES*

By

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Summary—*If two modulated radio frequencies are added, the envelope of the resulting signal can be found by means of a vector diagram. A number of envelopes corresponding to various conditions are shown. The distortions in the resulting envelopes are mainly due to phase shifts of audio frequency. Low percentage modulation helps to keep distortions small.*

The treatment applies to common-frequency broadcasting and to all cases in which the received signal consists of a direct and a reflected beam.

I. THE PROBLEM

THE purpose of this paper is to determine the output of a detector in case the detector input consists of two modulated carriers. Carrier frequency and modulation frequency, respectively, are assumed to be equal for both signals.

In practice, the conditions considered apply to two different cases: to common-frequency broadcasting and to television. Analytically, the treatment of both cases is exactly alike. In common-frequency broadcasting the receiving antenna picks up signals from two or more different stations simultaneously. For television with ultra-short waves, reflections on buildings, water, or hills may occur such that the receiver signal consists of one "direct" beam and of one or more "reflected" beams. We shall consider the case, in which only two "beams" are involved, which will be called beam 1 and beam 2. The assumption made above that the modulation frequencies are equal holds for both synchronized broadcasting and television, while as far as the carrier frequencies in common-frequency broadcasting are concerned quite noticeable differences may exist in practice. However, this investigation will be confined to a perfectly synchronized system.

Another assumption will be made regarding the paths of the individual carriers and their associated side bands. It is known that a distorted signal is obtained at the receiver if carrier and side bands travel over paths of different lengths.[1] Refractions in the Heaviside layer may be responsible for such phenomena. To treat this case is not within

* Decimal classification: R111.6. Original manuscript received by the Institute, July 27, 1932.

[1] R. K. Potter, "Transmission characteristics of a short-wave telephone circuit," PROC. I.R.E., vol. 18, pp. 581; April, (1930).

the scope of this note. We consider only the case in which the carrier and its side bands describe paths of equal lengths.

II. Derivation of the Vector Diagram

The electric field at a distance r which is due to a sinusoidally varying current in a transmitting antenna can be described by the equation of a traveling wave:

$$e = E \sin \omega \left(t_0 - \frac{r}{c} \right) \tag{1}$$

where ω is the radio radian frequency and c is the velocity of light. If the antenna current is modulated then the field becomes:

$$e = E \sin \omega \left(t_0 - \frac{r}{c} \right) \left(1 + k \sin \mu \left(t_0 - \frac{r}{c} \right) \right) \tag{2}$$

μ being the radian frequency of the audio frequency and k being the modulation factor (percentage modulation). In case two signals are obtained simultaneously in the receiving antenna then we have:

Beam 1:

$$e_1 = E_1 \sin \omega \left(t_0 - \frac{r_1}{c} \right) \left(1 + k_1 \sin \mu \left(t_0 - \frac{r_1}{c} \right) \right)$$

Beam 2:

$$e_2 = E_2 \sin \left(\omega \left(t_0 - \frac{r_2}{c} \right) + \varphi_0 \right) \left(1 + k_2 \sin \left(\mu \left(t_0 - \frac{r_2}{c} \right) + \psi_0 \right) \right).$$

Introducing a new origin of time, we put

$$t_0 - \frac{r_1}{c} = t. \tag{3}$$

This yields for beam 1:

$$e_1 = E_1 \sin \omega t (1 + k_1 \sin \mu t). \tag{4}$$

By means of the abbreviations

$$\frac{\omega}{c}(r_1 - r_2) + \varphi_0 = \frac{2\pi}{\lambda_\omega}(r_1 - r_2) + \varphi_0 = \varphi, \tag{5}$$

$$\frac{\mu}{c}(r_1 - r_2) + \psi_0 = \frac{2\pi}{\lambda_\mu}(r_1 - r_2) + \psi_0 = \psi, \tag{6}$$

the expression for beam 2 is transferred into

$$e_2 = E_2 \sin (\omega t + \varphi)(1 + k_2 \sin (\mu t + \psi)). \tag{7}$$

Inspection of (5) shows: φ is the phase displacement for the *carriers* of beams 1 and 2. It consists

of the initial phase displacement φ_0 and

of the path difference measured in degrees with respect to the wave-length, λ_ω, of the carrier.

Correspondingly, the term ψ (equation (6)) measures the *phase displacement* between the *radio-frequency envelopes.*

The resulting signal,

$$e = e_1 + e_2, \tag{8}$$

is applied to the input terminals of the detector. As shown in the preceding paper, the detector output is given by the rectification characteristic of the detector and by the envelope of the input radio frequency e. For finding the envelope, we apply the graphical method shown there. Putting

$$\alpha = \frac{E_2}{E_1} = \text{field strength ratio} \tag{9}$$

we obtain from (4), (7), and (8)

$$\begin{aligned} e = E_1 [& (\sin \omega t(1 + \alpha \cos \varphi) + \alpha \cos \omega t \sin \varphi) \\ & + \sin \omega t [k_1 \sin \mu t + \alpha k_2 \cos \varphi(\sin \mu t \cos \psi + \cos \mu t \sin \psi)] \\ & + \cos \omega t [+ \alpha k_2 \sin \varphi(\sin \mu t \cos \psi + \cos \mu t \sin \psi)]]. \end{aligned} \tag{10}$$

In (10), the term

$$E_1 [\sin \omega t(1 + \alpha \cos \varphi) + \alpha \cos \omega t \sin \varphi]$$

represents the carrier, while the rest of (10) represents the modulation vector. Applying the rule given in section 22 of the preceding article, we transfer (10) into vectorial form. We put:
in the expression for the carrier

$$\sin \omega t = +1,$$

$$\cos \omega t = +j,$$

in the expression for the modulation vector

$$\sin \omega t = -j\mathbf{R}_\mu$$

$$\cos \omega t = +\mathbf{J}_\mu$$

$$\sin \mu t = +1$$

$$\cos \mu t = +j.$$

Thus, (10) takes on the following form:

$$\begin{aligned} e = E_1[(1 + \alpha\epsilon^{j\varphi}) \\ + \mathbf{R}_\mu(- jk_1 + \alpha k_2 \cos \varphi\epsilon^{j(\psi-90^\circ)}) \\ + \mathbf{J}_\mu(\alpha k_2 \sin \varphi\epsilon^{j\psi})]. \end{aligned} \tag{11}$$

The symbols indicate:

$\mathbf{R}_\mu$ · · · only the *real* component is to be taken

$\mathbf{J}_\mu$ · · · only the *imaginary* component is to be taken

subscript μ · · · the vector is to be rotated with the angular velocity μ.

Equation (11) if represented graphically yields the vector diagram Fig. 1. The vectors S_{10} and D_{10} are to be rotated counterclockwise with

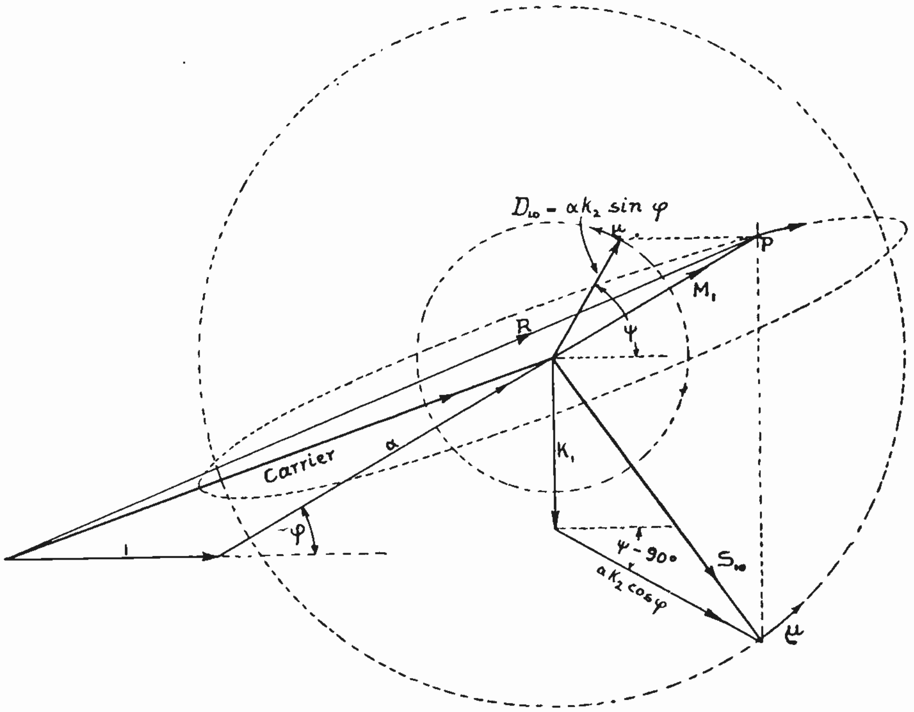

Fig. 1

the angular velocity μ. Their real and imaginary components respectively result in the modulation vector M_1, the end-point of which traces an ellipse. The vector R represents the instantaneous value of the amplitude of the radio-frequency envelope.

It can be seen immediately that the method lends itself equally well to the investigation of the case in which three and more signals of equal carrier frequency are superimposed. In this case, the three terms appearing in (11) would simply obtain additional members equivalent to those contributed by the beam 2.

In (2), we have assumed a simple sinusoidal modulation. But we have no difficulty in considering a more complicated audio function. Assuming, for instance, that the audio function contains many harmonic frequencies, we may put in (2)

$$e = E \sin \omega \left(t_0 - \frac{r}{c} \right) \left(1 + n \sum_{n=1}^{n=N} k_n \sin n\mu \left(t_0 - \frac{r}{c} \right) \right), \quad (12)$$

where,

$n = 1, 2, 3, 4 \cdots$

N = total number of audio frequencies present.

Superposing two signals of this type, and writing the resulting function in vectorial form (according to (11)), we get

$$e = E_1 \left[(1 + \alpha \epsilon^{j\varphi}) + n \sum_{n=1}^{n=N} \left\{ \mathbf{R}_{n\mu}(-jk_1 + \alpha k_2 \cos \varphi \epsilon^{j(\psi - 90°)})_n \right. \right. \quad (13)$$

$$\left. \left. + \mathbf{J}_{n\mu}(\alpha k_2 \sin \varphi \epsilon^{j\psi})_n \right\} \right]$$

whereby we indicate by the subscript n that the terms k_1, k_2, and ψ are to be taken for the nth component, while the summation sign refers to a geometrical summation of the individual modulation vectors according to Fig. 6, in the preceding article.

III. Radio-Frequency Envelopes Obtained by Superposition of Two Modulated Signals

In Figs. 2, 3, 4, and 5 radio-frequency envelopes are shown which are obtained by the superposition of two modulated signals. The curves have been obtained graphically by means of the method outlined above. The modulating frequency is a pure sine wave. The modulation factors, k, are in all figures equal for both beams. The envelopes are fully defined by four magnitudes:

field strength ratio, α,
modulation factors, k_1 and k_2
radio phase difference, φ
audio phase difference, ψ.

For the definition of the angles φ and ψ see (5), (6), and (7). In general, the envelopes are not sinusoidal functions, but show more or less distortion. We define:

Audio distortion: is obtained if the radio-frequency envelope is not a sine function.

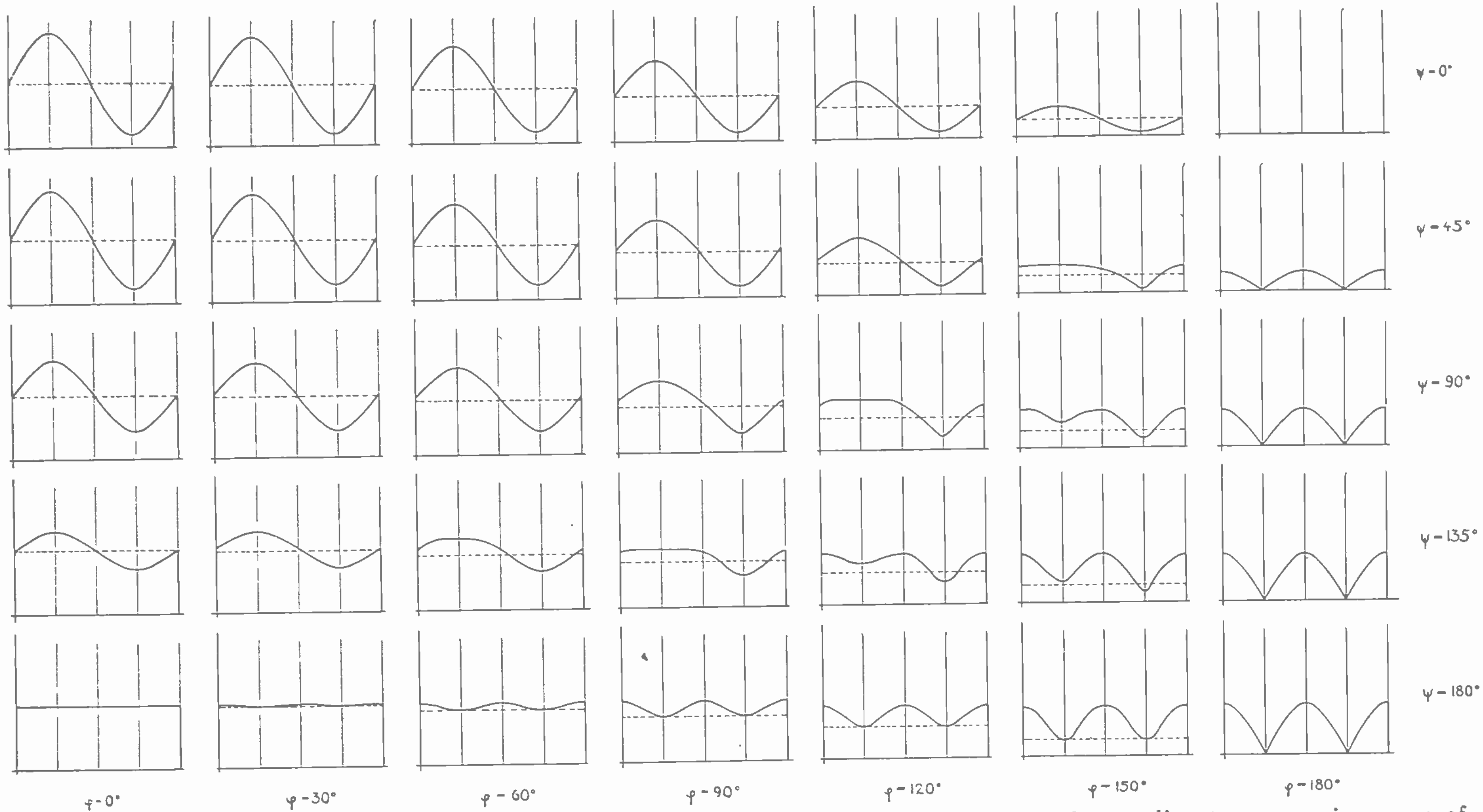

Fig. 2—Radio-frequency envelopes obtained by the superposition of two signals modulated according to a pure sine wave of audio frequency. 80 per cent modulation. Field strength ratio 1:1. The angles φ and ψ measure the path difference in degrees with respect to radio or audio frequency, respectively (see equations (5) and (6)).

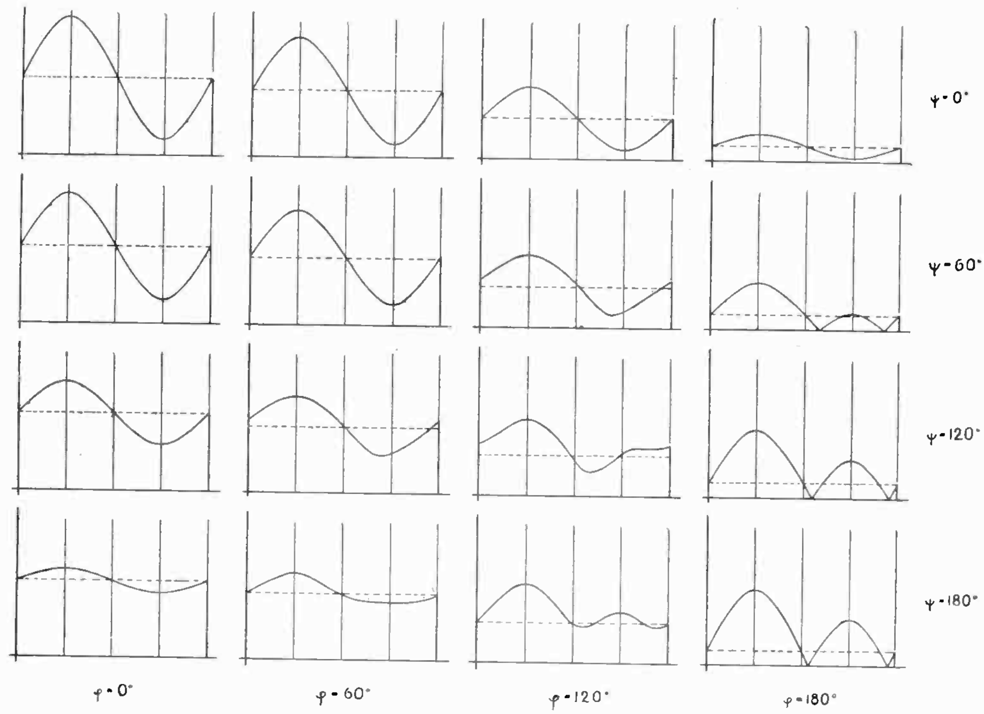

Fig. 3—Same as Fig. 2, but field strength ratio 1:1.5.

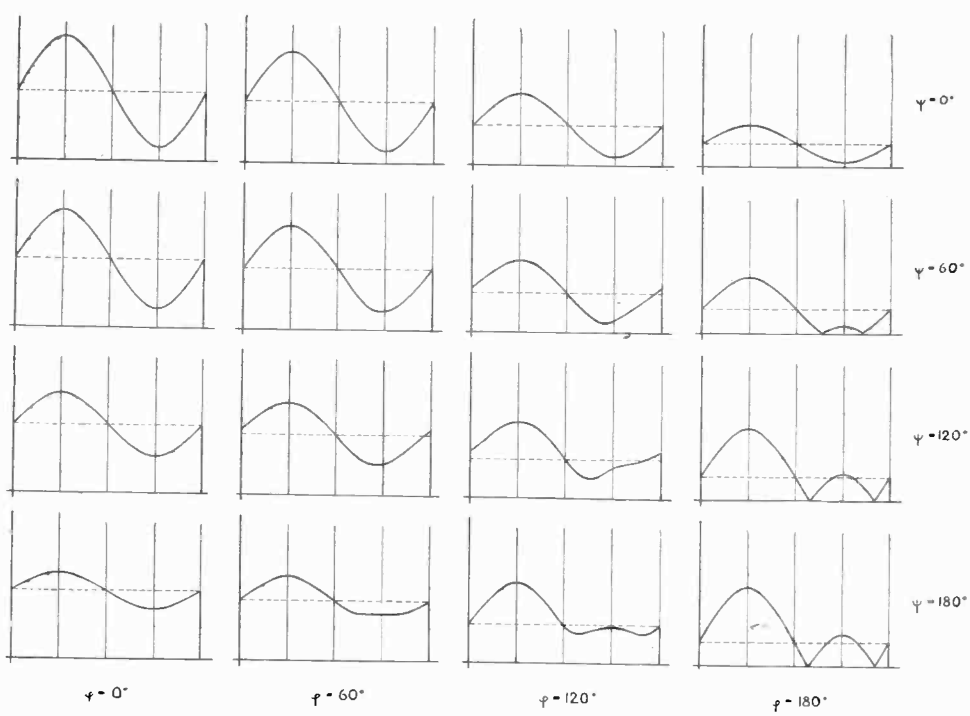

Fig. 4—Same as Fig. 2, but field strength ratio 1:2.

Amplitude distortion: is obtained if the ratio

$$\frac{\text{fundamental audio component of the envelope}}{\text{carrier}}$$

is not equal to k (percentage modulation). With these definitions we find by inspection of Figs. 2, 3, 4, and 5 $(m=1, 2, 3, \cdots)$.

If $\psi=2m\pi$, neither audio nor amplitude distortion is observed. The interference between the direct and indirect beam solely affects *the intensity of the signal.*

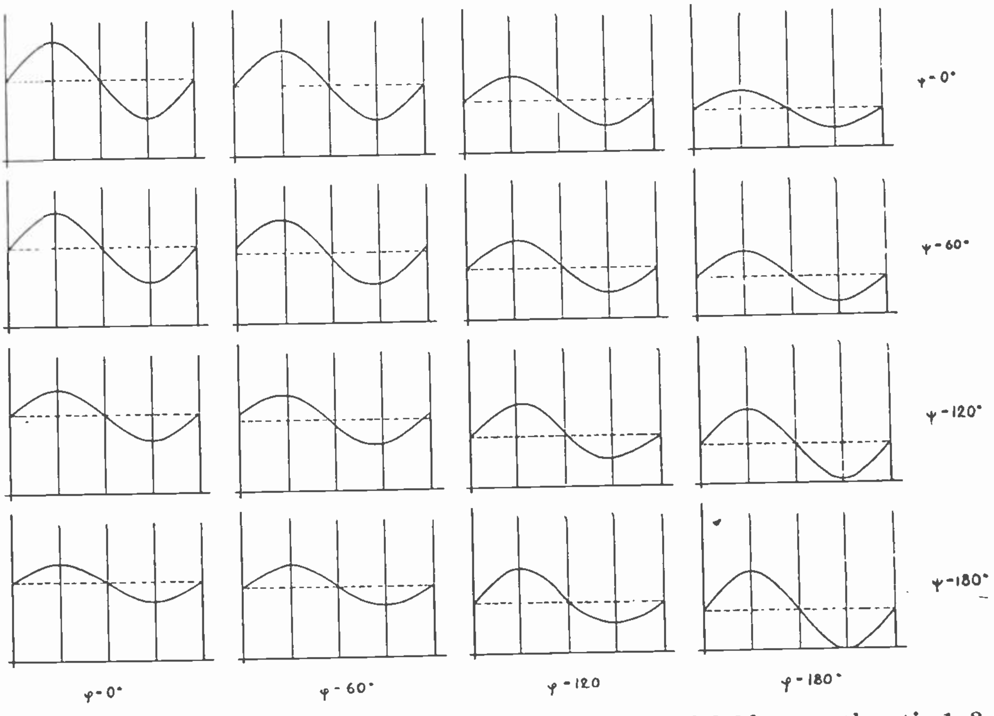

Fig. 5—Same as Fig. 2, but 50 per cent modulation and field strength ratio 1:3.

If $\varphi=(2m-1)\pi$, amplitude distortion is obtained. In case $\alpha=1$ and $\psi=(2m-1)\pi$, the side bands will cancel each other and only the carriers will be left.

With $\varphi=(2m-1)\pi$, in Figs. 2, 3, and 4 amplitude and audio distortion is observed. In Fig. 5, however, the audio distortion is very small, while amplitude distortion is still present. It can be shown easily from (11) that the severe second harmonic audio distortion being characteristic in this case for Figs. 2, 3, and 4 will not be obtained if

$$\frac{\alpha-1}{\alpha+1} > k.$$

The function

$$\frac{\alpha - 1}{\alpha + 1} = k \tag{14}$$

may, therefore, be used to discriminate between the conditions of "heavy distortions" and of "small distortions." This definition, of course, is rather arbitrary, but on account of the fact that the magnitudes α (ratio of field strengths) and k (percentage modulation) are in-

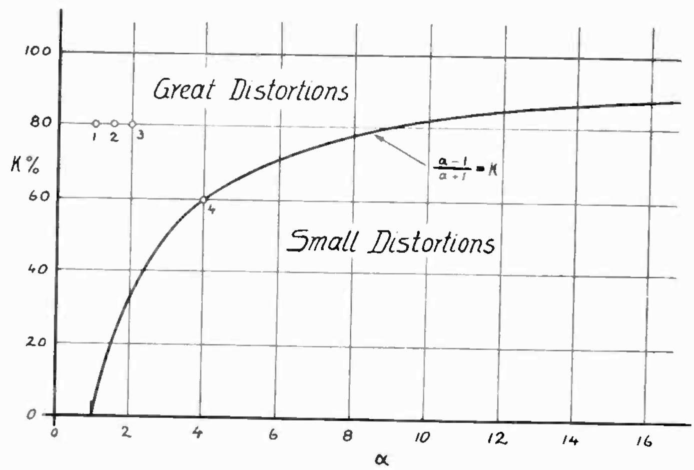

Fig. 6—Relationship between distortions, percentage modulation (k), and field strength ratio (α). Points 1, 2, 3, and 4 correspond to Figs. 2, 3, 4, and 5, respectively.

dependent of ω, μ, φ, and ψ, the expression (14) may be used advantageously to give quickly information about the type of distortions which are to be expected. Fig. 6 shows (14) graphically. From this diagram, it is observed that high percentage modulation is liable to cause severe distortions with greater probability than does low percentage modulation.

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

DISCUSSION ON "SOME NOTES ON GRID CIRCUIT AND DIODE RECTIFICATION"*

J. R. NELSON

Frederick Emmons Terman:[1] Mr. Nelson's extension of the work on power detection done by Colebrook, Peterson and Llewellyn, and Terman and Morgan represents a valuable contribution. There are, however, several matters bearing on the paper by the late N. R. Morgan[2] and myself that need elaboration.

In our article it was shown that the input resistance of the grid rectifier to the radio-frequency signal is *in excess* of $R/2 \cos \theta$, where R is the grid leak resistance, and $\cos \theta$ is the completeness of rretification. The value $R/2 \cos \theta$ represents the value of input resistance that would be obtained if all the grid currentflowed at the crest of the radio-frequency cycle, but since some of the current flows either just before or just after the crest, the actual losses are slightly less and the input resistance is correspondingly higher. Mr. Nelson's expression $R/2 \cos^2\theta$ for the input resistance can be shown to give a value that is always higher than the actual input resistance. This results from the fact that the value $R/2 \cos^2\theta$ is derived on the assumption that the losses in the input resistance equal the energy consumed by the grid leak. The energy lost in the rectifying device at the input electrode is hence neglected, making the apparent input resistance too high.

In the Terman-Morgan paper it was stated that in order to have distortionless grid rectification the effective grid condenser reactance X, the grid leak resistance R, and the degree of modulation m must satisfy the relation:

$$X/R \geqq m/\sqrt{1-m^2}. \tag{1}$$

This relation is equivalent to stating that the voltage across the grid condenser must be able to follow the variations in the modulation envelope throughout the cycle. Mr. Nelson prefers to replace equation (1) by the expression:

$$X/R \geqq m \tag{2}$$

and arrives at this result by determining the value of X/R required to enable the voltage across the grid condenser to die away as fast as the modulation envelope at the instant when the modulation is decreasing and the envelope amplitude is equal to the carrier amplitude. *This is not the part of the modulation envelope at which it is most difficult for the grid condenser voltage to follow the modulation envelope, as reference to our derivation will make clear, and so represents a condition at which some distortion is inevitably present.* Actually, if $X/R \geqq m$, the grid condenser voltage is theoretically, under ideal conditions, unable to follow the modulation envelope for slightly over a quarter of each modulation frequency cycle. Practically, however, unless the degree of modulation is high the difference between (1) and (2) is too small to be of much importance. Just what the situation would be with high degrees of modulation is not clear on the basis of the evidence now available, but offhand the proper starting point would appear to be with (1), since this relation is derived on the assumption of no distortion, while (2) is not.

* Proc. I. R. E., vol. 20, pp. 989–1004; June, (1932).
[1] Stanford University, California.
[2] F. E. Terman and N. R. Morgan, "Some properties of grid leak power detection," Proc. I.R.E. vol. 18, pp. 2160–2176; December, (1930).

The problem of obtaining distortionless rectification with 100 per cent modulation is a very interesting one. If grid leak power detection, or diode power detection with leak and condenser, is employed and it is assumed, as seems reasonable, that in order to obtain distortionless detection the voltage across the grid condenser must be able to follow the modulation envelope, then (1) must be satisfied, and any physical study of rectification that leads one to expect different results is incorrect. With 100 per cent modulation (1) requires that $X/R = \infty$; i.e. the grid condenser capacity must be zero. Practically, however, a certain amount of distortion can be tolerated so that even if (1) is not completely satisfied the distortion is not necessarily excessive. Furthermore there will ordinarily be other sources of distortion present, and these may either augment or cancel each other. Altogether the problem is a complicated one, without sufficient data now available for making a decision.

In conclusion, it is gratifying to note that Mr. Nelson's four listed conclusions are completely consistent with the Terman-Morgan paper on grid leak power detection. This article, which was submitted to the Institute in July, 1929,

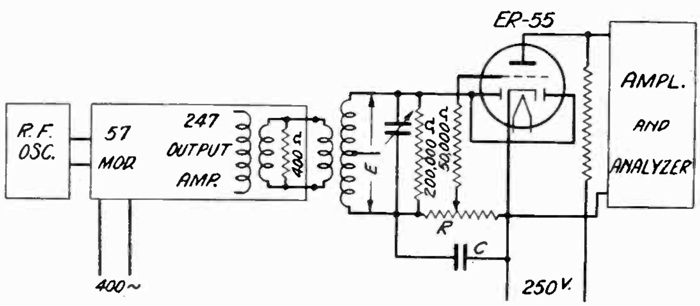

Fig. 1—Schematic diagram of apparatus used to measure detector distortion.

although not published until seventeen months later, showed that grid leak power detection was a practical possibility and outlined the conditions necessary to obtain satisfactory results. At the time it was met by considerable skepticism, although the commercial broadcast receivers using grid leak power detection that are now appearing on the market attest to the soundness of the ideas we presented.

J. R. Nelson:[3] Dr. Terman points out that the expression of $R/2 \cos^2 \theta$ gives values of input resistance which are too high, and that his expression $R/2 \cos \theta$ gives results which are too low. The values of calculated input resistances given in Fig. 3 of the above paper show up this as the theoretical value given by curves B which lie between the values of the above two expressions.

Since the above paper was written the writer has built some additional equipment by means of which any carrier up to 30 volts peak modulated with any desired percentage may be obtained. A new type of detector tube having two diodes and a triode in one bulb has also been developed since the paper was written. This type of tube is almost ideal for testing out the theory developed in the paper by F. E. Terman and N. R. Morgan and that given in the paper by the writer, and hence was used in the experimental work.

The equipment was set up as shown in Fig. 1. The unmodulated carrier voltage E was left constant at 7.5 volts peak for all the measurements and the potentiometer used for R_g was varied to give approximately a constant output

[3] Raytheon Production Corporation, Newton, Mass.

voltage going to the amplifier and analyzer. The distortion caused by a 55 tube acting as an audio amplifier and the output amplifier was less than 1.5 per cent for the input voltage used. A few check runs with values of x/R greater than one showed that the distortion was less than two per cent for any percentage of modulation up to 100 per cent. The modulation process undoubtedly causes some distortion but every effort has been made to keep this distortion low. The tuned circuit used was coupled quite closely to the 400 ohms output resistance of the 247 output amplifier, and it was also shunted with 200,000 ohms resistance so that the resonance curve was quite broad. It is believed that the following curves represent the distortion caused by the process of detection to a high degree of accuracy with the exception noted below.

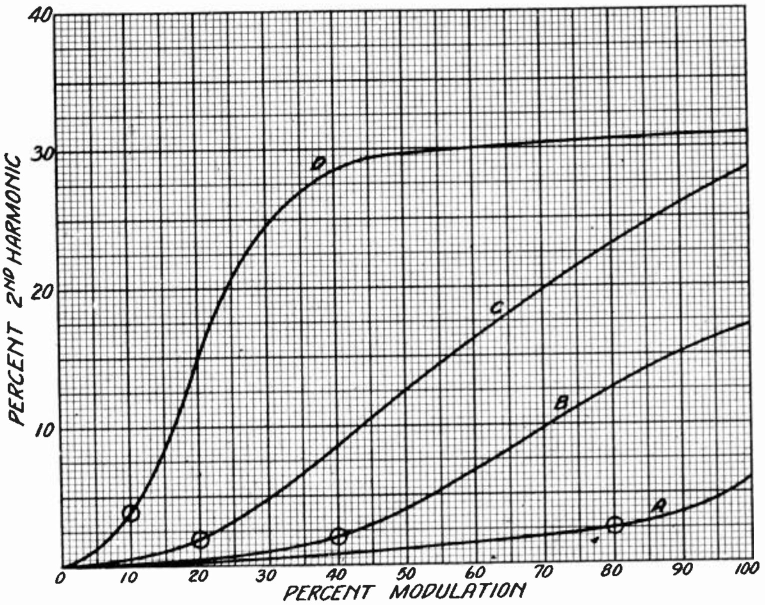

Fig. 2—Per cent 2nd harmonic plotted vs. per cent modulation

$A-x/R=0.8$	$R=0.5$ megohm	$C=1000\ \mu\mu f.$
$B-x/R=0.4$	$R=1.0$ megohm	$C=1000\ \mu\mu f.$
$C-x/R=0.2$	$R=1.0$ megohm	$C=2000\ \mu\mu f.$
$D-x/R=0.1$	$R=2.0$ megohms	$C=2000\ \mu\mu f.$

Fig. 2 shows the per cent second for a series of different values of R and C giving values of x/R equal to 0.8, 0.4, 0.2, and 0.1, and for modulation percentages up to 100 per cent. The values of m equal to x/R are marked with circles on the distortion curves. These curves bear out the writer's expression that the distortion will be negligible provided $x/R \geqq m$. On curve A for 80 per cent modulation the value of x/R according to the formula given the Terman and Morgan would have to be 1.34 to give negligible distortion, whereas, the writer found that any value of x/R greater than one would give negligible distortion even up to 100 modulation which of course is impossible with the expression $x/R \geqq m/\sqrt{1-m^2}$. As a matter of interest the above curves were repeated by placing the collectors in push-pull, and the results were practically the same.

The envelope amplitude is taken as $P(1 \div \cos t\ at)$. The writer's expression $x/R \geqq m$ picks the point where the rate of change of the envelope is greatest and that is when either a sine or cosine wave is passing through zero. This holds for all percentages of modulation and this theory explains why it is possible to obtain good quality with 100 per cent modulation and $x/R \geqq 1$.

Some might object to the theory developed by saying that the distortion is caused by a low ratio of alternating-current to direct-current impedance. There is some truth in this particularly when the x/R ratio is very low. The writer hopes to cover this subject in the near future as a few preliminary checks show that the effect of too low a ratio of alternating-current to direct-current impedance may be separated from the effect discussed here. It is believed that the distortion curves shown by curves A, B, and C are caused by the effect discussed above, while that shown in D is probably caused by both effects.

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Volume 20, Number 12 *December, 1932*

DISCUSSION ON "A NEW CIRCUIT FOR THE PRODUCTION OF ULTRA-SHORT-WAVE OSCILLATIONS."*

H. N. Kozanowski

Nello Carrara:[1] In his paper on the above subject, the author describes a circuit utilizing a pair of UX-852 tubes connected by symmetrical plate and filament Lecher systems instead of the usual plate-grid arrangement.

I wish to bring to your attention the publication of a paper by myself entitled "Sopra uno schema a due triodi per la produzione di onde ultracorte", which appeared in the December, 1931, issue of "*Elettrotecnica*" (volume XVIII, number 34, page 874). In this paper, a circuit is described which is not substantially different from that employed by Mr. Kozanowski. I have also pointed out that it is convenient to connect the Lecher system to the plates and to the filaments, and that the law $\lambda^2 V_g = K$ is not satisfied.

* Proc. I.R.E., vol. 20, no. 6, p. 957; June, (1932).
[1] Regio Istituto Elettrotecnico e delle Comunicazioni della Marina, Leghorn, Italy.

BOOK REVIEWS

Hochfrequenztechnik in der Luftfahrt, by H. Fassbender. Published by Julius Springer, Berlin. 577 pages, 1932.

This work has been prepared under the auspices of the German Research Institute for aviation. The matter contained in the twenty-three chapters has been prepared by various members of the staff of that institute and edited by its director, Dr. Fassbender. There is gathered together in this book and enormous amount of material on both theory and practice in the applications of radio to aviation which has heretofore been available only in articles scattered through the technical literature in several languages. Not only are the technical details as to antenna installations, transmitters, and receivers for the various frequency ranges in actual use treated in a very satisfactory manner, but also much information on methods of navigation of aircraft and organization of commercial airways is included. The theory of the propagation of electromagnetic waves in both the long- and short-wave ranges is quite adequately covered. As a matter of fact, radio engineers not specifically interested in the applications to aircraft will find much of interest and profit in this valuable compendium. The subject matter is logically and clearly arranged. The illustrations and printing are unusually good and the bibliographies which are appended to each major sub-division of the subject matter are very full and accurate.

Altogether this book is to be highly recommended to all interested in this rapidly growing application of the radio art. The radio fraternity has been placed under a great debt of gratitude to the German Research Institute for aviation.

*Lynde P. Wheeler

* Naval Research Laboratory, Bellevue, Anacostia, D.C.

Electronics, by Ralph Gorton Hudson, published by John Wiley & Sons, New York, 135 pages, 1932, price $2.00.

In order to appreciate this book, one must understand its purpose, which the author in his preface states is "for the reader who may wish to know something of what is going on and who has not heretofore given the matter much attention." Without this in mind, the average reader would most likely be disappointed in what he would find between the covers. A more descriptive title might have been used to advantage, such as "Electronics; the Physical Fundamentals."

These two points are understandable when one finds that twenty-two pages are devoted to evolution of electron theory; fourteen pages to constitution of matter and nine pages to conduction in nonmetallic liquids, while no mention of any radio application is made and only two pages are devoted to applications outside the broad field of talking motion pictures and television. Also the whole subject of high vacuum diodes, triodes, pentodes, and tetrodes is covered in nine pages.

It is a short book, only 131 pages of text, and yet thermionic emission is not taken up until page 89.

There are sections devoted to subjects not commonly associated with electronics, such as the "Theory of the Origin of the Gravitational Force," "The Bohr Model," "The Principle of Indeterminacy," and the "Principle of Least Action."

All of these points are mentioned not as a criticism of the book but to explain better that it covers the basic physical principles in electronic devices and their scientific background rather than the engineering viewpoint. There are a few detail points on which an engineer on vacuum tube work might not agree entirely with the author but these are not important from the viewpoint of the purpose of the book.

It is a rather unique publication inasmuch as it has no chapter numbers, no table of contents, no references, no footnotes and no index. It might, however, have been improved by including the last feature. Mathematics are used only sparingly.

It is a good book for every electrical engineer dealing with vacuum tubes to read for it may remind him of the scientific background of his whole activity and it is helpful to see more clearly the mental processes that have led to the evolution of the tools placed in his hands.

*W. C. White

* General Electric Co., Schenectady, N.Y.

Proceedings of the Institute of Radio Engineers
Volume 20, Number 12 *December, 1932*

RADIO ABSTRACTS AND REFERENCES

THIS is prepared monthly by the Bureau of Standards,* and is intended to cover the more important papers of interest to the professional radio engineer which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the "Classification of Radio Subjects: An Extension of the Dewey Decimal System," Bureau of Standards Circular No. 385, obtainable from the Superintendent of Documents, Government Printing Office, Washington, D.C., for 10 cents a copy. The classification also appeared in full on pp. 1433–1456 of the August, 1930, issue of the PROCEEDINGS of the Institute of Radio Engineers.

The articles listed are not obtainable from the Government or the Institute of Radio Engineers, except when publications thereof. The various periodicals can be secured from their publishers and can be consulted at large public libraries.

R100. Radio Principles

R113 T. L. Eckersley. Direct ray broadcast transmission. PROC. I.R.E. vol. 20, pp. 1555–1579; October, (1932).

The paper is written with a view of enabling predictions to be made as to the field strength of direct ray transmission on wavelengths between 60 meters and 2000 meters. The main part of the paper is concerned with daylight transmission. The question of night transmission and the influence of the Heaviside layer are considered briefly at the end.

R113 T. L. Eckersley. Studies in radio transmission. *Jour. I.E.E.*, vol. 71, pp. 405–459; September, (1932).

"With the advent of short-wave telegraphy, a new technique of echo and facsimile measurement has been developed, facilitating signal-intensity measurements in the wavelength range between 15 and 50 meters. Part 1 of this paper deals with the method adapted for making facsimile measurements, and describes the results obtained, whilst in part 2 the author discusses transmission problems in the light of these data and suggests the theoretical methods to be employed in solving such problems. Part 3 discusses the problem of scattering, while in part 4, the author deals with theory."

R113 I. Ranzi. Causes of ionization in the upper atmosphere. *Nature* (London), vol. 130, p. 545; October 8, (1932).

A letter in which conclusions are drawn from observations of the virtual reflection height of radio waves 40–140 meters.

R113.3 J. F. Coates. A note on the theory of night errors in Adcock direction-finding systems. *Jour. I.E.E.*, vol. 71, pp. 497–506; September, (1932).

The paper deals with the theory of night errors. Expressions are described for errors which may be obtained as a result of the presence of both ground and atmospheric waves. The fixed Adcock system is shown to be less liable to error than loop systems, but there are substantial zones in which the fixed Adcock system is subject to blurred minima and to errors of bearing. The rotating Adcock is shown to be free from blurred minima and errors due to night effect.

R113.5 E. B. Judson. Science Service Ursigrams. *QST*, vol. 16, p. 35; September, (1932).

Interpreting the broadcasts of cosmic data from NAA.

* This list compiled by Mr. A. H. Hodge and Miss E. M. Zandonini.

R113.55 The wireless eclipse—Corpuscular "ionization not proven?" *Wireless World*, vol. 31, p. 273; September 16, (1932).

It is stated that the evidence obtained during the August 31 eclipse indicates that there was probably no corpuscular eclipse. However, the data are not conclusive.

R113.55 E. F. W. Alexanderson. Effect of sun's eclipse on radio waves. *Radio Engineering*, vol. 12, pp. 19–20; October, (1932). *Electrician* (London), vol. 109, p. 446; October 7, (1932). *Everyday Science & Mechanics*, vol. 3, p. 1129; November, 1932.

Using a frequency of 8655 kc it was found that pulse signals almost totally disappeared during the two hours previous to the optical eclipse. This phenomenon is taken to establish the fact that the corpuscular or electronic eclipse was a reality and occurred as predicted.

R113.62 G. Goubau and J. Zenneck. Anordnung für Echo-messungen an der Ion-sphäre. (An arrangement for echo measurements in the ionosphere.) *Hochfrequenz. und Elektroakustik*, vol. 40, pp. 77–82; September, (1932).

An arrangement is described for the measurement of echoes from the ionized layers. It permits the use of six different frequencies between the wavelengths of 1000 and 40 meters, and has the further advantage that a frequency change can be made in a few seconds. The receiving device uses a Braun tube for observation means. Schematic circuit arrangements of the receiving and transmitting sets and pulser are given.

R113.62 E. V. Appleton and J. A. Ratcliffe. Polarization of wireless echoes. *Nature* (London), vol. 130, p. 472; September 24, (1932).

It is stated that some of the results published by T. L. Eckersley appear to be contradictory to the magneto-ionic theory and also to those obtained when other comparable methods of polarization delineation are employed in the same connection. It is requested that Mr. Eckersley make a complete publication for more complete comparison of results.

R125 T. McLean. Transmission-line feed for short-wave antennas. *QST*, vol. 16, pp. 25–29; October, (1932).

Two-wire antenna systems in which lines are uniform are discussed. Tuning with aid of a dummy antenna and matching line and antenna are discussed.

R133 J. Sahanek. Die Erzeugung Hertzscher Wellen mittels Dioden. (The production of Hertzian waves by means of diodes.) *Physikalische Zeits.*, vol. 33, pp. 693–703; September, (1932).

A study of the methods of production of Hertzian waves is first given. The author concludes that any arrangement consisting of two or more electrodes in a more or less exhausted gas-filled space is useful for the production of Hertzian waves if the following conditions are fulfilled. An electron current goes from one electrode to a second electrode, whose periodic intensity component lies in the plane of the first electrode, and whose periodic part changes synchronously with the electromotive force which is connected between the electrodes. It is found therefore that new ranges of oscillation may be found wherever suitable conditions for oscillation exist. Two new discharge paths are found in the diode. Results of an experimental study of diodes are given.

R133 ×R355.5 A. Roslagni. Electric oscillations. *Nature* (London), vol. 130, pp. 509–10; October 1, (1932).

A letter gives a brief account of a theory on the mechanism of oscillations produced in a positive-grid vacuum tube.

R133 H. Rindfleisch. Über den Einfluss von Gasen auf Barkhausenschwingungen. (On the influence of gases on Barkhausen oscillations.) *Ann. der Physik*, vol. 14, pp. 273–298, (1932).

The effect of gases, especially helium and neon on the Barkhausen oscillations, is investigated. The electrode structure of the tube is of the "Schott K" type. The introduction of gas caused in all cases a change in the intensity of oscillation and a decrease in frequency. The results of the variation of pressure are given. After the extended study of various conditions of voltages and gas content an explanation of phenomena observed is offered.

R134 N. Carrara. The detection of microwaves. PROC. I.R.E., vol. 20, pp. 1615–1625; October, (1932).

The results of researches made to recognize the best conditions in which triodes can be used for the detection of microwaves (frequencies of about 10^9 per second) are reported. It seems that the detecting triodes, which must have their grids at a very high positive potential and their anodes at a potential just lower than that of the positive end of the wire, act simply like rectifying diodes with electrodes very near to one another.

R140 J. G. Brainerd. Note on network theory. PROC. I.R.E., vol. 20, pp. 1660–1664; October, (1932).

Passive transducers may be connected in any manner between two pairs of terminals to form a resultant passive transducer between those terminals. In this note are given or indicated general expressions for the important properties of such a resultant transducer in terms of those of the transducers forming it for the case in which the arrangement of the subsidiary transducers can be achieved by some combination of series and parallel connections. Section (a) treats of transducers in parallel; (b) in series; (c) in series-parallel.

R145 ×R386 R. T. Beatty. Two-element band-pass filters. *Wireless Engineer and Experimental Wireless* (London), vol. 9, pp. 546–557; October, (1932).

This paper shows how the design of band-pass filters can be simplified by the use of charts from which the type of filter best suited to a particular problem can be immediately chosen. Numerical values can then be easily calculated. The treatment is limited to symmetrical filters.

R165 N. W. McLachlan. Damping of low-frequency oscillations in an m.c. loudspeaker. *Wireless Engineer and Experimental Wireless* (London), vol. 9, pp. 559–563; October, (1932).

A fourth order differential equation is given which can be adapted to investigate the low-frequency growth or decay of transients in a moving coil loud speaker. The stronger the magnetic field and the lower the closed coil circuit resistance, the greater the damping. It is stated that the quality of reproduction of commercial loud speakers would be improved by increasing the magnetic field strength.

R200. Radio Measurements and Standardization

R255 G. Leithäuser. Über die Leistung von Endröhren in Verstärken und deren praktische Bedeutung. (On the power of output tubes in amplifiers and its practical meaning.) *Elektrotech. Zeits.*, vol. 39, pp. 937–939; September 29, (1932).

A method of rating power amplifiers on the basis of their undistorted power output is proposed.

R261 O. H. Schuck. Visual test devices. PROC. I.R.E., vol. 20, pp. 1580–1598; October, (1932).

A device for showing on a screen the frequency-response curve of a tuned circuit, tuned transformer, amplifier, or complete radio set is described in this paper. The action of the device is practically instantaneous, and the effect of circuit adjustments may be seen immediately. The principles and operation of the device are explained.

R261.5 J. W. Alexander. Störungen beim Radio-Empfang. (Disturbances in radio receiver.) *Hochfrequenz. und Elektroakustik*, vol. 40, pp. 82–88; September, (1932).

A Fourier treatment of the disturbance produced by a rectifier, motor, etc., is given. The Fourier spectra of these disturbances are shown graphically. The maximum permissible noise or disturbance is calculated. Disturbance measurements are made for different sources of disturbance on several different receivers.

R261.6 R. F. Shea. Power transformer testing. *Radio Engineering*, vol. 12, pp. 14–15; October, (1932).

Design of a test board by means of which tests are made on power units used in receiving sets and kits.

R264.2 A. L. M. Sowerby. The new tuning coils. *Wireless World*, vol. 31, pp. 312–314; September 30, (1932).

This article gives practical measurements of the efficiency of iron-cored coils.

R264.2 O. Stuhlmann and S. Githens. The magnetic field of a solenoid oscillating at radio frequencies. *Rev. Sci. Inst.*, vol. 3, pp. 561–571; October, (1932).

It is usually assumed that the magnetic field under radio-frequency excitation is analogous to the field obtained in the same coil when excited by direct current. This paper considers the problem of whether this assumption is justified. When excited by a tuned-plate tuned-grid oscillator the same symmetrical magnetic field was not found. A push-pull circuit arrangement gave a symmetrical field.

R264.2 H. Vogt. New Development in tuning coils. *Wireless World*, vol. 31, pp. 272–273; September 16, (1932).

Coils having special cores of "Ferrocart" are described. Inductances of very high efficiency are obtained in this way.

R300. Radio Apparatus and Equipment

R320.8 S. Couzin. A three-sided radio tower. *Radio Engineering*, vol. 12, pp. 17–18; October, (1932).

A method is described of erecting self-supporting radio towers, the main members being pipe sections, and the bracing pipe or double angles. Liberal use is made of welding.

R325.31 ×R526.2 R. Hardy and Bertrand-Lepaute. Radio-compas stroboscopique à lecture directe. (A direct-reading radio-compass stroboscope.) *Comptes Rendus*, vol. 195, pp. 518–520; September 5, (1932).

A stroboscope is described which makes it possible to read directly radio directions. The current from rotating coils is superposed on the current of an adjustable antenna. Twice for each revolution of the coil a point of zero e.m.f. occurs. A wave form is thus obtained which is amplified and applied to a stroboscope.

R325.31 ×R113.5 G. H. Munro and L. G. H. Huxley. Shipboard observations with a cathode-ray direction-finder between England and Australia. *Jour. I.E.E.*, vol. 71, pp. 488–496; September, (1932).

The paper describes the installation of a cathode-ray direction finder on board a ship and observations on low-frequency stations and atmospherics during a voyage from Port Said to Brisbane. Directional observations on low-frequency stations showed little evidence of errors in bearings. Daily observations on atmospherics on 30,000 meters were made. Directions of atmospherics corresponded to region of low pressure and thunderstorms.

R330 Tube types tabulated. *QST*, vol. 16, p. 36; September, (1932).

List of present-day tubes.

R330 K. Henney. Characteristics of American electronic tubes. *Electronics*, vol. 5, p. 308; October, (1932).

The complex meaningless system of nomenclature is lamented. A brief mention is made of the nomenclature being considered by the Vacuum Tube Committee of the Radio Manufacturers Association.

R330 H. E. Mendenhall. Radiation-cooled power tubes for radio transmitters. *Bell Laboratories Record*, vol. 11, pp. 30–36; October, (1932). *Electronics*, vol. 5, pp. 316–317; October, (1932).

Three new power tubes are described which are intended to fill the gap between 250 and 5000 watts. They are all radiation-cooled type with peak power output capacities of 500, 1500, and 2000 watts, respectively. The tubes are numbered 270-A, 251-A, 279-A in order of increasing power.

R331 A. Gehrts. Oxydkathoden. (Oxide cathodes.) *Die Naturwissenschaften*, vol. 20, p. 732–738; September 30, (1932).

The oxide cathode is discussed. Its emission, composition, activation, current conductivity, reactions, etc., are treated.

R331 C. H. Marshall. Testing the elasticity of vacuum tube filaments. *Bell Laboratories Record*, vol. 11, pp. 48–52; October, (1932).

The method and apparatus used in testing the physical properties of vacuum tube filament wire are described.

R339 K. W. Jarvis. Notes on the 59-type power output tube. *Electronics,* vol. 5, pp. 310–311; October, (1932).

Operating notes and characteristics.

R355.21 A. W. Kishpaugh. A low-power broadcast transmitter. *Bell Laboratories Record,* vol. 11, pp. 37–42; October, (1932).

Parts and arrangement of a transmitter intended to work between power limits of 100–1000 watts are described. Schematic circuit arrangement is given.

R355.9 G. Grammar. Electron-coupled oscillators for the small transmitter. *QST*, vol. 16, pp. 13–17; October, (1932).

Difficulties encountered in experiments with low-power electron-coupled oscillators for transmitters are enumerated. Vacuum tubes and circuit arrangements are given.

R355.9 H. J. Reich. The thyratron relaxation oscillator and some of its applications. *Rev. Sci. Instr.*, vol. 3, pp. 580–585; October, (1932).

The method of oscillation of the thyratron and several applications of the circuit are given.

R357 W. F. Westendorf. An inverter-lamp for the conversion of 60-cycle power into 1000-cycle modulated light. *Physics*, vol. 3, pp. 193–202; October, (1932).

A gaseous discharge lamp in combination with a special electrical circuit is described with which a high-efficiency conversion of 60-cycle alternating-current power into 1000-cycle pulsating light is obtained. The efficiency of the device is 17 lumens per watt as compared to 6 lumens per watt for an incandescent lamp with a mechanical shutter. The modulated light is designed for use in beacons.

R361 R. B. Parmenter. An all-wave midget receiver. *QST*, vol. 16, pp. 14–16; November, (1932).

A semiportable receiving set covering from 12 to 4500 meters is described.

R361.2 J. J. Lamb. An intermediate-frequency and audio unit for the single-signal superhet. *QST*, vol. 16, pp. 9–16; September, (1932).

Adjustment and performance.

R365.3 L. O. Grondahl and W. P. Place. Copper-oxide rectifier used for radio detection and automatic volume control. PROC. I.R.E., vol. 20, pp. 1599–1614; October, (1932).

A new type of radio detector is described which depends for its action on the rectifying properties of the boundary between copper and cuprous oxide formed on the copper at a high temperature. The circuits developed possess unique advantages in that harmonic distortion is practically eliminated, a stage of audio-frequency amplification is eliminated, and automatic volume control of variable-μ tubes as well as other tubes is achieved without the necessity of using an auxiliary tube for volume control. A new form of automatic volume control made possible by the use of a single rectifier element as an asymmetrical resistance is described and discussed.

R365.3 H. W. Lord. Electronic timer for very short time intervals. *Electronics*, vol. 5, p. 309; October, (1932).

A device is described which uses a photocell to detect an event and trip off a thyratron. Another photocell operates a thyratron at the end of the interval. A milliammeter is used for indicating time. It is placed in the plate circuit of a vacuum tube whose grid voltage is proportional to time of event.

R366 D. Dekker and W. Keeman. Stabilized "B" supply for a.c. receivers. *QST*, vol. 16, pp. 18–20; October, (1932).

A method of using the neon tube to smooth out voltage variations in "B" eliminator output is given.

R366 J. Dunsheath. Primary battery substitutes for automobile radio receivers. *Radio Engineering*, vol. 12, pp. 9–10; October, (1932).

A review of the subject of "B" battery substitutes from the viewpoint of the manufacturers of radio receivers and the manufacturers of automobiles.

R385.5 H. F. Anderson. A sure-fire condenser microphone. *QST*, vol. 16, pp. 22–24; November, (1932).

Full details for the amateur builder.

R400. Radio Communication Systems

R430 Selectivity—Methods of cutting out interference. *Wireless World*, vol. 31, pp. 332–333; October 7, (1932).

The connection between real and apparent selectivity and the dependence of selectivity upon amplification, volume level, and reaction are discussed in this article.

R430 W. S. Percival. A balanced wave trap. *Wireless World*, vol. 31, p. 274: September 16, (1932).

A circuit arrangement for eliminating local station interference is described.

R500. Applications of Radio

R521.2 ×R270 F. Eisner; H. Rehm; H. Schuchmann. Frequenzanalyse von Flugzeuggeräuschen. (Frequency analysis of airplane noises.) *Elek. Nach.-Tech.*, vol. 9, pp. 323–333; September, (1932).

There is given a survey of the method of noise analysis used up to the present time. The analyzers are treated theoretically. The experimental results of noise analyses are given. The frequency spectrum of airplane noises is usually contained between 100–1000 cycles.

R526.1 E. Kramer. Neuere Arbeiten auf dem Funkbaken-Gebiete. (Recent work in the field of radio beacons.) *Hochfrequenz. und Elektroakustik*, vol. 40, pp. 88–92; September, (1932).

A brief historical development of the radio beacon is given. By means of a new keying method a sharpening of the directive ray is obtained. A description of a new optical direction indication for a radio beacon follows. The applicability of the beacon principle for ultra-short waves is outlined.

R581 Y. Niwa. A synchronizing system for electrical transmission of pictures. *Electrical Communication*, vol. 11, pp. 91–96; October, (1932).

A system for synchronizing picture transmitter and receiver is described. It uses a tuning fork at transmitting station and one at receiving station. A small synchronizing current is transmitted which holds the two forks in synchronism.

R583 H. R. Lubcke. Receiving television in an airplane. *Radio Engineering*, vol. 12, pp. 12–13; October, (1932).

In order to prove that a self-synchronized receiver would operate away from power lines common to transmitter, a receiver was carried on test flights in an airplane. Recognizable images were obtained. Results of the test are given.

R800. Nonradio Subjects

535.3 F. C. Nix. Photo-conductivity. *Rev. Modern Physics*, vol. 4, pp. 723–766; October, (1932).

An extensive and comprehensive treatment is accompanied by 189 references.

535.3 E. D. Wilson. Photocells from rectifier disks. *Electronics*, vol. 5, pp. 312–313; October, (1932).

A discussion is given of the rectifier disk and its sensitivity to light. Three graphs are given, namely: a current-light curve of a typical cuprous-oxide cell; a power-load curve of a typical cell; and a voltage-light curve of a cuprous-oxide cell.

535.38 J. C. Peters and E. B. Woodford. Characteristics of certain caesium-oxide photo-electric cells. *Physics*, vol. 3, pp. 172–178; October, (1932).

Results of tests made to determine the effects of illumination and time upon the sensitivity of 13 commercial caesium-oxide photo-electric cells are given. The effect of ambient temperature upon four cells was also measured.

537.7 W. L. Barrow. A new electrical method of frequency analysis and its application to frequency modulation. Proc. I.R.E., vol. 20, pp. 1626–1639; October, (1932).

A method of analyzing an arbitrary combination of sine wave voltages is described and the analysis of several examples carried out. The method is based on the appearance of certain figures, typical of definite frequency ratios, appearing in an oscillogram of the superposition of a constant frequency and a "search" voltage. The resolving power of the method is very high, allowing component voltages of only two cycles per second frequency difference to be clearly resolved. A frequency modulated wave is then analyzed.

537.7 ×R363.1 L. B. Hallman, Jr. A Fourier analysis of radio-frequency power amplifier wave forms. Proc. I.R.E., vol. 20, pp. 1640–1659; October, (1932).

A theoretical treatment of Class B and C radio-frequency amplifier wave forms by means of the Fourier series is presented. Assuming constant plate tuned circuit impedance, general expressions for the Fourier coefficients for any value of grid bias from cut-off to the position for class A operation are delivered. The variation in plate circuit efficiency as the bias is moved from the position for class A operation to cut-off is considered. Ideal wave forms with which class C operation would be obtained are analyzed.

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PROCEEDINGS

OF

THE INSTITUTE OF RADIO ENGINEERS

(INCORPORATED)

VOLUME 20

1932

PUBLISHED MONTHLY BY

THE INSTITUTE OF RADIO ENGINEERS

(INC.)

33 WEST 39TH STREET, NEW YORK, N. Y.

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An Index covering the years 1909 through 1930 is available in pamphlet form, and may be obtained from the Institute at $1.00 per copy. A limited number of the 1931 Index, which was published in pamphlet form as a supplement to the January, 1932, issue of the PROCEEDINGS, are offered for distribution.

The Index for 1932 is a continuation of the previous ones. It is numbered chronologically, and the numbers at the left of the titles are keys for use in referring to it from the Authors Index and the Cross Index.

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S

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Haigis, C. D.	R.C.A. Victor Co., Camden, N.J.
Haldane-Duncan, B.	122 Fifth Ave., Rm. 1009, New York, N.Y.

Hammer, Robert H.	220 Lincoln Place, Brooklyn, N.Y.
Hampton, S. G. A.	c/o S.S. Incalite, International Petroleum Co., Talara, Peru, So. Am.
Hardin, Forrest F.	5534 Cabanne Ave., St. Louis, Mo.
Harness, Sam A.	463 West St., New York, N.Y.
Harris, Charles S.	P. O. Box 53, Ampere, N.J.
Hay, Albert E.	Oak Lodge, Nathan Rd., North Wembley, Middlesex, England.
Hayes, Wilber A.	289 Schenck St., No. Tonawanda, N.Y.
Heather, Harold	2214 S. La Brea Ave., Los Angeles, Calif.
Heina, William M.	Crosley Radio Corp., Cincinnati, Ohio.
Hild, George E.	621 Walnut Ave., Syracuse, N.Y.
Hill, Frederick A.	P. O. Box 212, Hinsdale, Ill.
Hinklin, Lewis G.	643 W. Spring St., Lima, Ohio.
Hinton, Norman P.	British Thomson-Houston Co., Ltd., Alma Street, Coventry, England.
Hoffman, R. W.	306 West 112th St., New York, N.Y.
Hoffman, Walter H.	R.R. 4, Monroeville, Ind.
Holst, P. F. G.	1115 White Horse, Oaklyn, N.J.
Hopper, C. L.	Box 543, Frankfort, Mich.
Houdyshell, Lowell B.	1043 S. Kingsley Dr., Los Angeles, Calif.
Hudson, Julius	Duratron Radio Tube Corp., 409-38th St., Union City, N.J.
Hull, Charles E.	426 Cedar Ave., Highland Park, New Brunswick, N.J.
Humphreys, Irl W.	5402 Page Blvd., St. Louis, Mo.
Johns, F. J.	Westinghouse Club, Wilkinsburg, Pa.
Karcher, Edmund M.	c/o R.C.A. Victor Co., Camden, N.J.
Kilgour, Charles	2617 University Ct., Cincinnati, Ohio.
Klinestiver, Gordon H.	Warner House, Emporium, Pa.
Klingelhoeffer, R. H.	74 Wellington St., W., Toronto, Ont., Canada.
Knapp, Harold D.	2431 Merchantville Ave., No. Merchantville, N.J.
Knight, Charles	c/o Magnolia Petroleum Co., Beaumont, Texas, Box 793.
Kowalczik, William J.	11 Tacoma St., Springfield, Mass.
Kronenwetter, Harold G.	Maud Muller Apts., Dayton, Ohio.
Kruse, Charles C.	226 W. Meinecke Ave., Milwaukee, Wisc.
Kynaston, B. H. J.	Harmonic Radio Co., Ltd., Nottingham, England.
Lang, Connie	1801 Alta Vista Drive, Alhambra, Calif.
Lawrenz, William	Boeing Air Transport, Cheyenne, Wyoming.
Lebedeff, George M.	Dewalt Hotel, 201 Levenworth St., San Francisco, Calif.
Lee, Fat Chang	557 W. 124th St., Apt. 26, New York City.
Levasseur, Lt. J.J. U.S.N.	U.S.S. Detroit, c/o Postmaster, San Francisco, Calif.
Levy, Mortimer N.	205 East 42nd St., New York City.
Little, Martin B.	c/o R.C.A. Victor Co., Inc., Camden, N.J.
Lockwood, Edward C.	R 9 College Hill, Cincinnati, Ohio.
Lovell, George M.	97 Mayer Ave., Buffalo, N.Y.
Lowe, Carr E.	1854 Sanford, Muskegon, Mich.
Ludvigsen, Leonard E.	306 Maryland Ave., Royal Oak, Mich.
Maccornack, Edwin A.	417 Main St., Glen Ellyn, Ill.
Manchester, R. M.	1171 Bush St., San Francisco, Calif.
Marquette, David L.	1126 Wisconsin Blvd., Dayton, Ohio.
Martlieu, C. H. O.	4 Blowers Street, Halifax, N.S., Canada.
Matthews, Basil W.	9 Park View Ave., New Rochelle, N.Y.
Maurer, J. P.	30 Woodlawn St., W., Toronto, Ont., Can.
Maxwell, John F.	56 Mt. Vernon St., Lawrence, Mass.
McCachren, W. S.	1110 Payne-Shoemaker Bldg., Harrisburg, Pa.
McCash, Perry V.	3730 Arlington Ave., Los Angeles, Calif.
McCullough, Frank S.	Menlo Park, Calif.
Meacham, J. F. B.	86-04-117th Street, Richmond Hill, N. Y.
Miller, Joseph J.	5130 Locust St., Philadelphia, Pa.
Moore, Raymond M.	1627 No. Alvarado St., Los Angeles, Calif.
Morrison, Roy H.	263 Fairmount Ave., Jamestown, N.Y.
Morrson, E. J. W.	64 Spring Ave., Arlington, Mass.
Mowry, Charles E.	376-7th Ave., San Francisco, Calif.
Mullen, Joseph G.	Brunswick Radio of Canada, Ltd., Hanna Avenue, Toronto, Ont., Can.
Nauth, G. Raymond	145 Clendenan Ave., Toronto, Ont., Can.
Nelma, Arsene	845 Barrington St., Halifax, N.S. Canada.
Nelson, Ivar	616 East 5th St., Yankton, S.D.
Newcombe, Jack	111 Grand Ave., Brooklyn, N.Y.
Newton, Harold B.	10742-85th Ave., Edmonton, Alberta, Canada.
Newton, John F.	c/o Royal Southern Hospital, Carley Street, Liverpool, England.
Nichols, F. A.	1115-15th Street, Greeley, Colo.
O'Connell, Lieut. J. D.	Fort Monmouth, Oceanport, N.J.
Overton, George P.	Dept. of Commerce, Monitoring Station, Grand Island, Nebraska.
Oxley, Allan B.	Williams Piano Co., Ltd., Oshawa, Canada.
Palmer, C. Walter	31-31 St., Woodcliff, N.J.
Parker, Ray H.	5355 Poinsette Ave., Richmond, Calif.
Parman, Allen R.	1901½-11th Ave., N., Nashville, Tenn.
Pata, Y. J.	1615 N.W. 29th Street, Oklahoma City, Okla.
Pelikan, B. Z.	51 W. Frambes Ave., Columbus, Ohio.
Peters, C. W.	1716 Painter St., New Orleans, La.

Pierce, R. Morris	1416 Lewis Drive, Lakewood, Ohio.
Pitts, A. B.	255 Whitney Ave., New Haven, Conn.
Porter, Samuel	135 Nevada, W., Detroit, Mich.
Prickett, Norman R.	158½ Park Ave., Rochester, N.Y.
Rasmussen, Robert	P. O. Box 318, Oil City, Pa.
Reesor, Delbert A.	R.C.A. Victor Company, Inc., 100 West Monroe Street, Chicago, Ill.
Reihman, Earl F.	c/o R.C.A. Victor Co., Camden, N.J.
Riddle, William E.	9 Stevenson Lane, Saranac Lake, N.Y.
Robb, Robert J.	202 Castle Bldg. Montreal, Canada.
Rodgers, H. C.	3911 Jefferson St., Houston, Texas.
Roedell, Leroy W. F.	c/o Brunswick Radio of Canada, Ltd., Toronto, Ont., Can.
Rost, William A.	645 N. 39th St., Philadelphia, Pa.
Rothenberger, W. L.	c/o R.C.A. Radiotron Co., 1400 S. Penn Square, Philadelphia, Pa.
Ruelius, Louis F.	210 N. 33rd St., Philadelphia, Pa.
Rush, Floyd M.	c/o Radio Station KMED, Sparta Bldg., Medford, Oregon.
Ryley, Raymond	12011-85th Street, Edmonton, Alberta, Can.
Schlichting, Edward N.	3 Harding Ave., Oaklyn, N.J.
Schwarz, Harvey F.	Brunswick Balke Collender Co., Metal Products Division, Muskegon, Mich.
Serge, Igor Bobrovsky	Radio Division, Peter Smith Stamping Co., 10501 Haggerty Ave., Detroit, Mich.
Shanafelt, Lysle O.	834 George St., Chicago, Ill.
Shaw, Robert E.	8855 So. Bishop St., Chicago, Ill.
Sheffield, Charles W.	Radio Service, 37 Stanley Road, Bolton, Lancashire, England.
Sherwood, John W.	104 Oswego St., Springfield, Mass.
Shive, Ray L.	79 Washington St., East Orange, N.J.
Shmied, Ernest A.	Radio Experiment Laboratory, 1804 West Congress St., Chicago, Ill.
Spates, James L.	249 Pine St., Bangor, Me.
Sponseller, Joseph F.	68 Summit Ave., Jersey City, N.J.
Starner, Charles J.	Stanford University, 1033 Guinda St., Palo Alto, Calif.
Sterling, M. F.	Alliance Hotel, Alliance, Neb.
Stewart, Arthur W.	604 Straight St., Cincinnati, Ohio.
St. Laurent, Herbert	Conn. Telephone & Electric Corp., Britannia St., Meriden, Conn.
Straughn, James B.	650 Harvard St., N.W., Washington, D.C.
Sturtevant, J. W.	15220 Hilliard Road, Lakewood, Ohio.
Sullivan, Frank T.	c/o Y.M.C.A., Lawrence, Mass.
Summers, R. H. J.	National Works High Road, Leyton, London, England.
Sweighert, D. V.	Box 574, Dayton, Ohio.
Tagart, Sam W.	1428 No. Marshall St., Apt. 25, Milwaukee, Wisc.
Terhune, J. A.	U. S. Naval Station, Guam, Mariannas Islands.
Thorsen, Orville T.	3547 Pierce Ave., Chicago, Ill.
Timmings, George H.	3206 Clifton Ave., Chicago, Ill.
Traugott, Paul	2134 W. Erie Ave., Philadelphia, Pa.
Trefery, Lawrence D.	c/o Magnavox Co., 155 East Ohio St., Chicago, Ill.
Tsushima, Yonekichi	Wireless Dept., N.Y.K., Marunouchi, Tokio, Japan.
Tustin, John L.	Tustin Radio & Electric, 428 Sutter St., San Francisco, Calif.
Valentine, F. C.	General Cable Corp., 920 Chamber of Commerce, Cincinnati, Ohio.
Van Pelt, John	c/o Jones, 922 Summit Ave., Bronx, N.Y.C.
Varcoe, H. R.	Suite 54, Dalkeith Apts., Balmoral Place, Winnipeg, Man., Canada.
Vogel, Erwin William	4606 Clarendon Road, Brooklyn, N.Y.
Voight, Richard J.	1427 Marlboro St., Sandusky, Ohio.
Walker, C. L.	68 Federal Street, Springfield, Mass.
Walker, Raymond E.	c/o W. P. Fuller Co., So. San Francisco, Calif.
Wallace, David R.	103 W. 13th St., Okla. City, Okla.
Waller, Paul	922 North Hughes St., Success Heights, Little Rock, Ark.
Wann, Richard H.	4825 Hutchinson St., Chicago, Ill.
Watts, Harley M.	820 E. Wells St., Milwaukee, Wisc.
Weatherford, Richard V.	5152 York Boulevard, Los Angeles, Calif.
Wengel, Raymond W.	P. O. Box 1225, Little Rock, Ark.
White, Charles D.	c/o H. H. Eby Manufacturing Co., 22nd St. & Lehigh Ave., Philadelphia, Pa.
Whittaker, Edmund	715 So. St. Andrews Place, Los Angeles, Calif.
Wilcox, B. B.	c/o W. H. Thompson, Asst. Manager C.P.L. Telegraphs, Winnipeg, Canada.
Wilcox, Nathan	Control Room Eng., Radio Station WMT, Waterloo, Iowa.
Wilkinson, L. G.	3111 Grove Ave., Berwyn, Ill.
Willard, Walter C.	Sales Engineer, Mfgrs. Agent, 718 Columbia St., Newport, Ky.
Winchell, Walter H.	c/o RCA Photophone, Inc., 261 No. Broad St., Philadelphia, Pa.
Wisegarver, Orton H.	Hotel Mayfair, Kansas City, Mo.
Wright, Andrew M., Jr.	Box 1004-A, Yale University, New Haven, Conn.
Yates, Raymond F.	419 Grider St., Buffalo, N.Y.
Young, Charles J.	1065 Avon Road, Schenectady, N.Y.
Zatorsky, E. F.	41-41-43rd Street, Long Island City, N.Y.
Zaun, Peter E.	R.C.A. Institutes, Inc., 75 Varick St., New York, N.Y.
Zeidlik, William J.	1428 Allen Bldg., Dallas, Texas.
Zinser, Henry	3997 West 226th St., Rocky River P. O., Cleveland, Ohio.

(Typewriting preferred in filling in this form) No..................

RECORD OF TRAINING AND PROFESSIONAL EXPERIENCE

Name ....
(Give full name, last name first)

Present Occupation ....
(Title and name of concern)

Business Address ....

Permanent Home Address ....

Place of Birth.......................... Date of Birth............ Age......

Education ....

Degree ....
(college) (Date received)

TRAINING AND PROFESSIONAL EXPERIENCE

DATES	

Record may be continued on other sheets of this size if space is insufficient.

Receipt Acknowledged............ Elected............ Deferred............

Grade .... Advised of Election........ . This Record Filed..........

The Institute of Radio Engineers

Incorporated

33 West 39th Street, New York, N. Y.

APPLICATION FOR ASSOCIATE MEMBERSHIP

(Application forms for other grades of membership are obtainable from the Institute)

To the Board of Direction

Gentlemen:

I hereby make application for Associate membership in the Institute of Radio Engineers on the basis of my training and professional experience given herewith, and refer to the members named below who are personally familiar with my work.

I certify that the statements made in the record of my training and professional experience are correct, and agree if elected, that I will be governed by the constitution of the Institute as long as I continue a member. Furthermore I agree to promote the objects of the Institute so far as shall be in my power, and if my membership shall be discontinued will return my membership badge.

....
(Sign with pen)

....
(Address for mail)

.... (Date)

....
(City and State)

References:

(Signature of references not required here)

Mr. ....

Address ....

City and State ....

Mr. ....

Address ....

City and State ....

Mr. ....

Address ....

City and State ....

The following extracts from the Constitution govern applications for admission to the Institute in the Associate grade:

ARTICLE II—MEMBERSHIP

Sec. 1: The membership of the Institute shall consist of: * * * (c) Associates, who shall be entitled to all the rights and privileges of the Institute except the right to hold any elective office specified in Article V. * * *

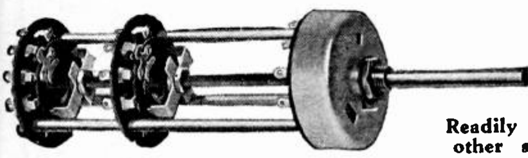
Sec. 4: An Associate shall be not less than twenty-one years of age and shall be a person who is interested in and connected with the study or application of radio science or the radio arts.

ARTICLE III—ADMISSION AND EXPULSIONS

Sec. 2: * * * Applicants shall give references to members of the Institute as follows: * * * for the grade of Associate, to three Fellows, Members, or Associates; * * * Each application for admission * * * shall embody a full record of the general technical education of the applicant and of his professional career.

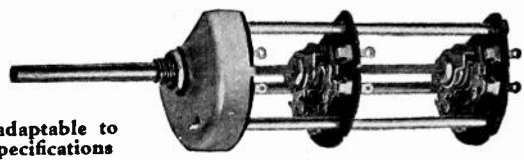
BNTRANCE FEE SHOULD ACCOMPANY APPLICATION

SPECIAL ITEMS FOR RADIO MANUFACTURERS

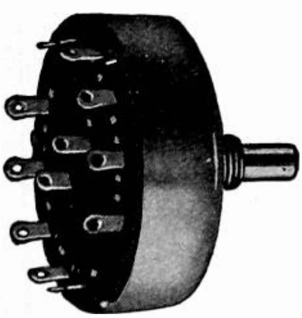


No. 7280A
3 gang, 4 positions
single circuit

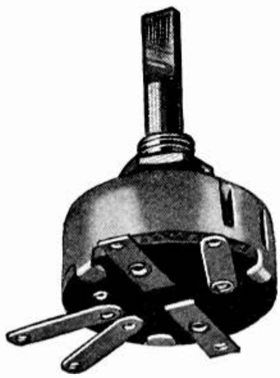
Readily adaptable to
other specifications



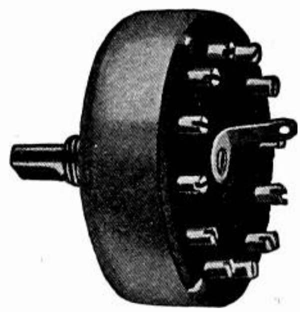
No. 7260A
3 gang, 2 positions
2 circuits



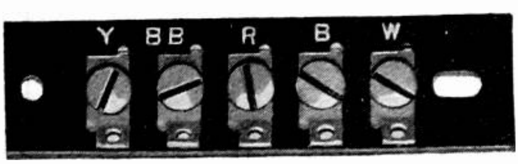
No. 7150A
5 positions, 2 circuits



No. 7120A
Combined Acoustic and muting switch 2 or 3 positions

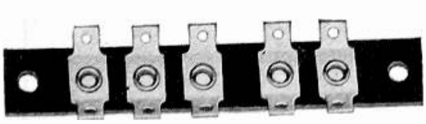


No. 7220A
12 positions, single circuit

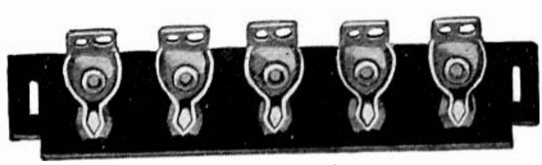


Terminal Strip
5 Lugs No. 6880A, 4 lugs No. 6990A

Terminal Strip
4 Clips, No. 6830A



Terminal Strip
5 Lugs, No. 6950A



Terminal Strip
5 Clips, No. A6310AA, 4 Clips No. A6320AA

SORENG - MANEGOLD CO.

1901-9 Clybourn Avenue, CHICAGO, ILL.

1646 W. Adams St.
Los Angeles, Cal.

701 Stephenson Bldg.
Detroit, Mich.

245-5th Ave.
New York City

Alphabetical Index to Advertisements

CHANGE IN MAILING ADDRESS OR BUSINESS TITLE

Members of the Institute are asked to use this form for notifying the Institute office of a change in their mailing address or the listing of their company affiliation or title in the Year Book.

The Secretary,
THE INSTITUTE OF RADIO ENGINEERS,
33 West 39th Street,
New York, N.Y.

Dear Sir:

Effective .... (date) please note change in my address *for mail* as follows:

FROM

....
(Name)

....
(Street Address)

....
(City and State)

TO NEW ADDRESS

....
(Street Address)

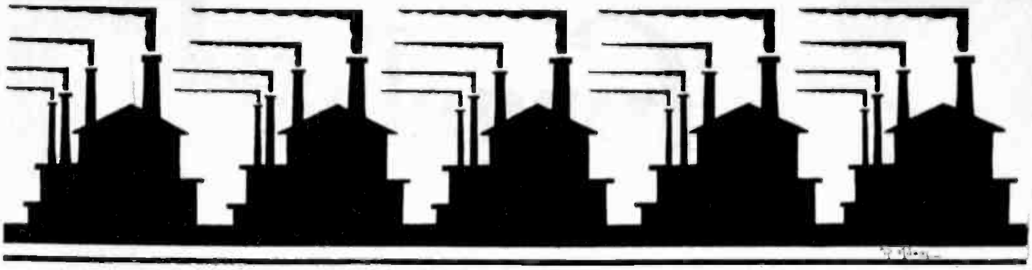
....
(City and State)

Please note following change in my Year Book listing.

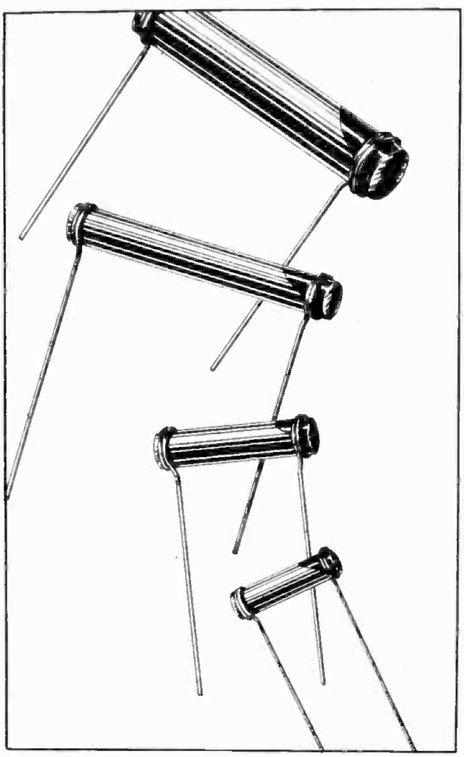
....
(Title)

....
(Company Name)

....
(Company Address)



UNIFORMITY



Continuous check and control on every manufacturing process is maintained by our engineering laboratories to insure absolute uniformity and highest quality in every Erie Resistor.

Human errors have been eliminated by automatic machinery which detects variations without failure.

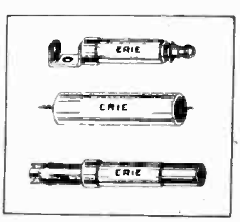
Because of the accurate control maintained over each step in the manufacturing processes and the elimination of human errors by automatic machinery it is now possible to make Erie Resistors within the desired limits instead of the old fashion method of manufacturing a large number—picking out the good ones and scrapping the balance.

Only by maintaining this uniformity and eliminating scrap is it possible to manufacture resistors having the highest quality and still hold the cost low enough to meet present day production demands.

ERIE SUPPRESSORS

An ERIE SUPPRESSOR RESISTOR will not fail mechanically at 120° C and 100% relative humidity.

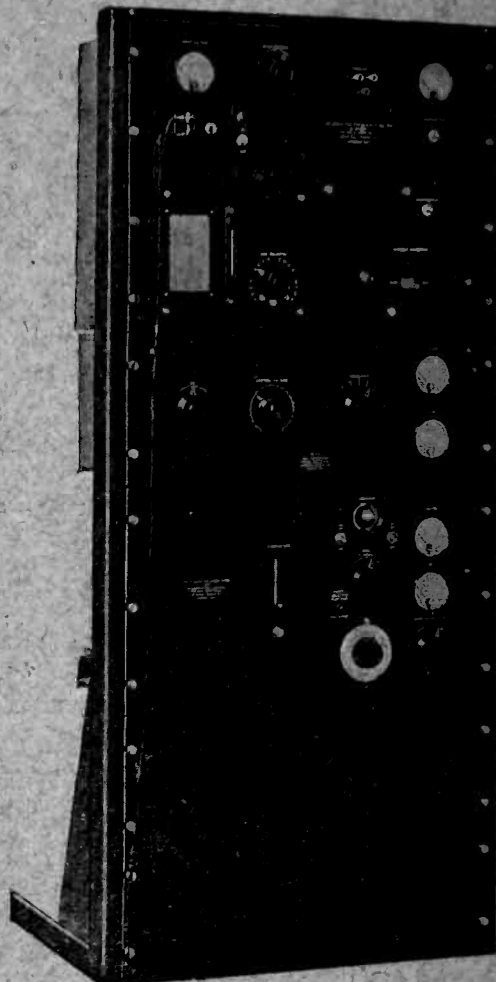
The resistance unit is enclosed in a ceramic tube to protect it from mechanical breakage as well as from oil, dirt and moisture.



ERIE RESISTORS

ERIE RESISTOR CORPORATION, ERIE, PA.
Factories in Erie, Pa., Toronto Can., and London, Eng.

HETERODYNE FREQUENCY MEASUREMENTS



Present-day tolerances on the frequencies of commercial stations require accurate frequency measuring equipment and methods.

The assembly shown here is capable of measuring frequencies from below 100 kilocycles to 30,000 kilocycles with an overall accuracy of 0.01% or better.

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A Class C-10 Standard Frequency Assembly with a Type 616-AR Heterodyne Frequency Meter makes a frequency-measuring outfit that is complete except for the necessary radio receiver.

Price $965.00

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