VOLUME 18 APRIL, 1930 NO. 4

PROCEEDINGS

of

The Institute of Radio Engineers

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Institute of Radio Engineers

Forthcoming Meetings

Los Angeles Section

April 21, 1930

Seattle Section

April 28, 1930

Fifth Annual Convention

Toronto, Ontario, Canada

August 18-21, 1930

PROCEEDINGS OF
The Institute of Radio Engineers

Volume 18 April, 1930 Number 4

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Volume 18, Number 4 *April, 1930*

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Oklahoma	Oklahoma City, 103 West 13th St.	Arnold, R. W.
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	Indiana, 1601 W. Philadelphia St.	Beck, H. J.
	Munhall, 419 Ninth Ave.	Critchlow, E. F.
	Oil City, P. O. Box No. 318	Rasmussen, Robert

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	Pittsburgh, 714 Plaza Bldg.	Herlihy, W. J.
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	Manchester, 8 The Grove, Whitworth Park	Handcock, F. V.
	Squirrell's Heath, Essex, "Heath View," Park Rd.	Fisher-Luttrelle, Wm.
Federated Malay States	Kuala Lumpur, Engineering Branch, Posts and Tels	MacIntosh, James
Holland	Amsterdam—O, Oosterpark 58	Rodrigues, de Miranda
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Japan	Sapporo, Tsukissapu Sending Station JOIK	Koshikawa, A.
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Arthur F. Van Dyck
Member, Board of Direction, 1930

Arthur F. Van Dyck was born at Stuyvesant Falls, N. Y., May 20, 1891. He was graduated from Sheffield Scientific School of Yale University with Ph.B. degree in 1911.

From 1907 to 1910 he operated both at sea in the commercial service and on land as an amateur.

After graduation he was engaged in research work at Brant Rock, Mass., for the National Electric Signalling Company until 1912. His next connection was in the Research Department of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa. Leaving there in 1914, he became instructor in electrical engineering at the Carnegie Institute of Technology. In 1917 he became an Expert Radio Aide for the U. S. Navy and was stationed at the New York Navy Yard and at the Navy Department in Washington until 1919, when he joined the Marconi Company at Aldene, N. J., in charge of the engineering department. From 1920 to 1922 he had charge of radio receiver design for the General Electric Company in Schenectady, N. Y. In 1922 he became associated with the Radio Corporation of America, later the Radio-Victor Corporation, as manager of the engineering and test department in 1929. At present he is with the Radio Corporation of America in the Patent and License Department.

Mr. Van Dyck is a charter Associate member of the Institute, having joined in 1913. He became a Member of the Institute in 1918 and a Fellow in 1925. He has been a member of the Committee on Admissions since 1929, and was in standardization work as the Chairman of the Technical Committee on Radio Transmitters and Receivers under the American Standards Association procedure from 1925 to 1929. He has been a member of the Underwriters' Laboratories Radio Industry Conference since 1925. In the U.S. Naval Reserve he holds the rank of Lieutenant Commander.

INSTITUTE NEWS AND RADIO NOTES

March Meeting of Board of Directions

A meeting of the Board of Direction was held at 3 P.M. on March 5, 1930, the following being present: Lee de Forest, president; Melville Eastham, treasurer; Alfred N. Goldsmith, editor; Arthur Batcheller, Raymond A. Heising, Lewis M. Hull, Cyril M. Jansky, Jr., Ray H. Manson, Robert H. Marriott, Arthur F. Van Dyck, and Harold P. Westman, secretary.

The following were elected or transferred to the Member grade. Elected: J. F. Church, Hugo Cohn, C. F. Lane, J. F. Moriarty, and V. K. Zworykin. Transferred: G. N. P. Allaway, W. F. Bardin, Harry Diamond, and H. A. Gambrell.

One hundred and eight Associate members and nine Junior members were elected.

Membership Cards

Membership cards for the year 1930 are available to all who desire them. They are not mailed to members unless specifically requested.

Associate Application Form

For the benefit of members who desire to have available each month an application form for Associate membership, there is printed in the PROCEEDINGS a condensed Associate form. In this issue this application will be found on page XXXIII of the advertising section.

Application forms for the Member or Fellow grades may be obtained upon application to the Institute office.

The Committee on Membership asks that members of the Institute bring the aims and activities of the Institute to the attention of desirable and eligible non-members. The condensed form in the advertising section of the PROCEEDINGS each month may be helpful.

Radio Signal Transmissions of Standard Frequency

APRIL TO JUNE, 1930

The following is a schedule of radio signals of standard frequencies for use by the public in calibrating frequency standards and transmitting and receiving apparatus as transmitted from station WWV of the Bureau of Standards, Washington, D. C.

Further information regarding these schedules and how to utilize the transmissions can be found on pages 10 and 11 of the January, 1930, issue of the PROCEEDINGS and in the Bureau of Standards Letter Circular No. 171 which may be obtained by applying to the Bureau of Standards, Washington, D. C.

Eastern Standard Time	Apr. 21	May 20	June 20
10:00 P.M.	1600	4000	550
10:12	1800	4400	600
10:24	2000	4800	700
10:36	2400	5200	800
10:48	2800	5800	1000
11:00	3200	6400	1200
11:12	3600	7000	1400
11:24	4000	7600	1500

Broadcast Reports on Astrophysical and Geophysical Phenomena

We have been advised that after February 1, 1930, it is probable that a bulletin concerning astrophysical and geophysical phenomena capable of influencing the propagation of radio waves will be broadcast daily from the Lafayette, (17.751 kc or 16,900 meters) and Issy-les-Moulineaux (9,230 kc or 32.5 meters) radio stations immediately following the regular time signals transmitted at 2000 Greenwich Mean Time.

The text of these bulletins will comprise data from the Astronomical Observatory at Meudon, the Physical Institute of the Globe at Paris, and the National Meteorological Office. The last named body assumes the duty of collecting these data and compiling the bulletins.

These broadcasts have resulted from the efforts of the Committee on Cooperation of the American Section of the International Union of Scientific Radio Telegraphy (Union Radio Scientifique Internationale, or U.R.S.I.).

Committee Work

COMMITTEE ON ADMISSIONS

A meeting of the Committee on Admissions was held at 6 P.M. on March 4, 1930, in the Western Universities Club, 11 West 53rd Street, New York City. The following were present: Raymond A. Heising, chairman; C. N. Anderson, Arthur Batcheller, C. M. Jansky, Jr., R. H. Marriott, E. R. Shute, and A. F. Van Dyck.

The committee considered seventeen applications for transfer or election to higher grades of membership in the Institute.

Committee on Broadcasting

The last meeting of the Committee on Broadcasting was held at 1 P.M., March 5, 1930. L. M. Hull, chairman; Arthur Batcheller, C. W. Horn, and R. H. Marriott were present.

Committee on Constitution and Laws

At the March 5, 1930, meeting of the Committee on Constitution and Laws, held at 10 A.M., R. H. Marriott, chairman; Arthur Batcheller, Melville Eastham, H. E. Hallborg, R. A. Heising, and G. W. Pickard were present.

Standardization

In the past, the working committees operating under the Committee on Standardization of the Institute were known as subcommittees and any committees established by a subcommittee were known as subsubcommittees. To simplify matters, committees operating directly under the Committee on Standardization will now be known as technical committees and the subsubcommittees will be referred to as subcommittees.

Technical Committee on Radio Receivers and Parts—A.S.A.

A meeting of the Technical Committee on Radio Receivers and Parts, operating under American Standards Association procedure, was held at 10:45 A.M. on February 26th, the following being present: W. A. MacDonald, chairman; T. McL. Davis, E. T. Dickey, J. W. Fulmer (representing H. B. Smith), V. M. Graham, W. M. Grimditch, and H. P. Westman, secretary.

Technical Committee on Vacuum Tubes—I.R.E.

At the last meeting of the Technical Committee on Vacuum Tubes of the Institute, held at 10:30 A.M. on March 5, 1930, the following were present: J. C. Warner, presiding; Stuart Ballantine, Harry F. Dart, D. E. Harnett, M. J. Kelly, and H. P. Westman, secretary.

Technical Committee on Electro-Acoustic Devices—A.S.A.

The following were present at the meeting of the Technical Committee on Electro-Acoustic Devices, operating under American Standards Association procedure, which was held at 10:30 A.M., March 6, 1930: Irving Wolff, chairman; L. G. Bostwick, E. D. Cook, J. W. Fulmer (representing H. B. Smith), C. R. Hanna, E. W. Kellogg, Benjamin Olney, J. D. Phyfe, W. P. Powers, L. J. Sivian, Arthur Thiessen, J. E. Volkmann, and H. P. Westman, secretary.

Institute Meetings

Buffalo-Niagara Section

A meeting of the Buffalo-Niagara Section was held on February 19th in Room 239, Edmund Hayes Hall, University of Buffalo. A. B. Chamberlain, acting chairman, presided.

Karr Parker, engineer for McCarthy Bros. and Ford, presented a paper, "Radio and Public Address Distributions Systems, Especially as Applied to Statler Hotels Service." A general discussion followed the presentation of this paper.

Twenty-one members of the section attended this meeting.

Chicago Section

The February meeting of the Chicago Section was held in the Lounge of the Western Society of Engineers, Engineering Building, on the 21st of the month.

The presiding officer was H. E. Kranz and the speaker, F. S. Huddy, assistant chief engineer of the Ceco Manufacturing Co., delivered a paper on "The Pentode." Messrs. Andrews, Arnold, Hassel, Henry, Kranz, Miller, and Weinberg participated in the discussion of the paper. Two hundred and twenty-five members and guests attended the meeting.

Cincinnati Section

The February meeting of the Cincinnati Section was held on the 20th of the month at Wright Field, Dayton, R. H. Langley presiding.

The meeting started early in the afternoon, and guides were provided to take those present through the laboratories at the field. Seventy-two members and guests assembled in the officers' mess for dinner at five o'clock and the usual meeting followed.

A considerable discussion followed the illustrated lecture given by Joseph Chambers, technical supervisor of Stations WLW and WSAI, discussing broadcasting in general and high-power broadcast stations in particular.

The second speaker, C. D. Barbulesco, discussed and demonstrated the advantages of super-regeneration for very high frequency reception. The use of this type of receiver for measuring the distance between a flying aeroplane and the earth was also considered.

The meeting was so successful that it is probable that the May meeting will be held at Dayton.

Detroit Section

A meeting of the Detroit Section was held on February 21st in the Detroit News Building.

The meeting was presided over by A. B. Buchanan and a demonstration of the RCA Theremin was given.

The second half of the meeting was devoted to a paper, "Radio Aids to Navigation," delivered by S. L. Bailey of the Bureau of Lighthouses. A general discussion was participated in by many of the ninety-five members and friends present.

Los Angeles Section

At the February 17, 1930, meeting of the Los Angeles Section presided over by T. C. Bowles, a paper on "Piezo-Electric Crystals and Their Formation" was delivered by W. L. Burnett. This paper covered the subject from the formation of the crystal in the earth to its being placed in service in a radio transmitter.

Messrs. Andersen, Eldridge, Fox, McDonough, and Nekirk discussed the paper.

Seventy-one members and guests were present.

New York Meeting

The regular monthly New York meeting of the Institute was held on Wednesday, March 5, 1930, in the Engineering Societies Building, 33 West 39th Street, New York City. Lee de Forest, president of the Institute, presided.

A paper on "Transmission Characteristics of a Short-Wave Telephone Circuit" was presented by R. K. Potter, of the Netcong, N. J., station of the American Telephone and Telegraph Company. The paper is summarized as follows:

> The frequency characteristic of a high-frequency, transatlantic radiotelephone channel is described and discussed in this paper. The frequency characteristic of a wire telephone circuit can be adequately portrayed in two dimensions—"frequency" and "amplitude"—but it is shown that such a characteristic of a high-frequency radiotelephone circuit requires the addition of a third dimension—"time," since the frequency-amplitude relation undergoes a continual change. To provide this third dimension a series of frequency characteristics were recorded in rapid succession. The regularity of peaks and depressions which appear in the records indicate that the phenomenon is due to wave interference between signals traveling over three or more paths of different electrical length between the transmitter and receiver.
>
> It is shown that during periods of very rapid fading radio frequencies spaced only 170 cycles apart fade differently. Curves are included illustrating the seasonal susceptibility of the circuit to this type of fading. An occasion of distinct speech echoes observed during a rapid fading period when a single side band of the signal was transmitted is discussed, and an explanation is offered for the reason that speech echoes are not more frequently identified on high-frequency circuits.

> Assuming certain relations between the lengths of different paths between transmitter and receiver, patterns similar to those recorded are constructed synthetically. A study of the changes in shape occurring in these synthetic characteristics indicates that a certain relation of the ether paths will produce a complete and continual suppression of particular transmitted tones. Records show that this condition may exist for short periods. Another effect of the selective fading which produces these patterns is shown to be that of an effective variation in the percentage modulation of the received signal which imposes a limitation upon the operation of an automatic output level regulator.
>
> An arrangement used for projecting a moving picture of the constantly changing frequency characteristic upon the screen of a cathode-ray tube is described. Observations of these moving pictures for short test periods frequently throughout the day and year at different frequencies showed that the recurrent shapes of characteristic vary with time of day and season and are of more simple pattern at the higher frequencies.

Three hundred and fifty members and guests attended this meeting.

Pittsburgh Section

On February 25th a meeting of the Pittsburgh Section was held at Utility Hall in the Philadelphia Building, L. A. Terven presiding.

J. G. McKinley presented an instructive paper on "Radio Interference," with special reference to the study of antenna pickup. The resonant wave coil used by the author was then considered with slides and illustrations.

Following this J. G. Allen described some recent tests with unilateral receivers in interference location work, and a demonstration of noise making appliances was given by Anthony Mag and J. G. Allen.

There were forty present at the meeting.

Toronto Section

A meeting of the Toronto Section was held on January 8, 1930, at the Electrical Building, University of Toronto, V. G. Smith, chairman, presiding.

The speaker of the evening, P. C. Ripley of the Kester Solder Company, Chicago, presented an interesting paper on the subject, "Fluxes and Solder in the Radio Industry."

The paper was considered as being interesting by the eighty members and guests who attended the meeting and Messrs. Fox, Lowrie, Northover, Patience, and Smith discussed it.

Washington Section

A meeting of the Washington Section was held on February 13, 1930, in the Hotel Continental. C. B. Jolliffe, chairman of the section, presided. The following papers were presented: "Status of Frequency Measurement," by C. B. Jolliffe, and "International Frequency Measurement," by A. Hoyt Taylor.

Dr. C. B. Jolliffe spoke on the results of the work of the Bureau of Standards in developing and constructing an accurate frequency standard. He illustrated his discussion with lantern slides, and showed the construction of the constant temperature cabinets and thermostatic control units by which the temperature of the piezo-electric crystals is maintained constant. The mounting of the crystal was explained wherein a quartz disk is provided with an annular peripheral groove into which adjusting screws project to maintain the quartz plate in a position free for constant frequency oscillation. Dr. Jolliffe's experiences in Europe in comparing one of the secondary standards developed by the Bureau of Standards from the primary-frequency standard was described and the readings obtained in different laboratories in Europe compared. It was pointed out that by accurate maintenance of temperature in the immediate vicinity of the piezo-crystal element, the frequency drift would be very slight and an opportunity for more extended use of the available frequencies obtained.

Dr. Taylor described the constant frequency transmitter developed by members of the staff of the Naval Research Laboratory wherein a temperature-controlled piezo-electric crystal oscillator controls the operation of a frequency-doubling multistage amplifier system for transmission of constant frequency signals on 20,000 kc. These signals are to be checked in France, Germany, England, and probably Japan for the comparison of frequencies, and will give an even more accurate method of frequency standardization than the actual transportation of frequency standards from one country to another without the inherent travel and incidental delay.

These papers were discussed by Captain Guy Hill, L. P. Wheeler, G. D. Robinson, and A. Hoyt Taylor.

Personal Mention

Lewis M. Clement, formerly vice president and chief engineer of the Brandes Laboratories, is now in the Radio Division of the Westinghouse Electric and Manufacturing Company at their New York office.

Donald McNicol has been appointed editorial director of the two publications *Radio Engineering* and *Projection Engineering*.

Leo C. Kelly, who was previously a member of the Engineering Department of the American Telephone and Telegraph Company in

New York City, is now located at the International Communication Laboratories in New York City.

R. J. White, who has been a Radiotron specialist for the Radio Corporation of America in Dallas, Texas, is now field representative for the RCA-Victor Company at the same place.

D. C. Wallace has recently become zone manager for the General Motors Radio Corporation. He is located in Los Angeles, California, and prior to this connection was manufacturers' representative for a number of radio manufacturing organizations.

Harry Thomas, formerly on the engineering staff of the Audio Vision Appliance Company at Camden, has recently become connected with the American Bosch Magneto Corporation at Springfield, Mass., as radio production engineer.

Carl Stagg is now assistant supervisor at the RCA Communications station at Riverhead, N. Y. He was previously a receiving engineer for that organization.

Q. M. Shultise is at present a design engineer for the Universal Wireless Communication Company, Inc., at their Chicago plant.

D. R. Rossiter has recently become connected with the Automatic Electric Company in Chicago. He was previously a radio engineer for the Bremer-Tully Manufacturing Company of the same city.

Formerly an instructor in the Radio Institute at New York, Leon E. Pamphilon is now a sound engineer for RCA Photophone in New York City.

E. L. Koch is now chief engineer for the Universal Wireless Communication Company. Previously he was an executive engineer for the Kellogg Switchboard and Supply Company of Chicago.

A. W. Hershey has left the Development Department of Leeds and Northrup of Philadelphia to join the Bell Telephone Laboratories in New York City.

J. B. Harley, formerly with F.A.D.Andrea in New York City, has also joined the Bell Telephone Laboratories.

E. H. Hansen is now operating head and chief engineer of the Sound Department of the Fox Film Company at Los Angeles, California.

From chief code instructor, A. B. Burdick has risen to superintendent of the RCA Institutes, Inc., New York City.

J. W. Ashmore has been transferred from the Belfast, Maine, to the Riverhead, New York, receiving station of RCA Communications.

L. J. Andres has recently become chief engineer for the Carter Sound Equipment Company of Chicago.

H. C. Leuteritz is now the communications engineer for the Pan-American Airways in New York City. He was formerly a radio engineer at the New York City office of the Radio Corporation of America.

A considerable number of members have been affected due to the recent change in the status of the General Electric-Westinghouse-RCA-Victor radio grouping. The following who were formerly located in the Schenectady plant of the General Electric Company are now in the engineering department of the RCA-Victor Corporation at Camden, N. J.: Kirby B. Austin, Irving F. Byrnes, K.A. Chittick, Thomas F. DeHaven, Charles R. Garrett, John C. Hansen, W. A. Hargrave, L. H. Junken, Arthur V. Loughren, Clifton C. More, Robert W. Orr, Albert A. Pulley, H. E. Roys, J. P. Smith, F. Byron Stone, and Charles H. Vos.

D. H. Cunningham, G. L. Grundmann, W. R. Koch, and M. G. Sateren, who were formerly with the Westinghouse Electric and Manufacturing Company, are also in the engineering department of RCA-Victor.

In the same organization may also be found R. A. Braden, J. N. Hall, Abraham Ringel, and Irving Wolff, who were previously located at the Van Cortlandt Park laboratory of the Radio Corporation of America.

L. H. Miller is a member of the RCA Radiotron Company staff at Harrison, N. J. He was previously with the Radio-Victor Corporation of America at Camden.

A. F. Murray has left the Jenkins Television Corporation of Jersey City, N. J., to become division engineer of research and advance development of the RCA-Victor Company at Camden, N. J.

Albert Hauser is now a condenser engineer for the Transformer Corporation of America in Chicago. He was formerly chief engineer for Brown and Caine, Inc., of Chicago.

Part II

TECHNICAL PAPERS

Proceedings of the Institute of Radio Engineers
Volume 18, Number 4 *April, 1930*

ANTENNA-MEASURING EQUIPMENT*

By

J. K. Clapp

(Engineer, General Radio Co., Cambridge, Mass.)

Summary—*A self-contained equipment (with exception of batteries), of portable design, for measurement of apparent capacity, apparent resistance and natural frequency of antenna-ground systems, within specified limits, is described. A substitution method is employed, adjustment of the calibrated phantom antenna being made to maintain constant frequency and constant amplitude of oscillation in the driving oscillator circuit, as the oscillator is switched from the physical to the phantom antenna. In measurement of the natural frequency of the antenna, the antenna frequencies corresponding to various amounts of loading inductance are determined. A curve is then plotted and extrapolated to the zero loading ordinate. A very close approximation is obtained if the inductance of the small coupling coil is neglected, the antenna frequency with the coil in circuit being taken as the natural frequency.*

The sensitivity and accuracy of the apparatus is discussed with attention to the imperfections of the phantom condenser and resistance. The results of measurements on a calibrated dummy antenna, as well as on a ship's antenna, are given in graphic form. The effect of interfering signal voltages picked up by the antenna from nearby transmitters is considered.

Purpose and Range of Equipment

THE EQUIPMENT described below was designed specifically for the U. S. Coast Guard for measurements on antenna-ground systems at frequencies below the fundamental frequency of the antenna-ground system. The apparent reactance of the antenna-ground system is therefore condensive at all frequencies of measurement. Provision is made for the measurement of the apparent capacity, apparent resistance, and the natural frequency of the antenna-ground system within the following limitations:

(a) frequency range:
 100 to 600 kc for apparent resistance and capacity
 up to 2500 kc for fundamental frequency

(b) apparent resistance less than 111 ohms

(c) apparent capacity between 200 and 2000 $\mu\mu$f

Extreme accuracy was not held to be of prime importance in the design of the equipment, as the data to be obtained through its use were desired for indicating the relative trend of the apparent antenna coefficients with frequency and to furnish approximate design data for the design of transmitter and receiver circuits to be used with a given antenna.

* Dewey decimal classification: R300.

Through the use of an auxiliary calibrated antenna series condenser, measurements may be made at frequencies higher than the natural frequency of the antenna.

General Description of Equipment

The equipment with exception of batteries is contained in a single aluminum cabinet, 8 in. by 10 in. by 26 in. and weighing 40.5 lbs.

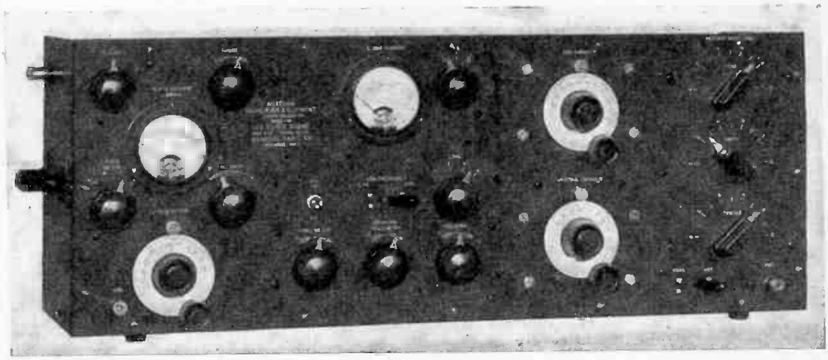

Fig. 1

Photographs of the front and interior of the apparatus are reproduced in Figs. 1 and 1a, and the wiring diagram in Fig. 2. The apparatus contained in the cabinet may be classified under four functional headings as follows:

Oscillator

A vacuum-tube oscillator is provided in one compartment for driving the antenna at any frequency within the range specified. The antenna-ground system is connected directly across the tuned-grid circuit of the oscillator with or without a series condenser. Feed back is obtained through mutual inductance between plate and grid circuits, and is controlled through the use of a variable resistance. The grid circuit of the tube is employed as a rectifier for indicating the amplitude of oscillation by the resultant change in plate current. A d-c milliammeter is provided for reading this change in plate current, the steady plate current being opposed by a voltage taken from the filament battery.

With the connections indicated, it may be found that the oscillator will pick up the antenna, acting as an inductance (at a frequency higher than the natural frequency of the antenna), and oscillate as a Hartley oscillator with the plate inductance and the plate-grid capacity of the circuit as the remaining circuit elements. This stray oscillation is

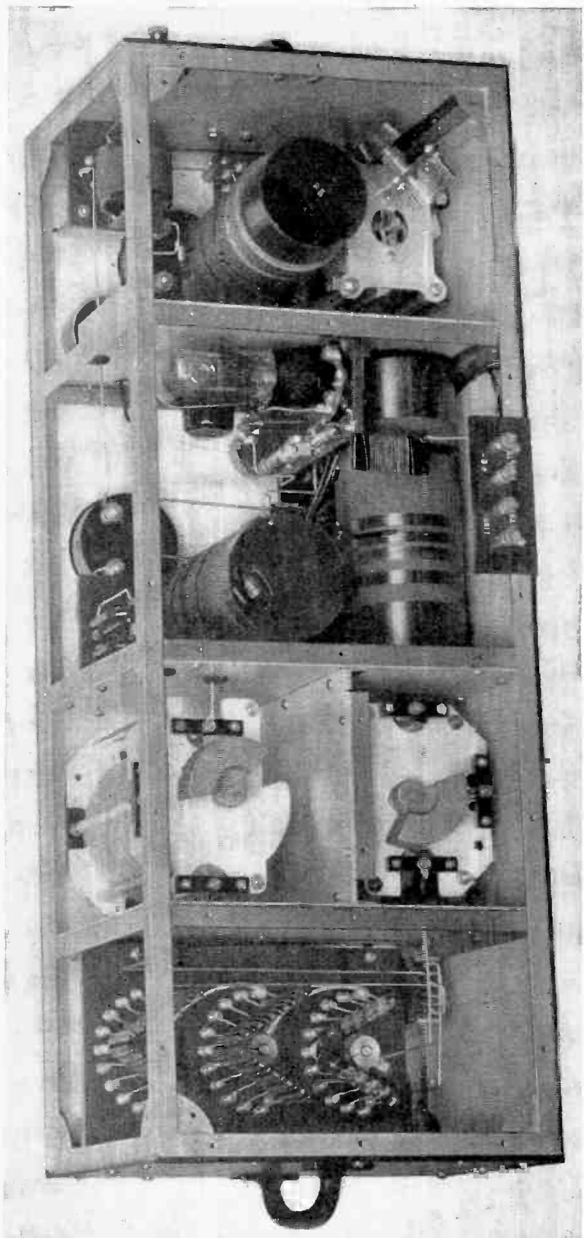

Fig. 1a

readily suppressed, without materially changing the normal circuit conditions, by inserting a resistance in the grid lead to the tube.

Frequency Meter

A tuned-circuit frequency meter, covering the range from 90 to 2,000 kc, is mounted in a second compartment, and inductively coupled to the oscillator circuit, the coupling being varied through the use of a variable resistance of low value. Resonance between the frequency

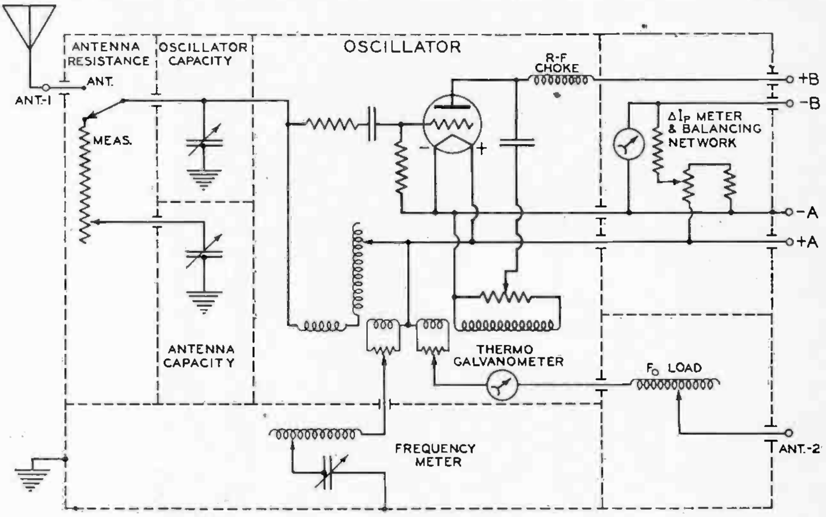

Fig. 2

meter and the oscillator is detected by means of the change in plate-current meter of the oscillator.

Phantom Antenna

The phantom antenna may be substituted in place of the physical antenna-ground system, across the oscillator tuned circuit. It consists of a calibrated variable air condenser in series with a calibrated decade resistance. The maximum value of capacity is approximately 2,100 $\mu\mu$f. The maximum value of resistance is 111 ohms. These units are mounted in individual compartments arranged to prevent coupling between either unit and the oscillator.

Antenna Loading

For measurement of the natural frequency of the antenna, a variable loading coil and thermogalvanometer are connected in series with the antenna. This combination is loosely coupled to the driving oscillator through a mutual inductance, the coupling being varied through the use of a variable resistance of low value.

PRINCIPLES OF MEASUREMENTS

Apparent Resistance and Capacity

The fundamental principle in the measurement of the apparent resistance and capacity of an antenna by means of this equipment is that of substitution. The reactance and resistance offered by the phantom antenna are separately adjusted, the first to maintain *constant frequency* and the second to maintain *constant amplitude* of oscillation as the oscillator is switched from the physicial to the phantom antenna. In the more usual methods, the frequency reaction of the measuring circuit on the oscillator is neglected, and the amplitude reaction rarely taken into account. In this arrangement, once the approximate values of resistance and capacity for the phantom antenna have been obtained, the final adjustment is readily obtained, based upon the consideration that (1) small changes in reactance produce first order changes in frequency, and (2) that small changes in resistance produce first order changes in amplitude of the oscillations produced by the driving tube.

It is for determining the conditions of constant frequency and constant amplitude that the frequency meter and change-in-plate-current milliammeter are provided. The use of the first is self-evident, but some further details on the use of the second are in order. Since the antenna systems, physical and phantom, are shunted in turn directly across the tuned-grid circuit of the oscillator, both are subjected to the same voltage as the input circuit of the vacuum tube. If the input circuit of the tube be used as a rectifier, a path being provided through a grid-leak resistance for the d-c component of rectification, the magnitude of the direct current in this path will serve as a measure of the amplitude of the radio-frequency voltage impressed on the tube (and on either antenna) for amplitudes of oscillation which are not too great. The tube may be used as a d-c amplifier and the measure of the magnitude of the direct current through the grid leak may be obtained by observation of the change in d-c plate current in the output circuit of the tube. As this method provided sufficient sensitivity and simple manipulation with inexpensive and rugged meters, it was adopted for this assembly.

The frequency-response characteristic of the "voltmeter" action of the oscillator tube, described in the last paragraph, is of no consequence as measurements are made at constant frequency. Any variation in plate-current change with frequency, for a fixed amplitude of input voltage, only serves to alter slightly the ease with which the phantom circuit may be adjusted.

Natural Frequency of Antenna

Through the use of the variable loading coil and thermogalvanometer the antenna circuit is tuned to frequencies which approach the natural frequency of the antenna as the amount of loading is decreased. When the loading inductance has been reduced to zero, only the coupling coil remains in circuit. Its effect on the antenna frequency is small and is further reduced by the low resistance shunted across it. Data are obtained for the frequency of the antenna circuit for each loading coil step, and the frequencies are then plotted against the number of the loading coil step. A curve is obtained which may be safely extrapolated to the zero loading ordinate, intersecting this ordinate at the unloaded, or natural, frequency of the antenna. For most purposes sufficiently accurate results are obtained if the loading effect of the coupling coil be neglected, by simply determining the frequency of the antenna system with this coil in circuit, and dispensing with the necessity of plotting a curve. This approximate method is of course much more rapid.

Accuracy and Sensitivity; Experimental Check; Interference

Accuracy of Measurements; Sensitivity

The absolute accuracy of measuring the apparent resistance and capacity of an antenna depends upon skill in manipulation of the equipment and upon the accuracy with which the constants of the phantom antenna are known. These factors will each now be given brief consideration.

The sensitivity of the equipment is such that with only moderate skill and experience in manipulation one may obtain readings of the capacity and resistance of the phantom antenna to better than ± 1.0 per cent for capacity (at 1,000 $\mu\mu$f) and to better than ± 1.0 per cent, for resistance (at 10.0 ohms). The ultimate accuracy of capacity readings depends on the accuracy of calibration of the condenser and the accuracy with which the calibration may be read. The resistance is made variable in 0.1-ohm steps as the finest variation, so that for low resistances, 0.1 ohm may appear as a relatively large variation. The resistance readings are consequently limited to the nearest 0.1 ohm.

The capacity of the phantom antenna has implicitly been assumed of zero resistance, in the description of the principle of the substitution method. Actually, however, the condenser has an appreciable resistance, a resistance which varies both with frequency and with the value of capacity employed. Based upon the work of Wilmotte[1] and

[1] Raymond M. Wilmotte, "A quick and sensitive method of measuring condenser losses at radio frequencies," *Jour. Sci. Instruments*, V, No. 12, 369–375; December, 1928.

upon 1,000-cycle measurements, the curves of Fig. 3 have been drawn, with notations applying to the use of the specimen condenser in the phantom antenna of this measuring equipment.

The dotted line at 0.1 ohm represents the minimum variation in resistance which may be observed with the equipment. It is at once evident that the specimen condenser may be used at all frequencies between 100 and 600 kc without introducing an error in the decade resistance of as much as 0.1 ohm, as long as the capacity is higher than

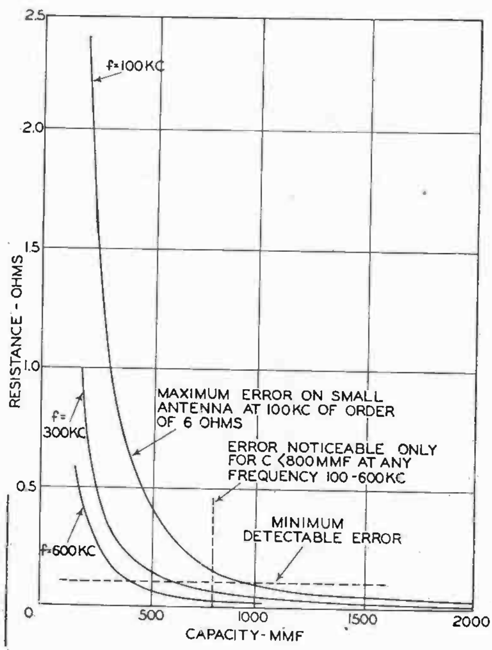

Fig. 3

1,000 $\mu\mu$f. As the antenna systems generally employed for operation at from 100 to 600 kc have a capacity of this order, it is seen that the error is usually negligible.

At a setting of 200 $\mu\mu$f, the condenser has a resistance of 2.4 ohms at 100 kc, 0.8 ohm at 300 kc, and 0.4 ohm at 600 kc. These figures represent the amount by which the decade resistance reading would be low for the conditions given; consequently a correction should be made when the condenser resistance exceeds one- or two-tenths of an ohm. For relative comparisons of antenna characteristics, as measured by the same equipment, the correction is of much less importance, and may usually be neglected.

The phantom antenna resistance has been implicitly assumed to have no reactance. Though every commercial precaution has been taken to reduce the reactance as far as possible, some reactance remains: a slight inductive reactance for the leads and a slight capacity reactance for the resistance units themselves. As the resistance of a ship's antenna is of the order of a very few ohms, the reactance of the resistance units is not of serious consequence, as they are used in series with a condensive reactance of the order of a few hundred ohms. If the resistance units are shunted by a loss-less self-capacity, the power loss remains the same for the same applied voltage. The reduction in impedance caused by the shunting capacity is negligible because of the relatively low value of the resistance.

The effect of any reactance in the resistance units of the phantom antenna on the apparent reactance as determined from the setting of the phantom circuit condenser must be considered. The large shunting reactance of the capacity of the resistance units may be replaced by a very small equivalent series reactance. In this form the phantom circuit is then composed of the reactance and resistance of the phantom condenser in series with the equivalent reactance and the resistance of the phantom resistors. The equivalent series reactance of the resistors must be small enough so that when it is placed in series with the phantom condenser reactance no change in the latter is observable. Consider the worst case; a large value of resistance, shunted with a relatively low reactance and operated at the highest frequency in the normal range of the equipment, 600 kc. If the shunting reactance is 10 times the resistance which in turn is 100 ohms, the equivalent series reactance is very closely one-tenth of the resistance value or 10 ohms. This is the reactance of an equivalent series condenser of 0.025 μf at the given frequency. This condenser is in series with the phantom capacity whose maximum value is 0.002 μf, but whose average value would be more nearly of the order of 0.001 μf. Using the larger figure, the maximum possible error in the antenna capacity as read from the phantom condenser would be 10 per cent. The error decreases as the frequency decreases, as the value of phantom resistance is decreased (as the capacity of the lower resistance units is materially less than that of the higher units), and as the value of phantom capacity is decreased.

Experimental Check

As a final laboratory check on the general performance of the equipment a dummy antenna was made up of inductance, capacity, and resistance in series, the constants being measured at 1,000 cycles per second. From these data, the apparent capacity of the dummy was calculated for frequencies in the range covered by the equipment. The dummy was then measured by means of the equipment and the experimental results compared with the calculated. A maximum discrepancy of one per cent was found.

Interference

The basis of the method presupposes that the antenna system is passive; that is, the only electromotive force in the system is that due to the driving oscillator. In case the antenna is being measured in the vicinity of a transmitter, and at frequencies near the transmitter frequency, the voltage induced in the antenna by the transmitter may be of the order of magnitude of the driving voltage. In such cases it is obviously not possible to obtain measurements of the passive antenna system, since the signal voltage appears in the system at a point beyond the accessible terminals. An advantage of the equipment lies in the fact that the change in plate-current meter responds to the interfering signal when it is large enough to cause difficulty and the presence of such a signal is at once made known. The measurement at the particular frequency may be deferred to a break in the transmission, as only a very few moments are required for the determination. If no break is likely, frequencies on either side of the particular frequency of the transmitter may be used, where the transmitter signal is not too great, which generally will serve to cover adequately the required frequency range for the measurements.

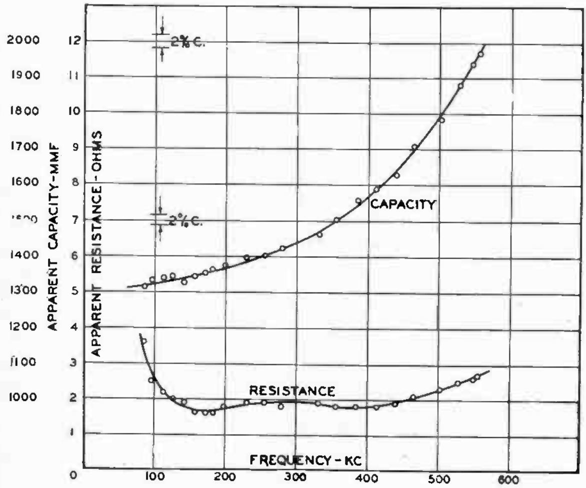

Fig. 4

EXPERIMENTAL RESULTS

The results of measurements on a ship antenna are given in Figs. 4 and 5. Fig. 4 gives the apparent capacity and apparent resistance of the antenna as measured with the equipment. On the capacity curve discrepancies of one per cent or less from the smooth curve through the points were assigned to experimental error and disregarded in drawing the curve.

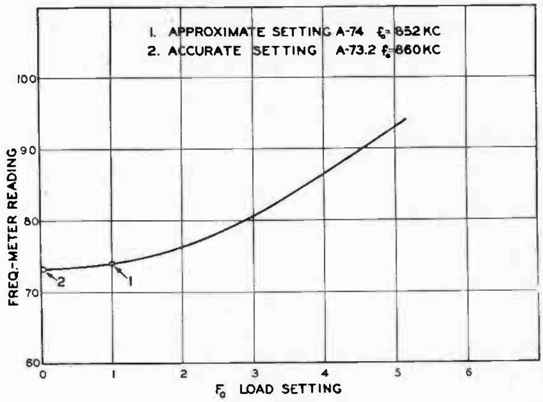

Fig. 5

Fig. 5 indicates the results of the variable loading and plotting method of determining the natural frequency of the antenna. The frequency determined with the coupling coil in circuit is indicated under "approximate method."

In conclusion the author wishes to express his appreciation of the cooperation of Arthur E. Thiessen in the laboratory work and of Warren F. Jepson of the U. S. Coast Guard in arranging for field tests.

Proceedings of the Institute of Radio Engineers
Volume 18, Number 4 *April, 1930*

TRANSMISSION CHARACTERISTICS OF A SHORT-WAVE TELEPHONE CIRCUIT*

By

R. K. Potter

(American Telephone and Telegraph Co., Netcong, N. J.)

Summary—*A method of observing and recording the audio-frequency transmission characteristics of a short-wave radiotelephone channel is described. These characteristics undergo rapid changes. They appear to be the result of wave interference between signals arriving at the receiver over paths of different group or electrical length possibly combined with the distortion produced by a progressive change in the angle of rotation of the polarization plane with frequency over the signal band. The persistence of certain pattern shapes during the observation periods and the changes in these shapes from hour-to-hour suggest that they are the result of progressive rather than erratic disturbances in the transmission medium. Times when the audio-frequency characteristics were flat were very rare. However, a considerable departure from flatness may occur without serious effect on the intelligibility of the speech transmission.*

Synthetic patterns used in the analysis of the characteristics are explained and illustrated. Types of audio-frequency distortion resulting from selective fading are discussed. The effect of frequency or phase modulation in producing distortion on such a circuit is considered.

Records are shown of the effect of an automatic gain control, following carrier amplitude variations, upon the audio-frequency transmission characteristic. "Rapid" fading records revealing unlike fading on radio frequencies separated by 170 cycles are included. The seasonal variation in susceptibility of the circuit to this "rapid" fading is illustrated.

The records mentioned above are for ordinary modulated carrier transmission and involve the results of interaction between the two side bands in the detection process. There are also shown records made on single side-band carrier-suppressed transmission. In this case detection does not modify the frequency-amplitude relations and the record delineates directly the frequency-amplitude characteristics of the received radio-frequency band.

THE USE of radio channels as links in connecting together wire telephone networks makes necessary the determination of the transmission characteristics of such links as telephone circuits. The considerable measurement technique which has been developed for wire circuits, such as the making of consecutive single-frequency measurements over the voice-frequency band is inadequate to disclose the true nature of the distortion which may exist in a radiotelephone circuit, especially when the link is of the short-wave type, because of the large changes in the transmission characteristics which may take place in a period as short as a fraction of a second. To disclose the

* Dewey decimal classification: R113. Presented before New York meeting of the Institute, March 5, 1930; before Philadelphia Section, March 12, 1930; before Washington Section, March 13, 1930; before Pittsburgh Section, March 14, 1930.

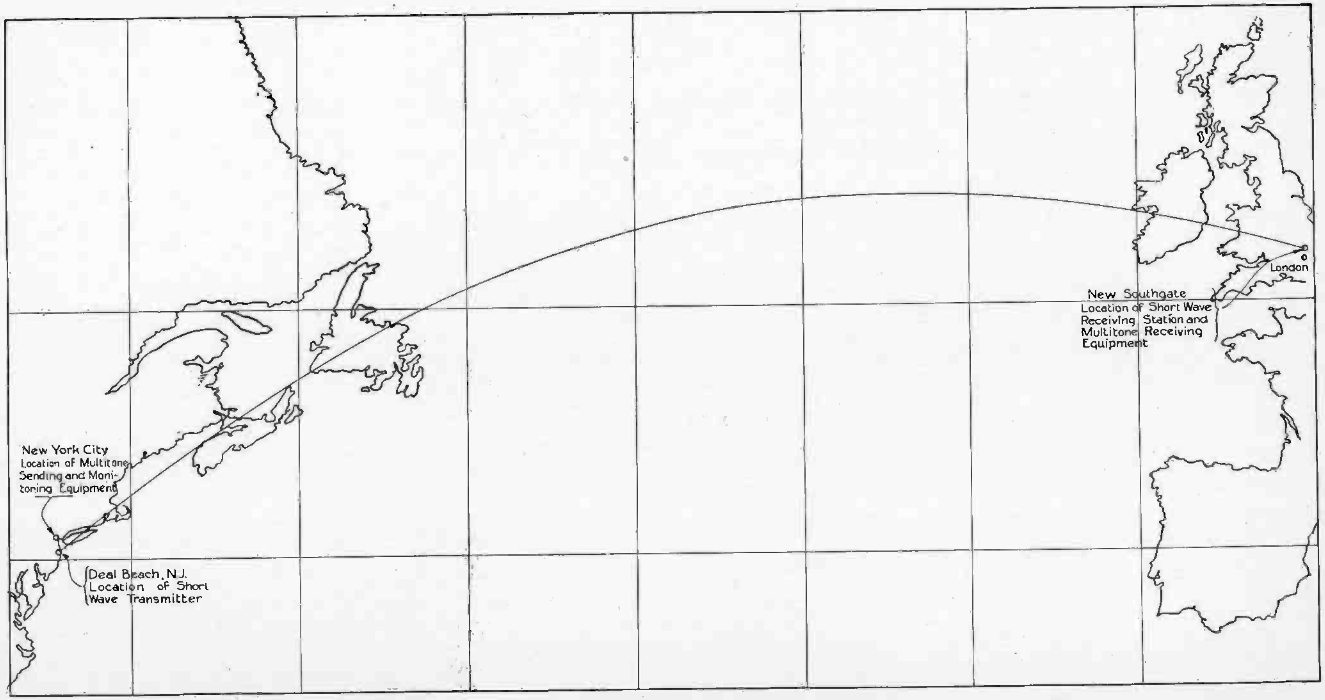

Fig. 1—Transatlantic short-wave circuit over which multitone tests were made.

transmission characteristics under these conditions, it is necessary to resort to a method which permits taking an entire characteristic quickly as a snapshot record and which enables making a rapid succession of such records as in moving-picture photography.

Except for the greater speed with which the data are secured by automatic recording, the essential difference between this process and the ordinary procedure used in measuring wire lines is that the measuring frequencies are sent simultaneously and continuously rather than individually and consecutively. The circuit is thus subjected to a steady state condition and complications due to transients are avoided.

In the analysis, classification and interpretation of the characteristic records which largely make up the subject matter of this paper, attention is necessarily concentrated upon abnormalities and defects in transmission, and the average performance of the channel as a service facility is not stressed. It should be appreciated that for the greater part of the time these defects are not of sufficient magnitude to hamper commercial service materially.

These transmission measurements were made over the short-wave circuit between Deal, New Jersey, and New Southgate, England. Test signals were sent from New York to Deal over wire circuits, and thence by the radio link to New Southgate where they were observed and recorded. In Fig. 1 is shown a diagram of the circuit arrangement. Most of these observations were made on frequencies of approximately 13 and 18 megacycles, and during those hours of the day which are of particular use for transatlantic telephone traffic, namely, 0900 E.S.T. to 1700 E.S.T. Occasional observations were made during the entire 24 hours when the frequencies used included approximately 6, 9, 13, 18, and 21 megacycles.

Test Method

The recognized method of measuring the transmission characteristic of a wire circuit is to send a known amount of single-frequency tone into the circuit and to measure the circuit output as the frequency is varied. A "frequency-amplitude" curve may then be constructed. In order to follow the changes which are apt to occur in a short-wave radio circuit, it is requisite that such measurements be performed very rapidly, and that they be repeated in continuous succession. One way in which this might be accomplished would be to send the different frequencies of the voice band in sufficiently rapid succession, and measure them at the same rate at the receiver. This method possesses a certain advantage insofar as equipment is concerned, but it introduces an undesirable complication due to the transient character of the test signals. In case the signal travels over paths of different length between transmitter and receiver, there is an overlapping of successive frequencies. Such overlapping has actually been utilized to determine the difference in length of overhead and direct radio transmission paths.[1] The extent to which this overlapping would confuse the measurements was not known at the time the tests were planned as there were little data available concerning the path differences which are apt to exist on such a short-wave circuit. It was decided, therefore, to eliminate such effects as completely as possible from the measurement method.

The method finally adopted consisted in the simultaneous transmission of a series of tones distributed at regularly spaced intervals over the voice band. At the receiving point these tones were separated by means of as many filters so that they were continually at hand for recording or observation. There was available for this purpose equipment which has been standardized for use on voice-frequency telegraph circuits. At the sending station for the test signals in New York there was installed a generator with an output of 12 frequencies from 425 to 2295 cycles at intervals of 170 cycles. A series of "sending" filters were inserted in the 12 output circuits of the generator to suppress harmonics, and means for adjusting and measuring the outputs of the 12 tones were included. Apparatus was also installed at the New York test station for making observations upon the signal leaving the transmitter. For this purpose the output of a monitoring receiver near the transmitter at Deal was sent back to New York over a separate wire circuit. The amplitudes of the tones were then adjusted to give equal output from the transmitter. Any inequality which appeared during the observations at the New Southgate receiving station in England would, therefore, be due to effects of the radio transmission path.

The apparatus used in New York for monitoring the output of the transmitter at Deal was the same as that employed at New Southgate for making observations on the received signal. The "multitone," as the 12-tone test signal has for convenience been designated, was separated into its single-frequency constituents at the output of the receiver by means of 12 "receiving" filters. A commutating device then impressed the outputs of the different filters in rapid succession upon the vertical deflection plates of a cathode-ray tube. At the same time a second commutator connected mechanically to the first, impressed progressively different biasing potentials upon the horizontal deflection plates for each of the tones selected by the tone commutator. As a

[1] R. A. Heising, Proc. I.R.E., 16, 75, January, 1928.

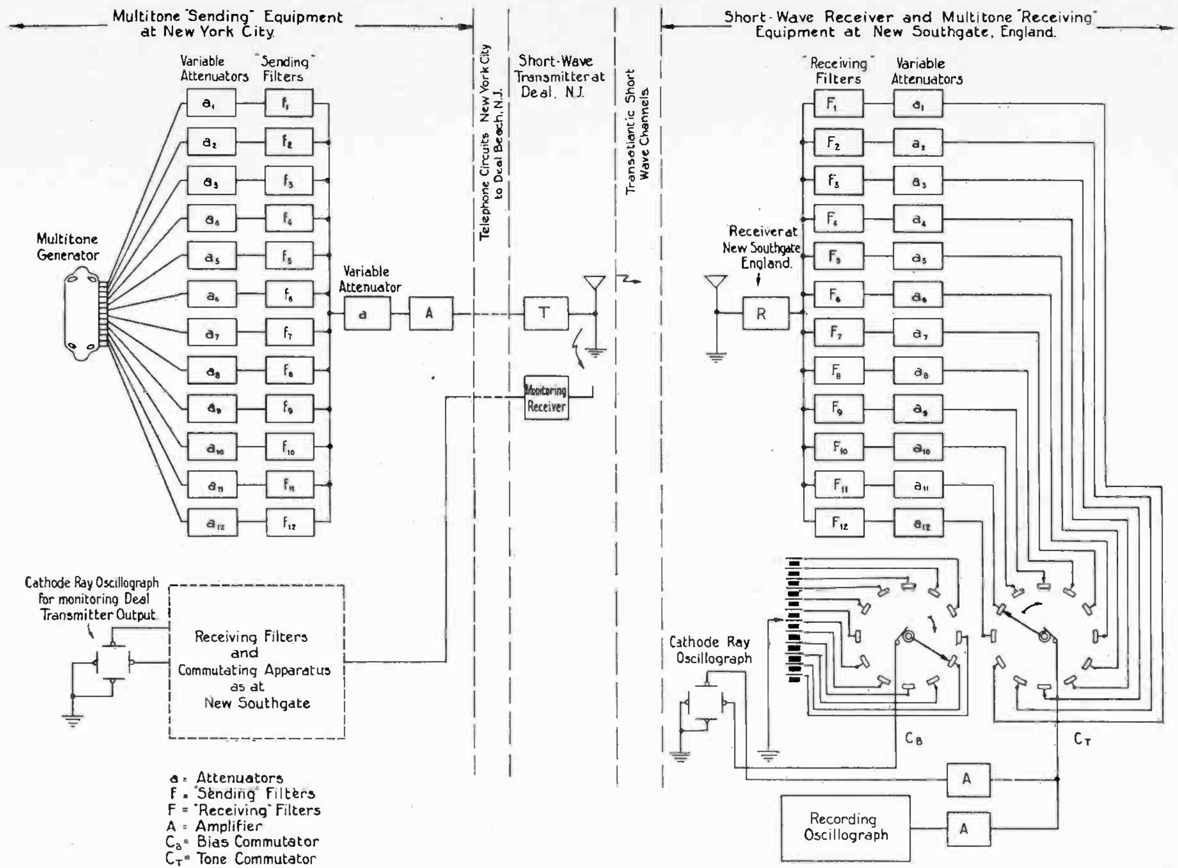

Fig. 2—Schematic of arrangement used for multitone tests on Deal-New Southgate short-wave telephone circuit.

result there appeared across the screen of the cathode-ray tube a series of 12 vertical lines, regularly spaced at intervals of something less than a quarter of an inch. These 12 vertical lines constituted a frequency-amplitude pattern representing the audio-frequency transmission characteristic of the radio circuit. The rate of commutation was about 12½ sweeps of the 12 tones a second, so that the pattern was sufficiently free from flicker, and yet fast enough to portray any variations which the eye was capable of following. In these 12 tones, which were entirely independent at the sending and receiving ends, there were available, incidentally, 12 separate telegraph circuits. The independence of these channels was clearly demonstrated by the appearance

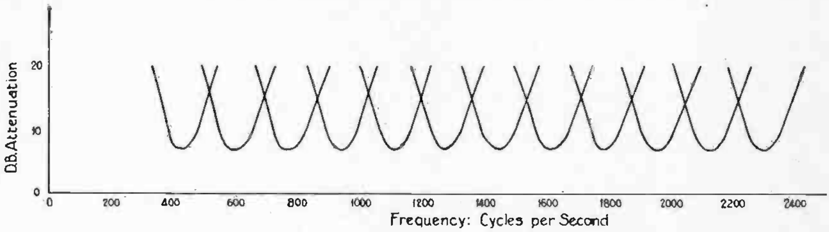

Fig. 3(a)—Characteristics of multitone "sending" filters.

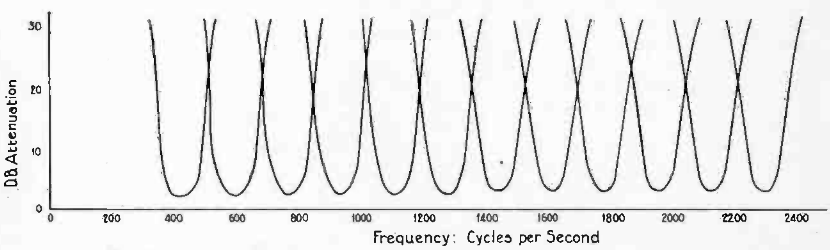

Fig. 3(b)—Characteristics of multitone "receiving" filters.

and disappearance of a particular tone on the cathode-ray tube pattern corresponding to the opening and closing of that particular tone circuit at the sending end. The remaining tones were undisturbed.

In Fig. 2 is shown a schematic of the entire test arrangement. In Fig. 3(a) are shown transmission characteristics of the voice-frequency telegraph "sending" filters used to suppress the harmonics of the 12 tones. Fig. 3(b) shows the transmission characteristics of the "receiving" filters. The frequency spacing of the 12 tones constituting the multitone test signal is such that the second harmonics are suppressed by the receiving filters. Such an arrangement is highly desirable since under certain conditions, which will be discussed later, a large amount of second harmonic may occasionally be produced at the receiver.

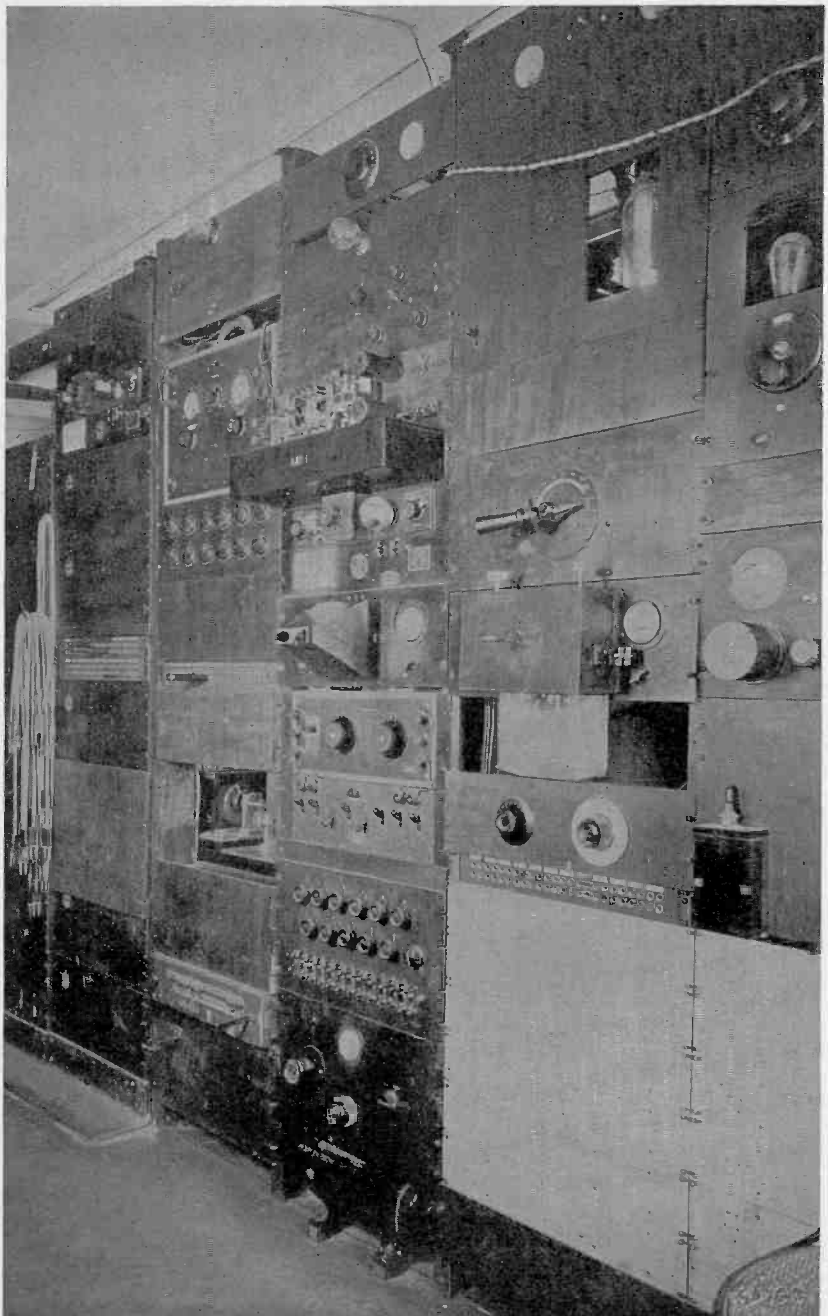

Fig. 4—View of multitone sending equipment at Walker Street, New York City.

In Fig. 4 is shown a view of the multitone sending equipment at 24 Walker Street, New York, N. Y.

The upper picture in Fig. 5 shows a view of the receiving site at New Southgate. The building in the foreground contains the short-wave receiver. The poles support two parabolas for 13 and 18 megacycles. During the last part of the period represented by the data described in this paper these two parabolas were replaced by the extended direc-

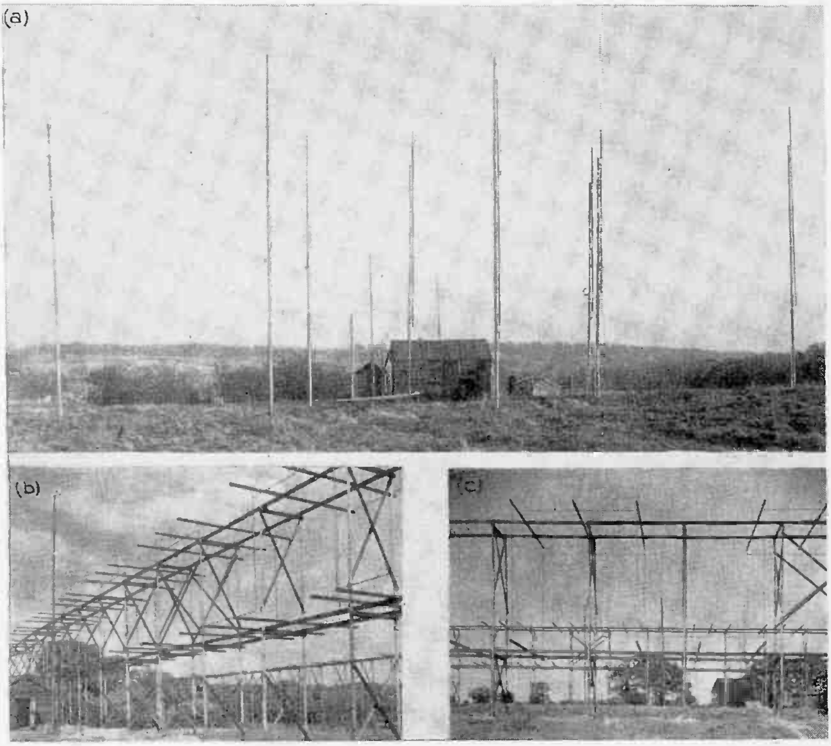

Fig. 5—Receiving site at New Southgate, England.
(a) Four-element parabolas used during first part of multitone tests.
(b) and (c) Views of array structures used on 13 and 18 megacycles during last part of multitone tests.

tional arrays shown in the lower photographs. The multitone records and observations were made in the building which appears in the background of the upper photograph in Fig. 5. Herein were the bays upon which were mounted the 12 multitone "receiving" filters, attenuators for equalizing the outputs of the filters, and amplifiers. A bench along one side of the room was equipped with a single-element oscillograph adapted to the making of long, slow records, and a three-element oscillograph used for making fast, commutated records of the multitone. One corner was partitioned off as a "dark" room in which were installed the multitone commutator and cathode-ray tubes.

A view of the multitone commutator is shown in Fig. 6. At the extreme left is the a-c motor which drives the commutator brushes. In the faces of two vertical rectangles of hard rubber beside the motor are embedded the segments of the "tone" and "bias" commutators. The brushes are adjusted to sweep over these two commutators in synchronism. At the right is a rotary switch which made it possible to use the same multitone equipment to observe the outputs of two different short-wave receivers on the same cathode-ray tube. To the

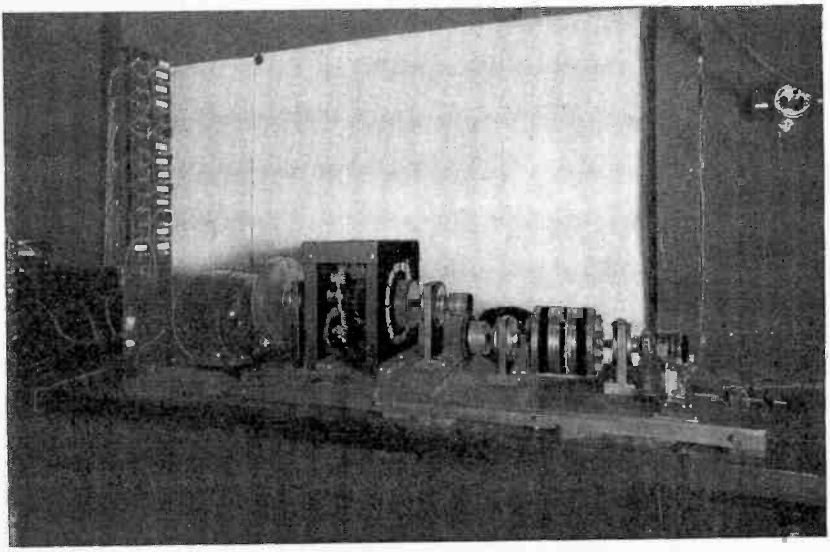

Fig. 6—View of switching device including multitone and bias commutators, rotary switch for comparing multitone from two sources, and film exposure timer.

right of this is a "timing" switch to close the anode circuit of the cathode-ray tube for a predetermined period when making records by pressing a film against the face of the tube.

Most of the multitone data which will be described were taken on a normal double side-band and carrier circuit. Toward the end of these tests, records and observations were made of single side-band transmission. The carrier was supplied by a specially designed adjustable oscillator at the receiver. In order to maintain a correct relation to the side band for the single side-band multitone tests, one of the multitones was sent back from the output of the filters to the control operator who maintained a "zero beat" relation to the output of an audio-frequency oscillator adjusted to that particular multitone frequency.

Multitone Records

Three methods of recording were used during the course of the tests. The first consisted of simply sketching the patterns which appeared on the CRO tube screen. When the variations in pattern shape were slow, this method was accurate enough to give a satisfactory record. Even during times when the changes in shape of the multitone patterns were more rapid, it was found that an experienced observer could make enough sketches of this kind to show with sufficient exactness the character of the distortion at particular hours of the day.

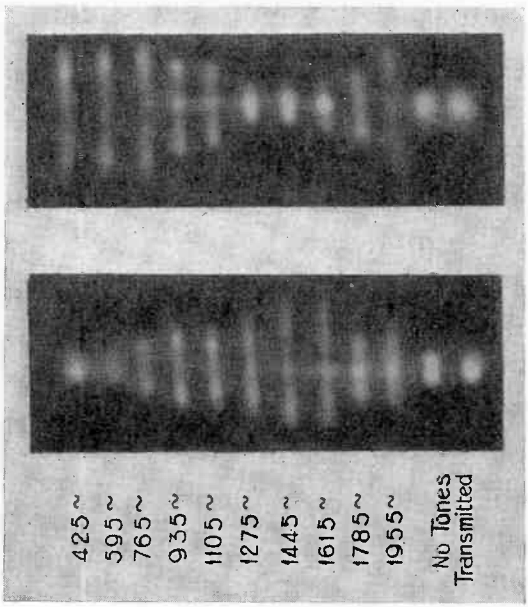

Fig. 7—Cathode-ray oscillograph contact pictures of multitones.

Another recording method consisted in making so-called "contact pictures" of the patterns. With the anode circuit of the CRO tube open a sensitive film was pressed against the screen. A trigger was then pressed which released the contactor on the spiral timing switch shown at the right end of the commutator in Fig. 6. The switch exposed the film by closing the anode circuit during one or more complete revolutions of the commutator shaft. A single sweep, exposing each tone about 1/150th of a second was found sufficient to give a useful record. When the patterns were changing slowly, the film was exposed two or more complete cycles to improve the contrast. Contact pictures gave much more accurate quantitative information than the sketches, particularly at times when the patterns were changing shape rapidly. They possessed the same disadvantage as the sketches, however, in that it was not possible to take contact pictures in rapid and regular succession so that the time sequence of changes could be recorded.

In Fig. 7 are shown two examples of "contact" pictures taken on the cathode-ray tube. Tones No. 11 and 12 were not transmitted at the time these prints were taken so that there is no deflection of the corresponding spots.

In order to obtain the sequence of changes in the multitone transmission characteristics, the commutated tones were recorded by means of a moving element oscillograph. Over 12 complete transmission characteristics could thus be recorded on sensitized paper each second. An enlarged record of one of these multitone patterns taken on os-

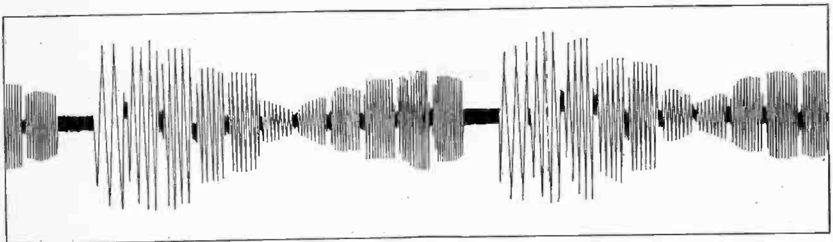

Fig. 8—Fast oscillograph record of a representative commutated multitone characteristic.

cillograph film is shown in Fig. 8. The detail in this record is sufficient to show the effect of commutation upon the patterns to be negligible. If the multitone band were extended below 425 cycles, it would obviously be necessary to decrease the commutation rate or apportion the commutation intervals so that the same number of cycles would be recorded for each frequency. Normally the multitone records were taken on sensitized paper strip moving at such a rate that each complete characteristic occupied about three-quarters of an inch. Tone No. 12 (2295 cycles) was not generally recorded in these multitone "movies," as they have been called, in order to show more clearly the interval occupied by successive characteristics. In all cases the low frequency (425 cycles) is at the left end of each characteristic.

Preliminary Aural Observations

After listening to speech over a short-wave circuit such as that between Deal, New Jersey, and New Southgate, England, for a while, we may become aware of at least four effects. The first is that of marked changes in the general amplitude of the received signal. During certain times of the day and year these general variations in signal amplitude may occur very slowly—perhaps at the rate of two or three fades a minute. More commonly, the fading rate is in the order of 10 to 20 fades a minute. On occasions there appears what has come to be described in the log sheets of the Deal-New Southgate circuit as "rapid fading." At such times the fading rate may be as high as several hundred a minute. Fortunately this condition is rather rare.

A second effect which will be noticed after a little experience with the short-wave circuit is that the voice is often distorted at the bottoms of the deep fades. When the signal decreases to a low level, it often happens that the speech becomes high-pitched as if considerable harmonic were present.

A third effect is the occasional very noticeable presence of a different kind of distortion on high and medium amplitudes of the signal. When this distortion is present it may result in the voice becoming low-pitched and guttural at one moment and high-pitched a moment later. This type of distortion is due to a partial suppression of certain fundamental frequencies in the voice, and not to the introduction of harmonic. As will be shown later, the second and third effects are, as these aural observations might indicate to a critical observer, actually different though the cause is fundamentally the same.

The fourth effect which might be detected by aural observation is that there apparently exists some relation between the average changes in amplitude of the signal and the changes in the character of the distortion represented as the third effect. To some extent, at least, this observation in itself would lead us to believe that the causes of general fading producing changes in volume of the signal from the receiver, and the selective fading represented by the partial suppression of certain speech frequencies, may be in some way related.

Preliminary Multitone Observations

The frequency-amplitude characteristics represented by the multitone patterns substantiate all except the second of the aural observations mentioned above, i.e., the presence of harmonic distortion at the bottom of the fades. The harmonics present at such times are, as will be shown later, largely even multiples of the fundamental which the multitone filters are purposely arranged to suppress.

Fig. 9 shows in outline some multitone pattern shapes of the type which are characteristic of the Deal-New Southgate short-wave circuit. The patterns under (a) indicating a general rise and fall in the signal amplitude without relative changes in the amplitude over the width of the multitone band are rare and are accompanied by a very slow fading rate. The patterns under (b) are more common. These have been designated as "tilting" characteristics, and when they are in evidence there ofttimes appear minima which move across the band in one direction or the other. These moving minima are not, as close observation will show, equally deep at all points in their transit.

The patterns shown under (d) of Fig. 9 are of a type which is most commonly observed. During the fading changes a minimum near the lower end of the multitone band becomes a maximum, while the maximum at the upper end of the band becomes, at the same time, a minimum. Incidentally these standing changes, as will be shown later, give us a clue as to the composition of these patterns. Another type of pattern which is fairly common is shown under (f). Here the minima

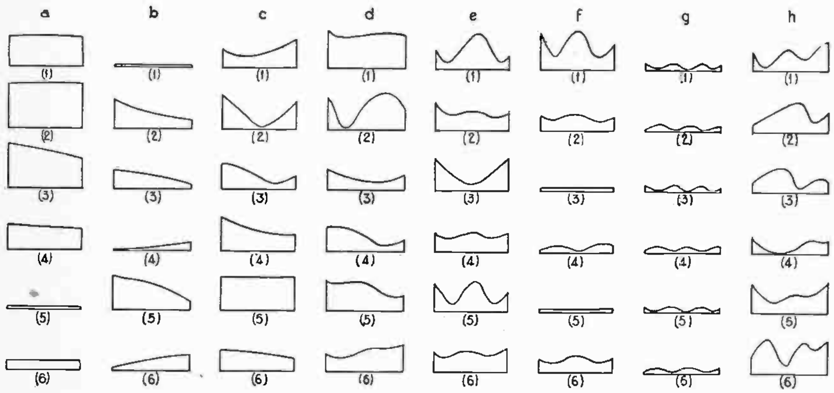

Fig. 9—Some representative multitone characteristics.

(a) "Tilting" characteristics generally accompanying very slow fading.
(b) "Tilting" characteristics with indication of shallow minima.
(c) "Moving" minima which often accompany (b).
(d) Single minimum in band alternating with maximum. (Most common sequence observed on 18-megacycle circuit.)
(e) Two minima alternating with single minimum.
(f) Two minima alternating with two low maxima.
(g) Three minima alternating with three maxima. (Rarely observed and generally only on low amplitude during fades.)
(h) Irregular pattern shapes occasionally observed.

also undergo standing changes to maxima, and vice versa. The presence of more than two deep minima in the multitone band is exceptional on the shorter wavelengths, but fairly common on the longer waves. On some occasions patterns, such as are shown under (*g*), were observed. These and the patterns under (*h*) are more usually confined to the longer wavelengths.

The rate of carrier fading generally increases in some relation to the number of minima which appear within the limits of the test band. It should also be mentioned that due to the standing changes described above, the amount of fading on different single tones (on a double side-band signal) may, at times, be quite unequal.

The Accuracy of Multitone Observations

There are two conditions under which the method of observing the transient changes in frequency-amplitude relation by means of the multitone patterns so far described may become unreliable. Fortunately, these conditions seldom exist. In the first place, if the fading rate is comparable to the rate of the commutation utilized in the production of these patterns, they will become distorted. The commutator distributes the tones across the screen of the cathode-ray tube at a rate such that over 12 complete patterns are constructed each second. Thus, if the change in conditions within 1/12th of a second is small the distortion will be correspondingly negligible. Simultaneous fast records of multitone and continuous single tone on a moving-element oscillograph show that except on infrequent occasions, when rapid fading is present, the patterns are reliable within the limits which are imposed by irregularities such as accompany static or circuit noise. As far as the direct observations on the cathode-ray tube are concerned, the distortion is in any case more or less negated by the inability of the eye to follow the changes at times when they become sufficiently rapid to produce distortion. On a multitone record of the type shown in Fig. 13 and elsewhere, the distortion is evidently negligible in direct proportion to the number of times that a certain shape of pattern is repeated. If the shapes of adjacent patterns are entirely different, it may be assumed that the pictures are distorted.

Another condition under which the multitone patterns become unreliable may result from an assumption that the separation of the minima is comparable to the 170-cycle separation of the single tones constituting the multitone. If this were the case, there would be no relation between the patterns on the cathode-ray tube and the sound of the multitone. Actually, it is very easy to recognize by simultaneous aural observation the suppression of certain frequencies, as indicated by the shape of the multitone patterns. Only during those infrequent periods, when very rapid fading is present, has there been any indication of minima separation comparable to the separation of the single tones in the multitone signal.

It is very unlikely that the patterns are complicated by signals received from the rear around the world, since during most of the tests, directive antennas were used for transmission and reception.

Analysis of Multitone Patterns

An interpretation of the multitone patterns requires a preliminary consideration of the possible immediate causes of the distortion. Such a consideration must start with the assumption that the signals at the point of reception may be subject to distortion both in space, and along the time axis. The wavefront might be skewed in space so that the amplitudes and phases of the signal components are selectively distorted when received on a vertical antenna. Distortion along the time axis would result if portions of the resultant signal at the receiver travel over two or more paths of different electrical length. We shall consider some of the possible conditions of the received signal which might account for selective fading as observed.

Effect of Change in Polarization with Frequency

Rotation of the plane of polarization by that component of the earth's magnetic field which is parallel to the direction of wave travel as been discussed by others.[2] Such rotation is due to the difference in velocity of propagation of the right- and left-hand circularly polarized components. The angle of this rotation varies with frequency. P. O. Pedersen[3] has given an approximate expression for the distance within which the plane of polarization of a short radio wave will be rotated through an angle of 2π. The approximate expression is as follows:

$$L_{2\pi}=\frac{mc}{Ne^2}\cdot\frac{\omega^2}{h}\cdot 10^{-5}\ \text{(km)} \tag{1}$$

where,
e = electron charge = $4.77\cdot 10^{-10}$ e.s.u.
m = $8.97\cdot 10^{-28}$ grams
c = velocity of light in cm per sec.
N = number of electrons per cc
ω = 2π times frequency (f)
h = e/mc times magnetic field in gauss.

For a distance D of transmission through the electron atmosphere the rotation angle ϕ will therefore be

$$\phi=\frac{2\pi D}{L_{2\pi}}=\frac{DNe^2h\ 10^5}{2\pi mcf^2}\quad \text{(radians)}$$

and the rate of change of rotation with frequency is,

$$\frac{d\phi}{df}=-\frac{DNe^2h\ 10^5}{\pi mcf^3}. \tag{2}$$

Knowing the rate of change of the rotation with frequency we can

[2] P. O. Pedersen, "The propagation of radio waves," Chap. VII, p. 95. H. W. Nichols and J. C. Schelleng, "Propagation of electric waves over the earth," *Bell. Sys. Tech. Jour.*, IV, 215, 1925.

[3] Page 110.

determine the separation of the minima occurring at those frequencies which would be polarized at right angles to a vertical antenna.

Assuming a transmission range through the ionized atmosphere of 2,000 km, $N=5\cdot 10^5$, and $H=0.2$ gauss, the minima separation for a frequency of $7\cdot 10^6$ is about 1,000 cycles. For a frequency of 10^7 it becomes 3,300 cycles, and for a frequency of $1.5\cdot 10^7$ the minima separation is 11,000 cycles.

According to these very approximate calculations, a selective rotation of the polarization plane over the signal band may contribute considerably to signal distortion when the transmission is parallel to the earth's magnetic field. It seems somewhat unlikely that this effect can produce material distortion on the short-wave channel between Deal and New Southgate, however. Here the component of the earth's field along the line of transmission is relatively small and undergoes a reversal in direction toward the midpoint. The direction of rotation would accordingly undergo a change.

Whether due to this effect or not the general experience has been that on the Deal-New Southgate circuit the distortion increases inversely with frequency in accordance with what we should expect from (2). Our knowledge of the several factors which in short-wave transmission contribute to the rotation of the polarization plane is as yet too limited to permit of any very conclusive statement concerning the importance of this effect. At the lower radio frequencies it may account for a part of the distortion revealed by the multitone tests.

By means of two separate multitone reception equipments arranged to receive the horizontal and vertical components of a single side-band signal, it would be possible to so combine the commutated outputs that the state of polarization of each of the high-frequency waves separated by 170 cycles would be shown side by side on the cathode-ray tube. These patterns might show that the polarization at a given instant is very different for the different frequencies, and that the figures are continually changing. Of the existence of this condition there is already available some experimental evidence. From the multitone tests and other similar data on selective fading we know that frequencies, separated by only a few hundred cycles in the high-frequency radio spectrum, fade in an apparently unrelated manner when received on a vertical antenna. It has also been noted that instantaneous fading conditions of the horizontal and vertical components of a single carrier wave are different.[4] Therefore, we might reasonably expect that multitone patterns representing horizontal and vertical components of the received signal wave would be unlike when viewed simultaneously.

[4] Unpublished data of H. T. Friis, Bell Telephone Laboratories. Discussion by T. L. Eckersley, *Jour. I. E. E.*, 66, 881.

This condition would necessitate a change in the state of polarization with frequency.

Incidentally a selective rotation of the polarization plane with frequency over the signal band would, when combined with the effect of a reflection from the earth's surface, result in a further distortion of the signal due to the fact that those components which are parallel to the incident plane will be less completely reflected than those which are perpendicular to this plane.

A change in the state of polarization with frequency may be accounted for by other effects than a selective rotation of the polarization plane. Assume, for example, that identical signals travel over two paths of different length to the receiver, and that each of these devious paths rotates the general plane of polarization differently (that is, the change in rotation with frequency over the signal band is negligible). As a result there will be present at the receiver two signal components which differ in time and space phase. To simplify matters let it be assumed further that the signals over the two paths are of the same amplitude and that their planes of polarization when they reach the receiver are at 90 deg. Due to the difference in length of the two paths, the relative time phase of similar frequencies in the two signals will vary progressively. Therefore, the state of polarization will be found to change from plane to circular, and back to plane polarization as we explore the frequency band.

Although there is some uncertainty as to the magnitude of the effect produced by the selective rotation of the polarization plane over the signal band, it may reasonably be expected that the polarization will change materially over the width of the signal band due to the combination at different space angles of waves arriving over different paths. As far as our analysis of such signals received on a vertical antenna is concerned we may neglect this difference in polarization for the different paths, bearing in mind, of course, that the relative magnitude of signals over separate paths may vary quite suddenly (and perhaps in some manner related to the fading) as the plane of polarization changes from the vertical to the horizontal.

Effect of Distortion Along the Time Axis

A source of selective distortion in a normal radio signal group (i.e., consisting of a carrier and two side bands), which may seem on first consideration to offer a plausible explanation of the observed effects, is side-band asymmetry. Such asymmetry occurs when the group velocity of the upper side band and carrier is different from that of the lower side band and carrier. (This effect is generally omitted as negligible in the derivation of equations expressing the velocity of a wave group). If side-band asymmetry is the cause of distortion in the normal signal such distortion should disappear when we transmit only a single side band, and supply the carrier at the receiver. Actually the distortion does not disappear when a single side band is transmitted and a comparison of the multitone patterns for single and double side-band signals suggests that the effect of side-band asymmetry, if not negligible, is at least a secondary source of distortion.

The character of the distortion predicted on the assumption that the signal travels over more than one path between transmitter and receiver, and that these paths are of different group lengths, corresponds reasonably well with that which actually occurs for both the normal double side-band transmission and for the transmission of a single side band. The combination of a certain high-frequency wave arriving over one path with waves of the same frequency following other paths of different electrical length produces an interference pattern at the earth's surface. As has been previously stated, we may reasonably expect that the planes of polarization may be different for these waves arriving over different paths. As a result an exploration of the ether in the vicinity of the receiver would probably show that the polarization changes progressively as we go from one part of this single-frequency interference pattern to another. This pattern would probably be continually shifting about due to the unsettled nature of the transmitting medium. Furthermore, it would shift with changes in frequency of the transmitted waves.[4] Therefore, at a particular point in a composite pattern produced by the transmission of a band of frequencies, we should probably find a progressive change in the state of polarization as we examine the different high-frequency components in the signal band. At those frequencies which are horizontally polarized, there would appear deep minima if single side-band multitone signals were received on a vertical antenna.

There is in the data here described no very definite evidence concerning the course of these different paths or the cause. Perhaps the most useful evidence that the multitone tests afford in this direction is that they show the complexity of the patterns to increase inversely with frequency, suggesting that the number of components or the number of paths perhaps increases. Making certain simple assumptions concerning the variation in ionization with height above the earth it is possible to account for two paths through two levels in the refracting medium where the rate of change of ionization with height may be effectively the same. These two points occur in regions of opposite

[4] G. Breit, Proc. I.R.E., 15, 709, August, 1927.

curvature in the "ionization-height" curve. The intensity of the ray through the upper convex portion of the above-mentioned curve would in general be much below that of the ray through the concave portion due to the focusing effect in the latter case. These two rays do not seem sufficient in themselves to account for the observed multitone pattern shapes.

Another possible cause of devious paths might be more than the two refracting levels mentioned above. It is possible that the change in ionization with altitude is not as simple as we are at present inclined to presume. More than two levels at which the rate of change with ionization with altitude is effectively the same would account for a greater number of paths. This is equivalent to the theory that more than one layer exists. How an apparent increase in the number of paths with a decrease in frequency could be made to agree with this theory is not obvious, since the lower radio frequencies would not so readily penetrate the lower levels to be refracted from those higher up.

On the assumption that multiple earth reflections occur it is less difficult to account for the increase in number of paths with decreasing frequency. The lower radio frequencies would return to earth at the shorter ranges necessary for multiple reflections. The reflection points on the Deal-New Southgate circuit would occur at the ocean surface. Considering both the relative regularity of the ocean surface and its conductivity, the reflection losses would be much lower than those for soil.

There seems to be little to justify the idea that the different paths follow widely devious routes in the horizontal plane. Selective fading patterns of multitone received on simple vertical elements appear to be the same as those received on an array which is directive within some 10 deg. in the horizontal plane.

In the analysis of the effect of wave interference due to signals traveling over more than one path, it will be assumed that the receiving antenna is responsive only to the vertical components of the electric field. Therefore, we may initially neglect other than the vertical components of polarization, but, of course, (as was previously suggested) the relative amplitudes of these vertical components may change rapidly as the planes of polarization shift. Actually, it has been found upon analysis of single side-band multitone data that the rate of change in the amplitude relation between the different signal components arriving over different paths is at times apparently comparable to the rate at which the pattern moves across the band. This suggests that the changes in relative length of path which presumably cause fading are accompanied by a relative rotation of the polarization plane.

If the condition of the received signal is complicated as suggested by variations in time and space phase of the components, a direct analysis of the multitone characteristics such as are shown in Fig. 9 is obviously difficult. The method of analysis which has been adopted is that of constructing synthetic patterns, and comparing these with actual records. The information obtained from the study of synthetic patterns also assisted in the collection of data during observations, for it directed attention to certain recurring shapes and sequences of pattern changes. Assuming that the distortion is due to signals traveling over paths of different electrical length from the transmitter to the receiver, it is then necessary to make assumptions concerning the number of such paths, their relative length, and the relative amplitude of components arriving over each. If there are only two signal paths between transmitter and receiver, the spacing of the minima in the frequency spectrum would be quite regular, and they would move across the high-frequency signal band in one way or the other, depending upon the relative changes in electrical length of the two paths. When more than two paths exist the movement of minima is complicated by the fact that the different combinations of two-path interference patterns do not necessarily move in the same direction or at the same rate at a given instant.

Under (a) and (b) of Fig. 10 are shown a series of double side-band patterns constructed synthetically upon the assumption that the signal travels over *two* paths. When the signal components are equal in amplitude, as assumed for (a) of Fig. 10, the minima do not change position during a fade. When the two components are not equal, as under (b), there is a shallow minimum which during a fade will be replaced by a low maximum. There is little correspondence between these synthetic "two-path" patterns and the representative observed patterns of Fig. 9. Patterns of this "two-path" type have occasionally been observed, however, and multitone records, illustrating selective fading of this character, will be shown later. From a careful comparison of synthetic two-path multitone characteristics with those observed throughout the year we are led to the conclusion that the selective fading on the Deal-New Southgate short-wave circuit must, except during a small percentage of the time, be the result of signals traveling over more than two paths between transmitter and receiver.

Synthetic patterns based upon the assumption that three paths exist between transmitter and receiver may be made to correspond rather well with the majority of the observed multitone pictures. The agreement between these synthetic three-path patterns and most of those observed is materially improved by making a further reasonable assumption that the amplitudes of the components received over the different paths are subject to change. Such changes may, as has previously been suggested, be due to shifts in the planes of polarization of the interfering components. They may also be due to changes in attenuation along the different paths, to wave interference between components arriving over slightly different paths (taken as a single path in our assumptions), or to changes in the direction of arrival of the components when the horizontal or vertical directivity of the antenna system is sufficiently sharp.

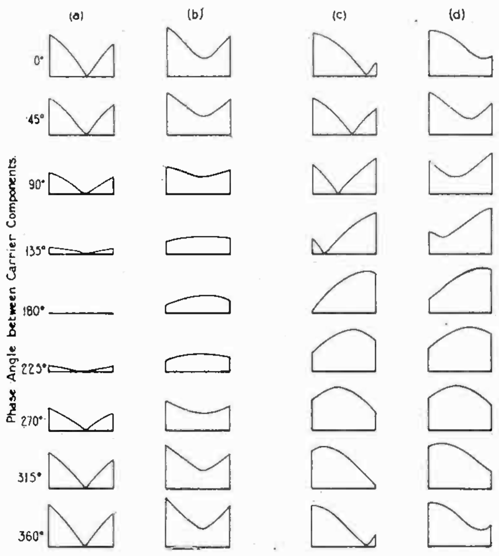

Fig. 10—Synthetic multitone characteristics for double and single side-band signals assuming only two paths.

(a) Double side-band signal, $D=100$ km; $k=1$
(b) Double side-band signal, $D=100$ km; $k=2$
(c) Single side-band signal, $D=100$ km; $k=1$
(d) Single side-band signal, $D=100$ km; $k=2$

In order to approximate the shape of some of the patterns which are observed, it is necessary to assume that more than three paths exist. Such patterns as these appear continuously only upon rare occasions. As a rule they occur for brief intervals as if the additional paths were short-lived, or ordinarily negligible in their effect upon the selective fading. The distortion produced as a result of the signal traveling over more than one path from transmitter to receiver will be discussed in the following section.

High-Frequency Signal Distortion Due to More Than One Transmission Path

Before going into the case of distortion produced in the detected audio-frequency signal the equations will be set down for the frequency-amplitude relation of the high-frequency signal components. Incidentally these equations represent also the distortion produced when only one side band of the signal is transmitted and the carrier is supplied at the receiving point. The case of distortion produced in the high-frequency band is less complicated than the double side-band, audio-frequency case in which the relative phases and amplitudes of the carrier and side-band components must be considered.

For the case in which the interfering components maintain a constant amplitude relation the distortion in the high-frequency band may be represented by (3) below, wherein the phase of one wave is taken as a reference value, and D_1 and D_2 denote the difference in group length of path as referred to the length of the reference path.[5]

$$E_a = E_0 \sin \omega t + E_1 \sin (\omega t - D_1\omega/c) + E_2 \sin (\omega t - D_2\omega/c). \quad (3)$$

Rewriting (3) and grouping sine and cosine factors we have,

$$\begin{aligned} E_a = & (E_0 + E_1 \cos D_1\omega/c + E_2 \cos D_2\omega/c) \sin \omega t \\ & - (E_1 \sin D_1\omega/c + E_2 \sin D_2\omega/c) \cos \omega t \end{aligned} \quad (4)$$

The values in the parentheses of (4) are the amplitude factors which for a given condition of the ether path vary with frequency. The equation (4) may be written as,

$$E_a = A_\omega \sin \omega t - B_\omega \cos \omega t$$

and the resultant amplitude for any particular frequency in the signal band (i.e., $\omega/2\pi$) becomes,

$$E_\omega = \sqrt{A_\omega^2 + B_\omega^2} \quad (5)$$

where,

$$\left.\begin{aligned} A_\omega &= 1 + k_1 \cos \alpha_1 + k_2 \cos \alpha_2 \\ B_\omega &= k_1 \sin \alpha_1 + k_2 \sin \alpha_2 \end{aligned}\right\} \quad (6)$$

In equations (6), k_1 and k_2 represent the ratios of voltages induced in the receiving antenna, E_1/E_0 and E_2/E_0, respectively, and α_1 and α_2 the angles $D_1\omega/c$, and $D_2\omega/c$.

[5] The difference in group length of two paths may be expressed in terms of the phase length of path as,

$$D = (L_g)_1 - (L_g)_2 = (L_1 - L_2) + f[(dL/df)_1 - (dL/df)_2]$$

The path difference, D, does not represent the actual difference in physical length of the two paths.

The amplitude-frequency characteristic for the high-frequency components of a double side-band signal or the equivalent audio-frequency components of a single side-band signal is, therefore, obtained by substituting values of k_1, k_2, D_1, and D_2 in (6), and solving for the resultant amplitude at different frequencies in (5).

A point of particular interest in connection with the frequency-amplitude patterns based upon (5) is that the minima of these patterns are entirely unrestricted in their position in the frequency band of the signal; that is, in a single side-band signal, no particular frequency will be subjected to greater fading than any other in the audio-frequency band. Such is not the case, as will be shown later, when we are considering the transient audio-frequency characteristic of a double side-band signal.

Transient Audio-Frequency Characteristics for Double Side-Band Transmission Case

In developing the amplitude-frequency equations for the double side-band case, we shall again assume that similar components of a signal travel over three paths between transmitter and receiver. The angular velocity of the carrier wave will be taken as ω and that of the modulation wave as q.

Then the three signal components arriving at the receiver over the three paths may be separately represented by the following equations:

$$\left.\begin{aligned}
E_0 &= \sin \omega t + m/2 \sin (\omega+q)t + m/2 \sin (\omega-q)t \\
E_1 &= k_1\{\sin (\omega t - D_1\omega/c) + m/2 \sin [(\omega+q)t-(\omega+q)D_1/c] \\
&\qquad + m/2 \sin [(\omega-q)t-(\omega-q)D_1/c]\} \\
E_2 &= k_2\{\sin (\omega t - D_2\omega/c) + m/2 \sin [(\omega+q)t-(\omega+q)D_2/c] \\
&\qquad + m/2 \sin [(\omega-q)t-(\omega-q)D_2/c]\}
\end{aligned}\right\} \quad (7)$$

In these equations k_1 and k_2 represent the ratio of voltages induced in the receiving antenna E_1/E_0 and E_2/E_0, respectively. The constant m depends upon the percentage modulation, and the phase of the voltage E_0 is assumed to be "zero" so that D_1 and D_2 are the differences in "group" length of the paths as referred to the path of the signal E_0.

Letting $\alpha_1 = D_1\omega/c$, $\beta_1 = qD_1/c$, $\alpha_2 = D_2\omega/c$, and $\beta_2 = qD_2/c$, substituting these values in equations (7), and adding E_0, E_1, and E_2, we have

$$\begin{aligned}
E_0+E_1+E_2 &= \sin \omega t + k_1 \sin (\omega t-\alpha_1) + k_2 \sin (\omega t - \alpha_2) \\
&\quad + m/2 \sin (\omega+q)t + k_1 m/2 \sin [(\omega+q)t-(\alpha_1+\beta_1)] \\
&\quad + k_2 m/2 \sin [(\omega+q)t-(\alpha_2+\beta_2)] + m/2 \sin (\omega-q)t \\
&\quad + k_1 m/2 \sin [(\omega-q)t-(\alpha_1-\beta_1)] + k_2 m/2 \sin [(\omega-q)t-(\alpha_2-\beta_2)]
\end{aligned} \quad (8)$$

When equation (8) is squared (i.e., the signal subjected to square law detection), and the fundamental audio-frequency terms are retained it reduces to the form

$$E_A = A \sin qt + B \cos qt \tag{9}$$

in which

$$\left.\begin{aligned} A = m\{&(1+k_1\cos\alpha_1+k_2\cos\alpha_2)+[k_1\cos\alpha_1+k_1^2+k_1k_2(\cos\alpha_1\cos\alpha_2\\ &+\sin\alpha_1\sin\alpha_2)]\cos\beta_1+[k_2\cos\alpha_2+k_2^2+k_1k_2(\cos\alpha_1\cos\alpha_2\\ &+\sin\alpha_1\sin\alpha_2)]\cos\beta_2\}\\ B = m\{&[k_1\cos\alpha_1+k_1^2+k_1k_2(\cos\alpha_1\cos\alpha_2+\sin\alpha_1\sin\alpha_2)]\sin\beta_1\\ &+[k_2\cos\alpha_2+k_2^2+k_1k_2(\cos\alpha_1\cos\alpha_2+\sin\alpha_1\sin\alpha_2)]\sin\beta_2\}\end{aligned}\right\} \tag{10}$$

These values of A and B can be handled more conveniently if we let

$$\begin{aligned} M &= (1+k_1\cos\alpha_1+k_2\cos\alpha_2)\\ N &= k_1\cos\alpha_1+k_1^2+k_1k_2(\cos\alpha_1\cos\alpha_2+\sin\alpha_1\sin\alpha_2)\\ P &= k_2\cos\alpha_2+k_2^2+k_1k_2(\cos\alpha_1\cos\alpha_2+\sin\alpha_1\sin\alpha_2)\end{aligned} \tag{11}$$

The resultant amplitude of any particular audio frequency is then determined by the relation

$$(E_A)_\omega = \sqrt{A_\omega^2+B_\omega^2} \tag{12}$$

in which

$$\begin{aligned} A_\omega &= m(M+N\cos\beta_1+P\cos\beta_2)\\ B_\omega &= m(N\sin\beta_1+P\sin\beta_2)\end{aligned} \tag{13}$$

From (13) fundamental audio-frequency-amplitude patterns for a double side-band signal may be obtained by assuming certain phase relations for the three carriers (determining α_1 and α_2), path differences (determining β_1 and β_2), relative strength of signals received over the three paths (determining k_1 and k_2) and the percentage modulation m.

It must be emphasized that the above equation (12) determines only the relative amplitudes of the *fundamental* modulation components since only the fundamental terms were retained when (8) was squared. The reason for neglecting the double frequency terms was that, in the test method, these frequencies were intentionally suppressed by a suitable spacing of the test tones, and the action of the receiving filters. The distortion caused by the generation of harmonics will therefore be considered later as a separate problem.

Synthetic Multitone Patterns

In Fig. 10 is shown a series of synthetic multitone audio-frequency transmission patterns for double and single side-band signals. Two transmission paths are assumed. The difference in electrical length of the two paths was taken as 100 km. For the double and single side-band series (a) and (c), respectively, the amplitudes of the two components were assumed to be equal. For (b) and (d) the amplitudes of the component received over one path was assumed to be twice that received over the other. It will be noted that the single side-band signal does not fade to zero in the series (c) as does the double side-band signal in the series (a) when the two equal carrier waves fall into opposition. Also the minima move across the single side-band characteristic, and remain fixed in the double side-band case.

When the components are not equal, the minima are shallow and in the double side-band pattern they are replaced by shallow maxima. Modifications in the double side-band pattern with relative phase shifts may be described as standing changes. Such changes will not occur in the single side-band patterns if only two paths are responsible for the selective fading. The single side-band patterns for the two-path case would consist simply of regularly spaced minima which would move across the multitone picture one way or the other depending upon whether the difference in the group length of the two paths is increasing or decreasing, and whether the upper or lower side band of the signal is transmitted. With an increase in the group path-length difference the minima move toward the low end of the high-frequency spectrum and vice versa. When the upper side band alone is transmitted and the carrier is supplied at the receiver, the audio-frequency pattern corresponds to that of the high frequency. Under these conditions a minima movement toward the low end of the audio band indicates a similar movement toward the low end of the high-frequency spectrum. If the lower side band is transmitted the sense of the movement at the audio frequency is opposite to that at the high frequency.

In Fig. 11 are shown several series of synthetic double side-band patterns based upon the assumption of three-path transmission. Each block of patterns represents a different path-length relation, and the assumption is made that the signal components received over the three paths are equal. Relative phase shifts of the carriers associated with two of the components are shown by the angles α_1 and α_2, described earlier. Disregarding for the moment the limitations of the multitone test band, it may be said that the shapes of these patterns depend primarily upon the ratio of the group path-

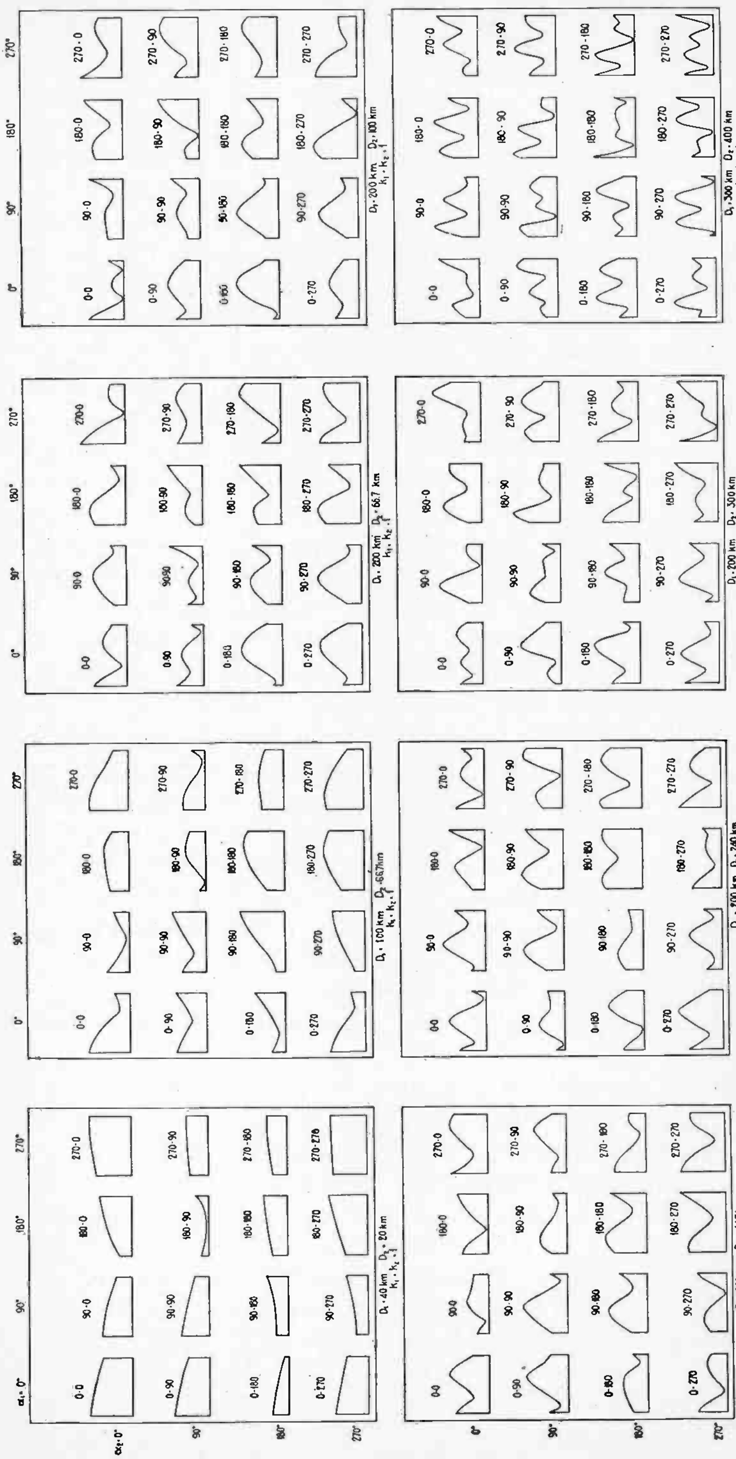

Fig. 11—Synthetic double side-band multitone characteristics assuming equal signal amplitude over three paths.

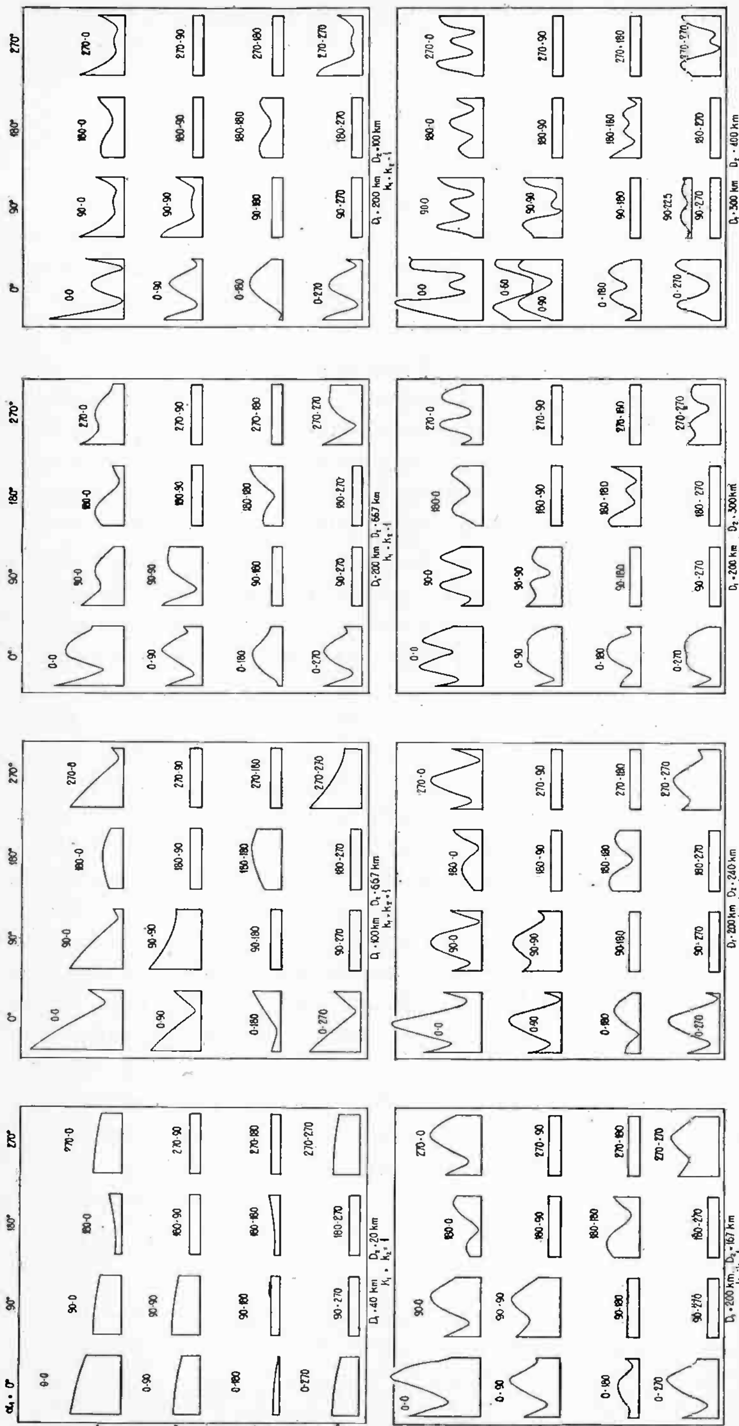

Fig. 12—Synthetic single side-band multitone characteristics assuming equal amplitude over three paths.

length differences. Thus the shape of the patterns for $D_1=20$ km, and $D_2=40$ km, is the same as for $D_1=200$ km, and $D_2=400$ km except that in the latter case there is much more of the pattern squeezed into the frequency range of the multitone band.

In these double side-band patterns it will be noticed that there are several conditions under which the amplitude-frequency characteristic is flat. This occurs when two of the three carrier components oppose one another and are, at the same time, at 90 deg. with respect to the remaining carrier. Under these conditions the side bands associated with the suppressed carriers are in such a phase relation to the remaining carrier that they do not contribute any *fundamental* audio frequencies during the detection process. When we come to a consideration of the harmonic produced by the selective fading, we shall find that although the fundamental characteristic is flat, the harmonic may, under the conditions discussed above, become relatively high so that actually the signal is not free from distortion even though the fundamental frequency-amplitude pattern is rectangular.

Due to the 90 deg. steps between the patterns, shown in Fig. 11, no zero fades appear. For the case of equal signal amplitude received over three paths the fundamental tones of the demodulated signal would drop to zero when the three carriers are spaced 120 deg. apart in time phase.

Fig. 12 shows a series of synthetic single side-band characteristics corresponding to those for the double side-band cases shown in Fig. 11. The single side-band patterns often resemble those for the same carrier phase relations in the double side-band case. The similarity is, as we might expect, most pronounced when the resultant carrier of the double side-band signal is at a point in the high-frequency amplitude-interference pattern where the pattern below the carrier frequency is a mirror image of that above in the high-frequency spectrum. The minima may move across the band or undergo standing changes in the three-path single side-band case. There is not the regular procession of minima across the multitone pattern that there is in the two-path patterns shown in (c) and (d) of Fig. 10. Another distinguishing difference between the single and double side-band patterns for the three-path case is that in the former the characteristic does not flatten out as it often does in the latter. A flat characteristic must be the result of a change in the amplitude ratio of the interfering components.

Recorded Multitone Patterns

Figs. 13 to 22, inclusive, show a series of multitone pictures for single side-band transmission of the multitone signal, and for the transmission of both side bands and carrier. These tests covered the hours between 0845 and 1545 E.S.T. on May 16, 1928. They were made at a carrier frequency of approximately 18.34 megacycles. The patterns were recorded oscillographically on sensitized paper in the manner previously described. In these illustrations successive multitone characteristics have been cut from the original record strip and arranged one above the other so that the minima movement, and changes in pattern shape, could be more readily followed.

Some of the small irregularities which appear in these patterns are due to static. Others may perhaps be due to small components of signal arriving over widely different paths so as to produce closely spaced minima. Since they were taken at the rate of 12–1/2 pictures a second, they actually represent but a very small portion of the whole test period. Visual observations were made on the cathode ray tube during the whole period of each test, and samples of the fading were "snapped" at intervals during the course of these observations. Up to about 1200 E.S.T. the average selective fading on the circuit was less severe than these oscillograph records would indicate. The different components producing the selective fading seemed, in themselves, to fade in and out slowly, perhaps due to changes in the angle of polarization. At times their amplitude relation became such that the minima were pronounced. Between these periods when deep minima were present the characteristic would often approach flatness. *A perfectly flat characteristic was at all times a rare and transient condition.* Those records taken after 1200 E.S.T. are fairly representative of average circuit conditions.

Although the records taken before 1200 E.S.T. are not representative of the average *amount* of distortion on the circuit, they are all representative of the *character* of the distortion. During the early part of the test it will be noticed that the minima were much further apart than they were between 1300 and 1500 E.S.T. The minima spacing during any one test appeared to remain the same, which indicates that although the different components did not remain the same in relative amplitude, the relative path-length remained practically constant. Since this is the usual experience during the course of any day's observations, it seems reasonable to assume that these interfering components do not appear at random, but are the result of some systematic condition of the transmission path.

During the early part of the tests represented by Figs. 13 to 21, there was very little evidence of closely spaced minima such as appear in Figs. 17, 18, and 19. The visual observations and some of the oscillograph records indicate that the closely spaced pattern was present occasionally in small amounts. In the single side-band

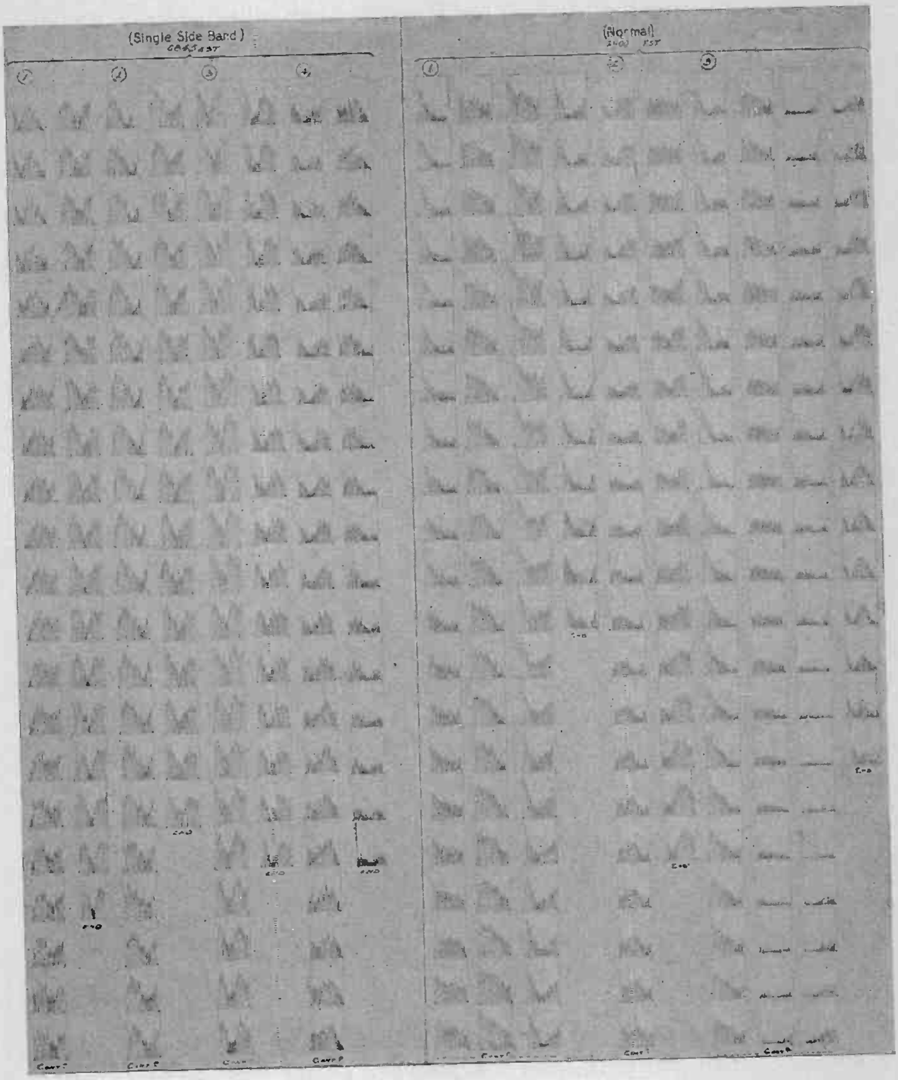

Fig. 13—Normal and single side-band multitone patterns recorded on 18 megacycle Deal-New Southgate channel, May 16, 1928. (Patterns recorded at rate of 12½ a second and arranged in sequence from top to bottom of rows.)

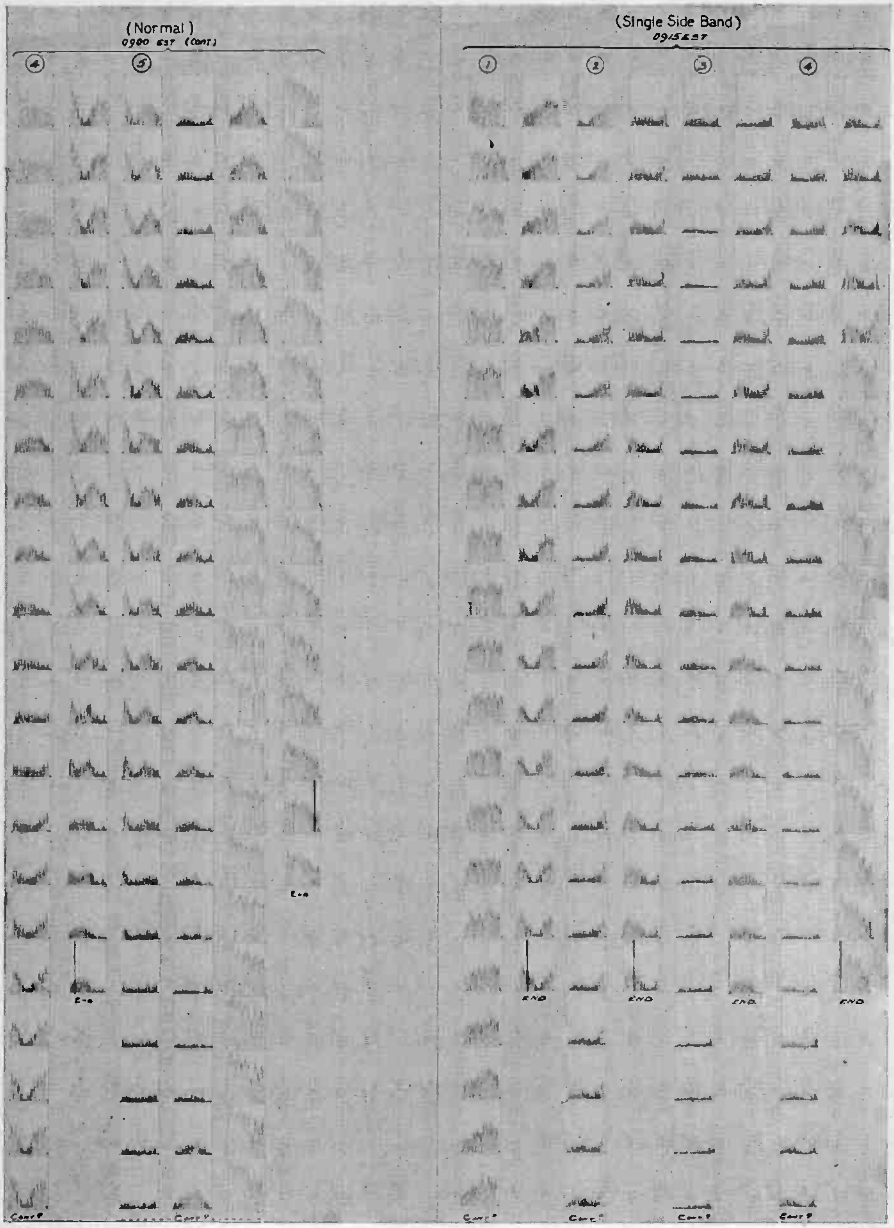

Fig. 14—Same as Fig. 13 continued.

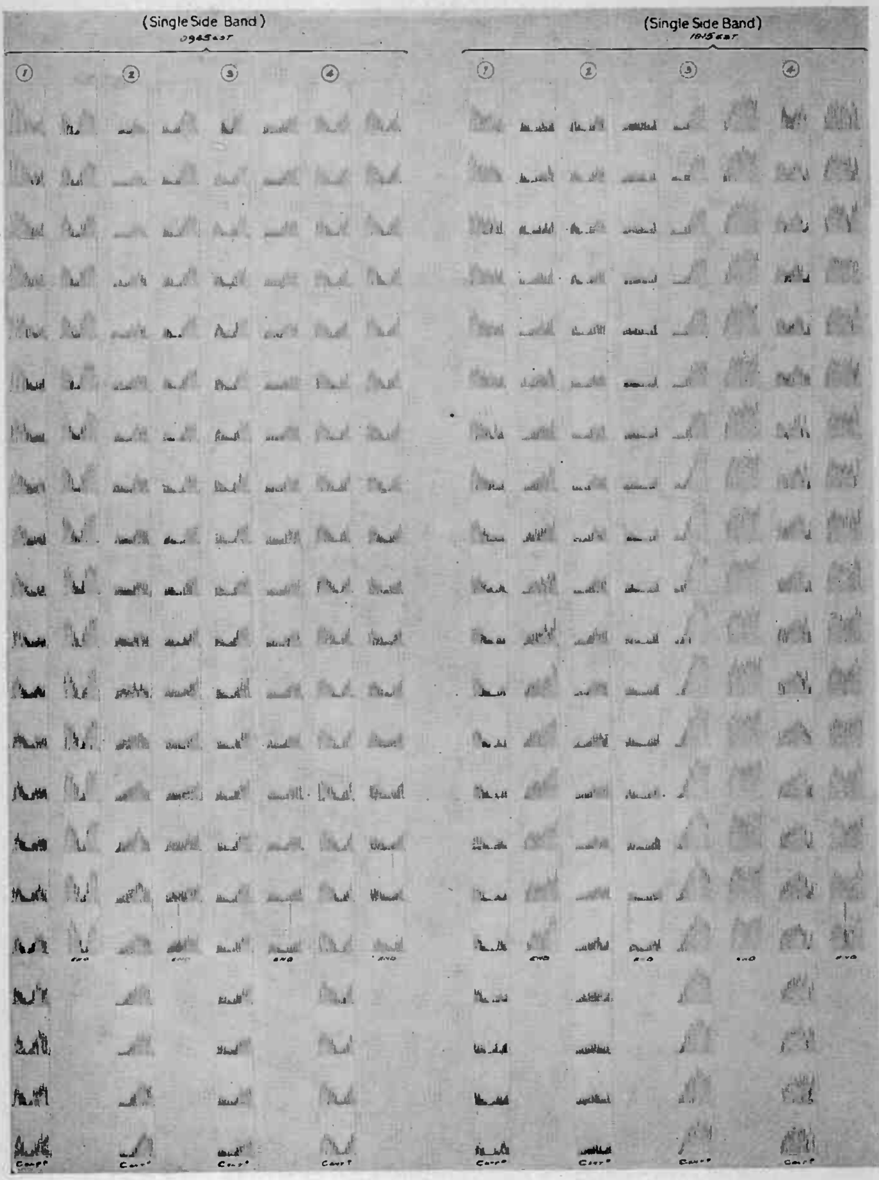

Fig. 15—Same as Fig. 13 continued.

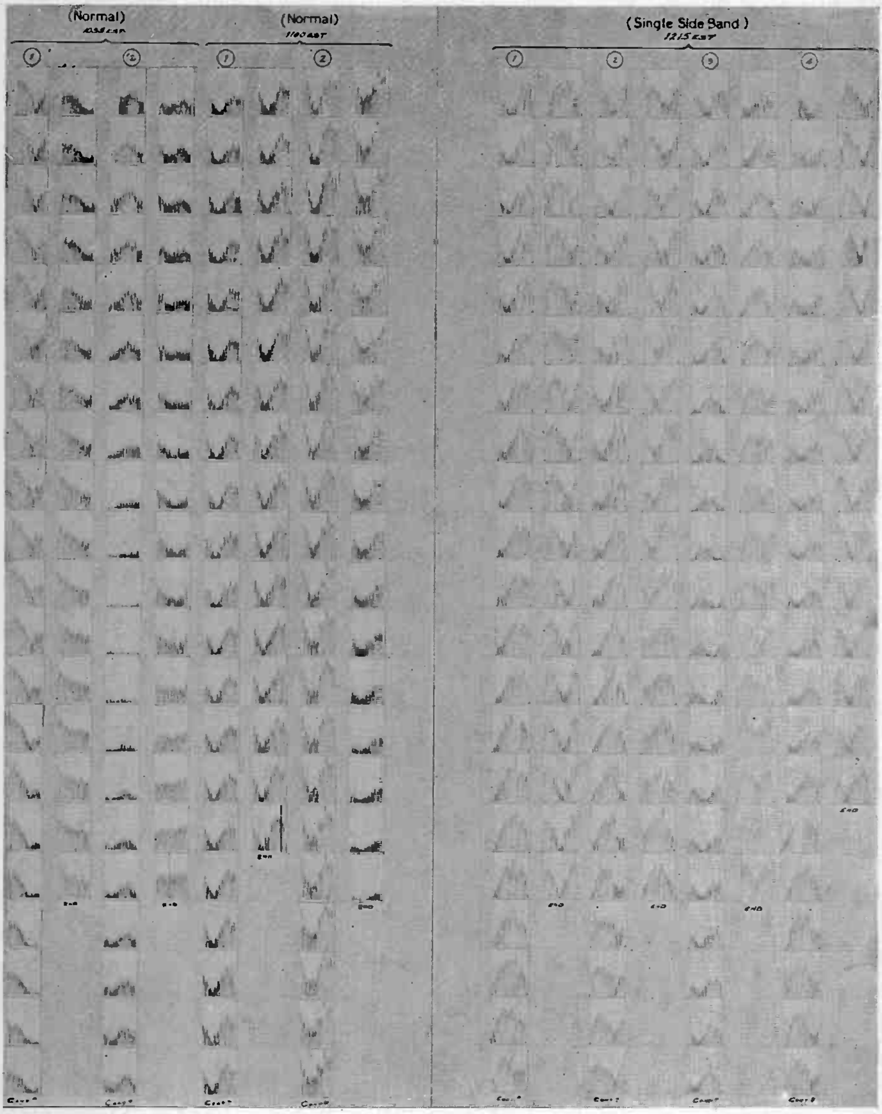

Fig. 16—Same as Fig. 13 continued.

record of Fig. 17 taken at 1115 E.S.T. there was much more of the closely spaced minima than appears in previous records. In this record there is evidence of changes in the relative amplitude of the interfering components which may, perhaps, be ascribed to variations in their planes of polarization. (By starting at the upper left-hand corner of this page and following down the columns in succession, one can visualize to some extent the actual appearance of the moving patterns which could be seen on the cathode-ray tube during this test. The 360 multitone pictures shown in Fig. 17 cover a period of about half a minute). In the single side-band record of 1215 E.S.T. the closely spaced minima pattern seems to have disappeared again. In Figs. 18, 19, and 20 they again appear very prominently. During this time the signal seems to have been received largely over two paths. A close examination of the normal records for 1300 and 1430 will reveal high maxima at two points in the multitone band which during the course of the fade are replaced by shallow minima. During that part of the fading cycle represented by the latter condition the general level of the signal is low because the two carriers arriving over the different paths are in opposition. The shapes of the patterns in the single side-band records for 1415 and 1445 E.S.T. are similar to those for the normal transmission at 1300 and 1430 E.S.T. but it will be noticed that the minima are moving across the multitone band instead of undergoing standing changes as they do for the "normal" case.

At 1515 E.S.T. during the single side-band observation the fading was very rapid. The changes were too fast to be followed by the commutator, or by the eye. However, at moments when the pattern hesitated for a brief interval in its movement, the close minima of the previous tests were clearly visible. The relative length of the paths was apparently changing rapidly. Fifteen minutes later during the observations on the normal signal the rapid fading and the closely spaced minima had both disappeared. The patterns which remained resembled those which had been observed earlier in the test. At 1545 the single side-band observations occasionally showed a small amount of the closely spaced minima. If, as the multitone tests suggest, portions of the received signal have actually followed separate paths from the transmitter, it seems likely that the diurnal variation of signal strength over these paths might be different. The variation in the average depth of the minima from hour to hour certainly suggests a dissimilar variation in the magnitude of the components producing the patterns. During the course of these tests it has been the experience that changes in average field are often, though not always, accompanied by changes in the character or depth of the

Fig. 17—A continuous sequence of single side-band multitone patterns covering about one-half minute. (Otherwise same as Fig. 13 continued.)

selective fading. Fig. 23 shows the changes in average field over the period represented by the multitone records of Figs. 13 to 22. Field-strength readings were taken every half hour upon the carrier received during the "normal" transmission period. The arrival of the closely spaced minima described above seems to have accompanied the disappearance of the peak around 1230 E.S.T. and the appearance of the peak at 1500 E.S.T.

General and Selective Fading

The audible signal amplitude is proportional to the product of the carrier and side-band amplitudes. The carrier is a single frequency, but the side band, as the term suggests, includes a range of frequencies which in radiotelephony may occupy some 3000 cycles either side of the carrier. The different frequencies in these side bands do not fade together so that an expression for the strength of the resultant audible signal becomes a little complicated. It is, however, approximately proportional to the product of the carrier and the average amplitude of the side bands (i.e., as averaged over the frequency range of these bands at any instant).

If now the signal travels over two paths from transmitter to receiver, and one of these paths is much longer than the other, two or more minima may appear in the side bands at the receiver. As these minima travel across the high-frequency signal band, the *average* amplitude of the side bands will remain practically constant, but the carrier will vary from a maximum to a minimum. Therefore, the general fading under these circumstances would be directly proportional to the variation in carrier amplitude.

When the path-length difference is small the minima separation in the high-frequency spectrum becomes large. Then both the side bands and the carrier fade in and out together. In this case the amplitude of the "general" fading would be proportional to the square of the carrier variation.

This line of reasoning would lead us to conclude that the depth of fading on normal transmission at times when the minima are widely separated will be much greater than when they are close together. The conclusion seems to agree with observation. During times when the multitone patterns for a signal consisting of two side bands and a carrier tilt and fade slowly out and in as if the minima were widely separated, the amplitude of the general fading, as judged by the ear, seems to be much greater than at times when two or three minima are crowded into the band.

It appears that there would be little advantage in transmitting only one side band with the carrier as far as the reduction of general

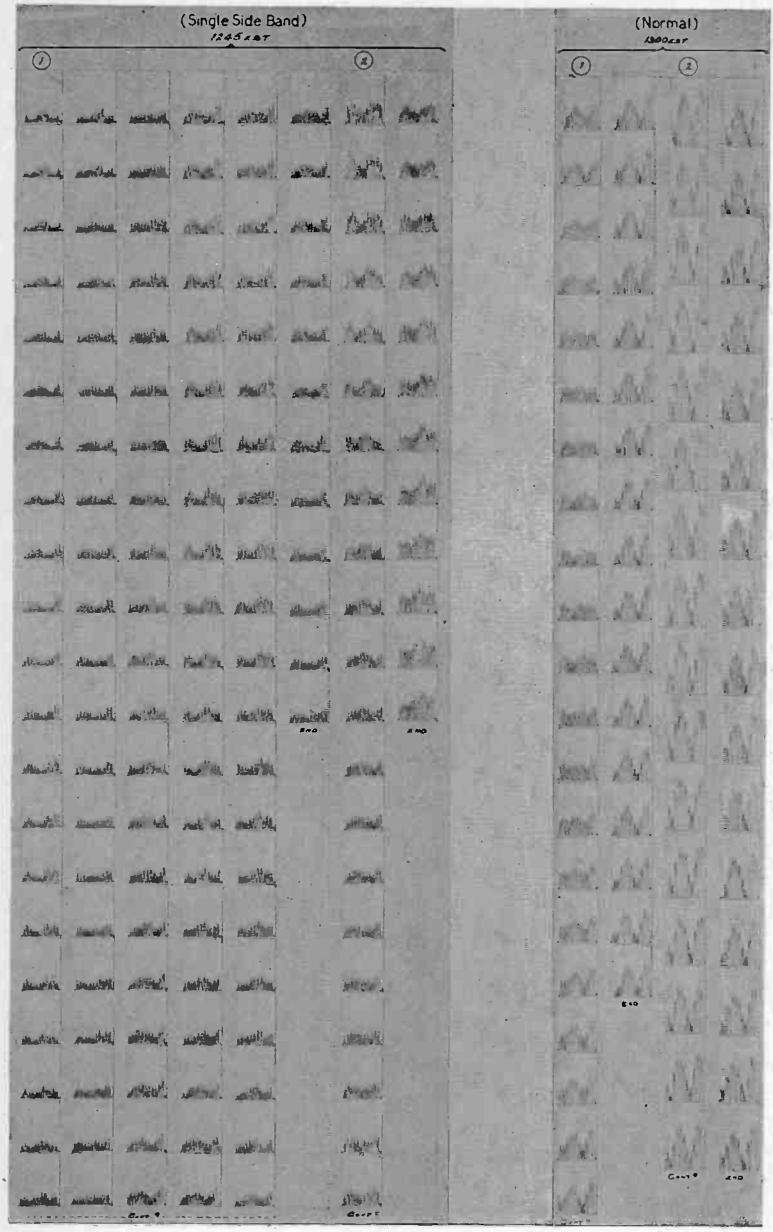

Fig. 18—Same as Fig. 13 continued.

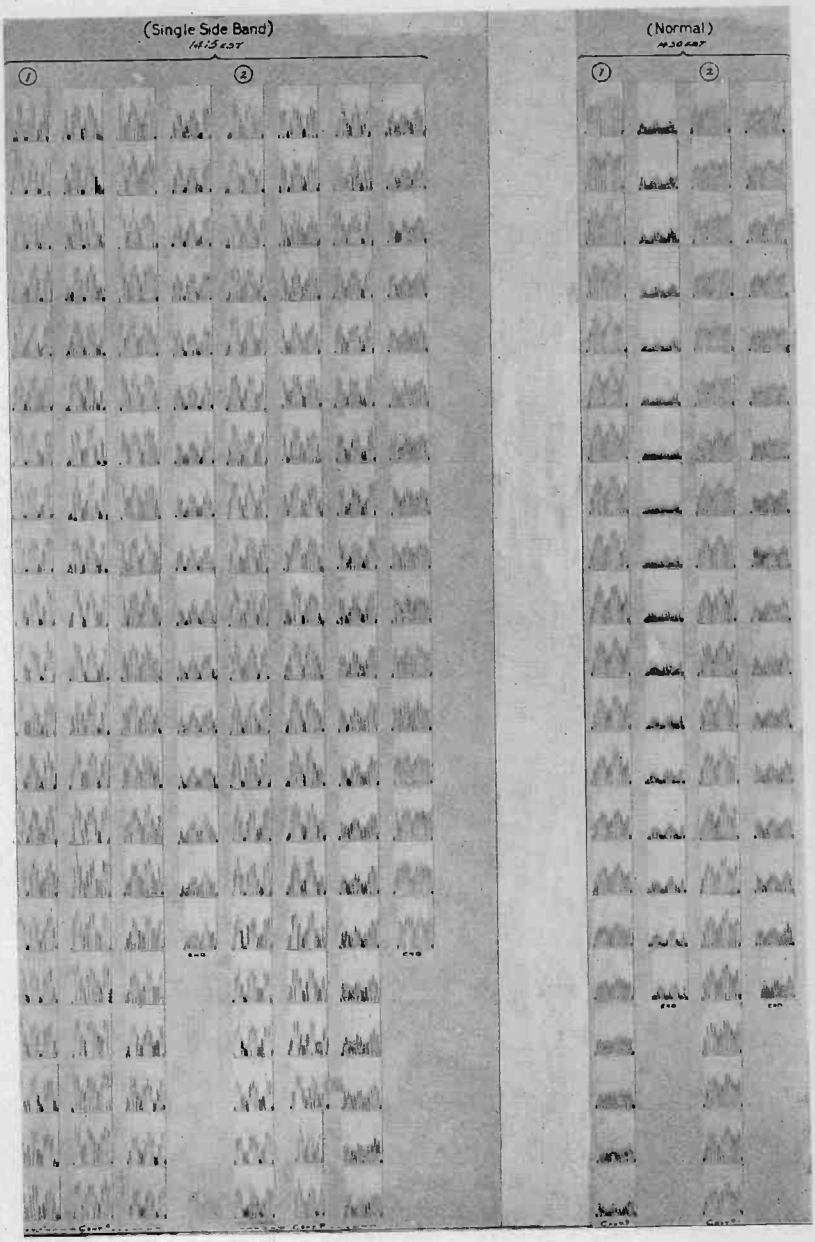

Fig. 19—Same as Fig. 13 continued.

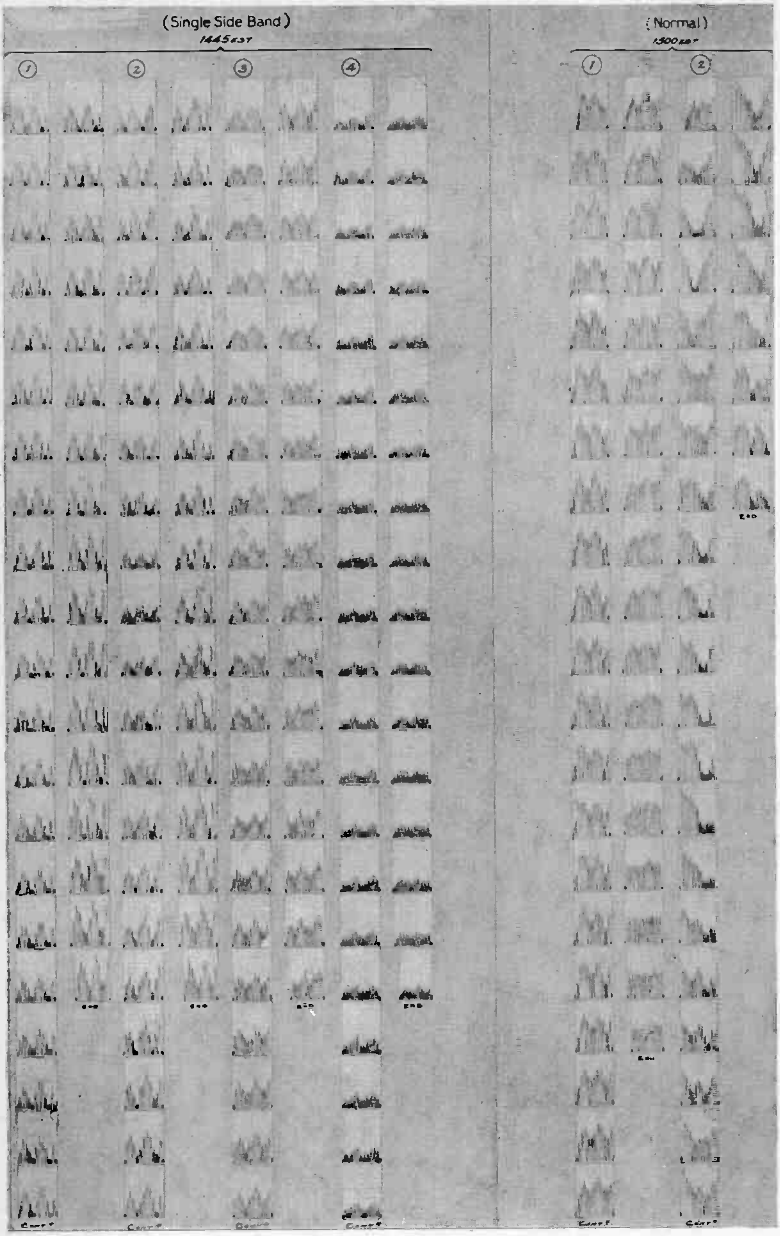

Fig. 20—Same as Fig. 13 continued.

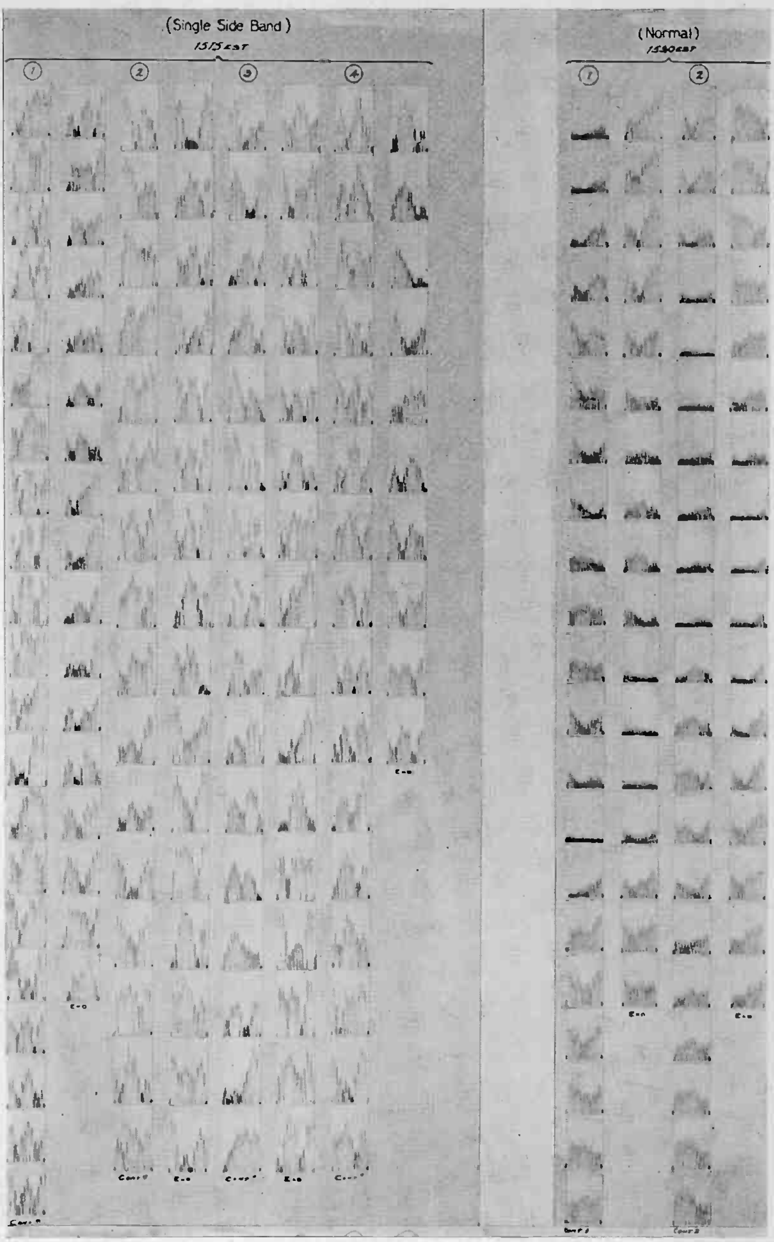

Fig. 21—Same as Fig. 13 continued.

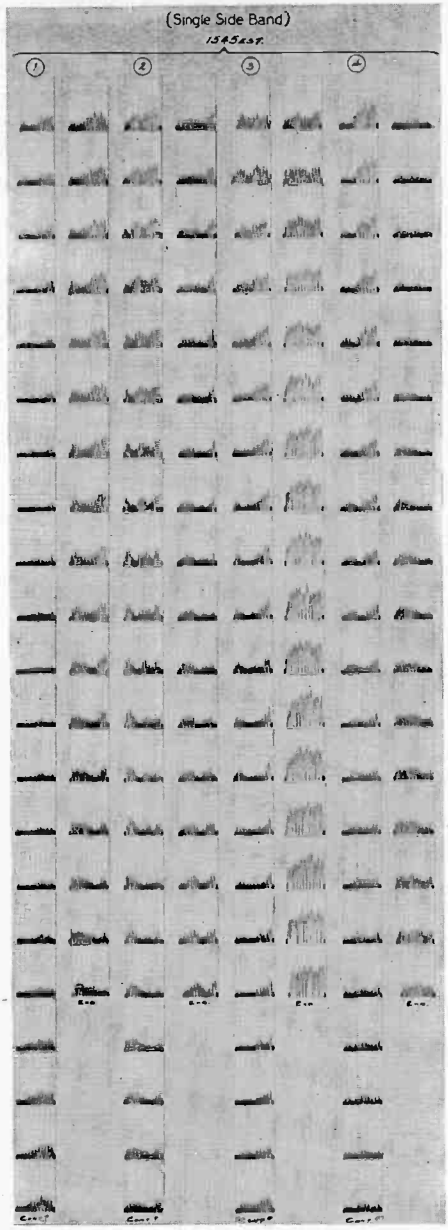

Fig. 22—Same as Fig. 13 continued.

fading and fundamental distortion is concerned. (The term fundamental distortion refers to the selective suppression or exaggeration of the audio frequencies which were modulated upon the carrier at the transmitter rather than to the introduction of harmonics.) When one or more minima are constantly present in the voice band there are conditions under which opposite side-band components associated with the same audio frequency tone in a double side-band signal tend to neutralize one another, but at other times the loss of one of these opposite side band components is offset to some degree by the presence of the same tone equivalent in the other. A very good idea of the relative fundamental distortion on a double side-band and carrier signal, as compared to a single side-band signal with

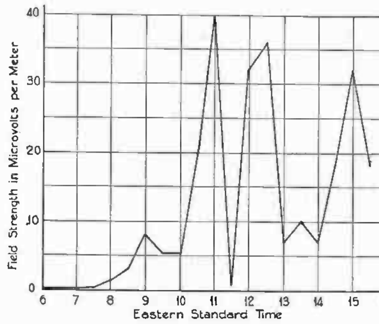

Fig. 23—Variation on field strength, May 16, 1928.

which carrier is transmitted, can be obtained by a comparison of the synthetic multitone characteristics of Figs. 11 and 12. If we modify the general amplitude of the single side-band patterns in Fig. 12 in accordance with the variation in carrier amplitude with α_1 and α_2, the result is the equivalent of single side-band transmitted with carrier.

The chief advantage then of transmitting only one side band with the carrier is in the reduction of harmonic distortion resulting from the intermodulation of side-band components when the carrier fades. Selective suppression of the carrier due to wave interference has an effect at the receiver similar to overmodulation at the transmitter.

The transmission of only one side band and the introduction of carrier from a source at the receiver does not suppress the fundamental distortion appreciably, but it does greatly reduce the harmonic distortion which is a pernicious product of selective fading. At times when the minima spacing is great the general fading amplitude becomes proportional to the field strength, rather than to the square of the field strength as is the case when the carrier is transmitted with the side band or side bands. The most evident improvement with

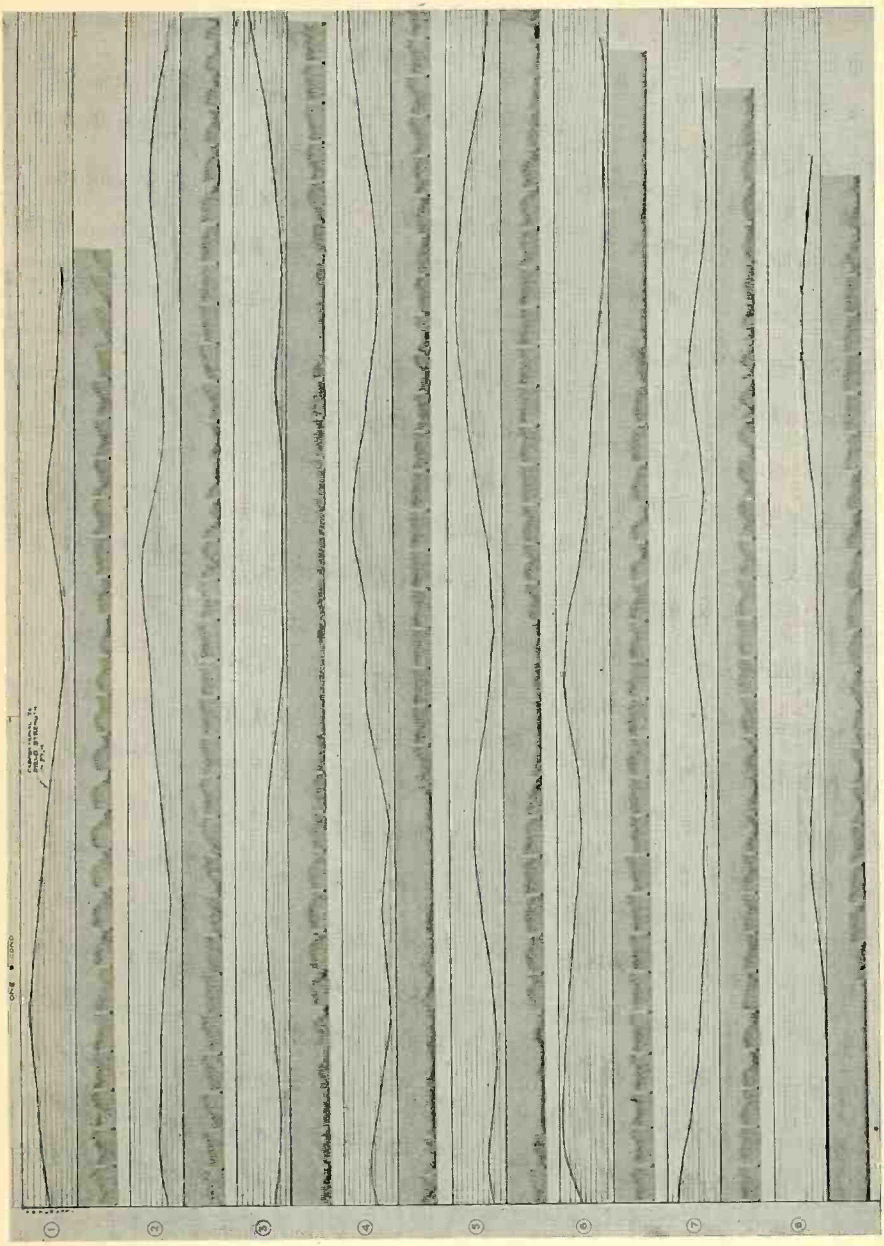

Fig. 24—Records showing variation in selective fading patterns with changes in carrier amplitude at 1500 E.S.T., March 14, 1928, on 18 megacycles.

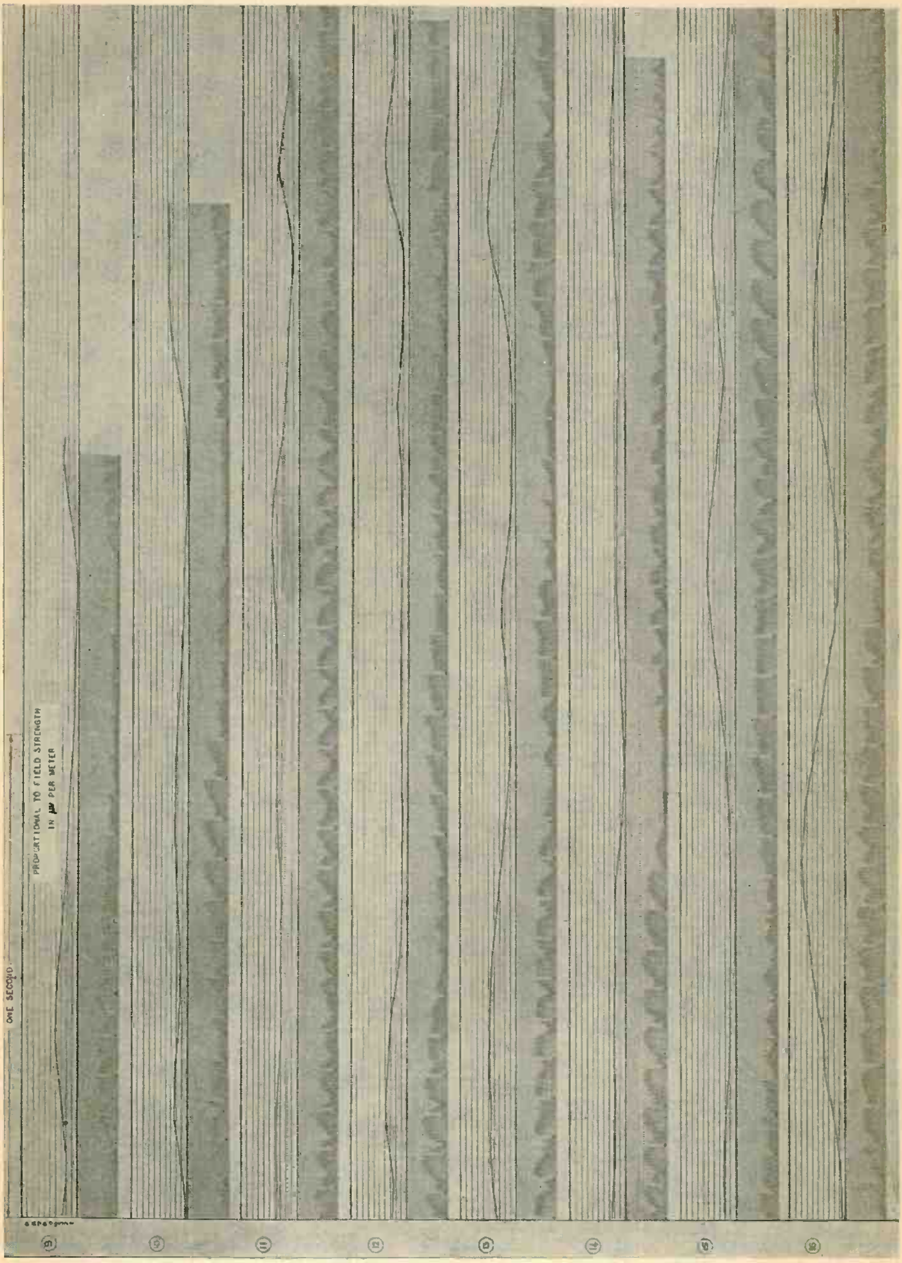

Fig. 25—Same as Fig. 24 continued.

the use of single side band and the introduction of carrier at the receiver occurs at times when the minima are closely spaced. When the minima spacing is comparable to the width of the signal band, single side band should have the two-fold effect of reducing general fading and at the same time suppressing harmonic distortion.

Examples of the relation between general and selective fading of a signal in which both side bands and carrier are transmitted are shown in Figs. 24 and 25. The field-strength variation was, in the making of these records, recorded on the same strip with the multitone characteristics. For this purpose a d-c amplifier was used to amplify the rectified output of the second detector in the receiving set. On the original record the "field" ordinates were, therefore,

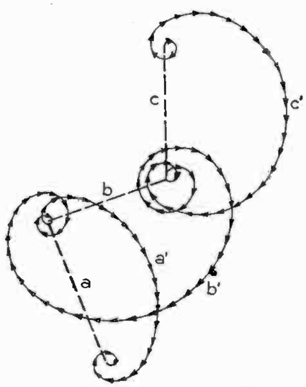

Fig. 26—Idealistic picture of probable relation between actual and assumed vector quantities representing received carrier wave components.

approximately proportional to the square of the field. In the reproduction here shown, the field variations have been reconstructed to show a direct proportionality. Allowing for a small time lag necessarily introduced by the d-c amplifier, the relative amplitude of the field corresponding to each multitone characteristic is shown graphically above the latter.

These particular records have been selected for illustration from a large number made because at this time the fading rate was high so that a more complete sequence of changes could be shown within a reasonable length of strip. At the same time the patterns are characteristic of a type which frequency appears on the 13- and 18-megacycle channels between Deal and New Southgate. Deep minima occur alternately around tones Nos. 3 and 4 (counting from the left) and 7 and 8. When the deep minimum shifts from one end of the band to the other, the change is usually brought about by a depression of the maximum accompanied by an elevation of the minimum, somewhat as is illustrated by strip (1) of Fig. 24. At other times the minimum appears to slide from one position to the other. In this latter case the depression almost invariably becomes shallow while

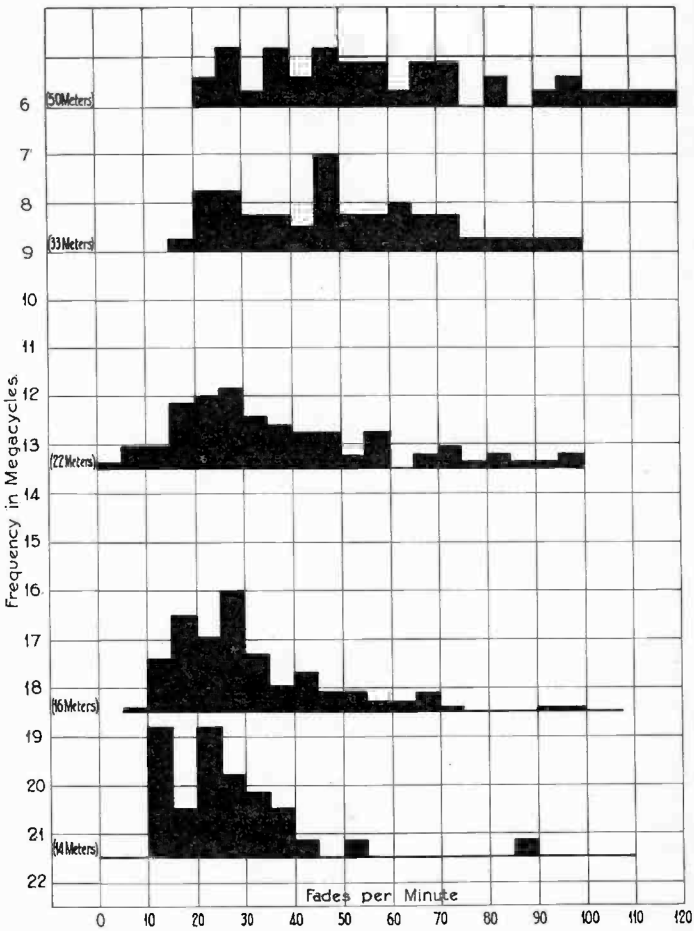

Fig. 27—Variation in fading rate with frequency on Deal-New Southgate short-wave circuit.

moving across the band. An example of this type of change is shown in strip (11) of Fig. 25. When the patterns are of the type illustrated in these figures deep minima are very common around tones Nos. 3 and 4, and the amplitude of the fading on these frequencies (765 and 935 cycles) is more pronounced than at any other point in the band. The depressions around tones Nos. 7 and 8 (1445 and 1615 cycles) are less marked than those around tones Nos. 3 and 4. When a minimum appears between these two points in the band it is extremely transient. An examination of synthetically constructed patterns suggests that the movement of deep minima across the band requires a simultaneous and particular change in amplitude and phase of the major components. Such an occurrence could be attributed to a change in the angle of polarization or to a condition under which the major components are, in themselves, made up of components arriving over slightly different paths. In the synthetic analysis it has been assumed that the components arriving over the paths of considerable group-length difference may be represented by aggregate vectors such as (a), (b), and (c) in Fig. 26. A more accurate representation of the elementary vector quantities contributing to the received signal would probably appear somewhat as is shown by (a′), (b′), and (c′) of Fig. 26. Due to transient changes in the refracting medium the configuration of (a′), (b′), and (c′) would undergo constant modification so that the amplitude as well as the phase of the aggregate vectors (a), (b), and (c) would change accordingly.

If, as the discussion thus far suggests, general fading is due, in a considerable part at least, to wave interference, some relation might be expected between the fading rate and minima separation in the interference patterns. As the difference in length of the interfering paths increases, similar changes along the paths would result in a greater number of interference bands sweeping across the receiver. The multitone observations at various radio frequencies show that, in general, the minima separation increases with frequency. Fig. 27 shows a similar increase in the fading rate as taken from tone records.

In Fig. 28 is shown the relation between minima separation in the multitone band and the fading at 18 megacycles. The shaded curves representing minima in the multitone band are based upon an approximate analysis of patterns for each test period and a weighting of components according to the order of their importance. At the lower end of the scale are designated the tilting and flat characteristics which represent the limiting case in which the multitone band only covers a part of the frequency interval between minima. During all seasons there is apparently an increase in the number of minima in the band toward the end of the useful period. There is also an abrupt rise in the fading rate at this time. In summer the fading rate is, on the average, lower than during other times of the year and the minima separation is correspondingly greater.

The average depth of the selective fading becomes a maximum when the interfering components are of about the same amplitude,

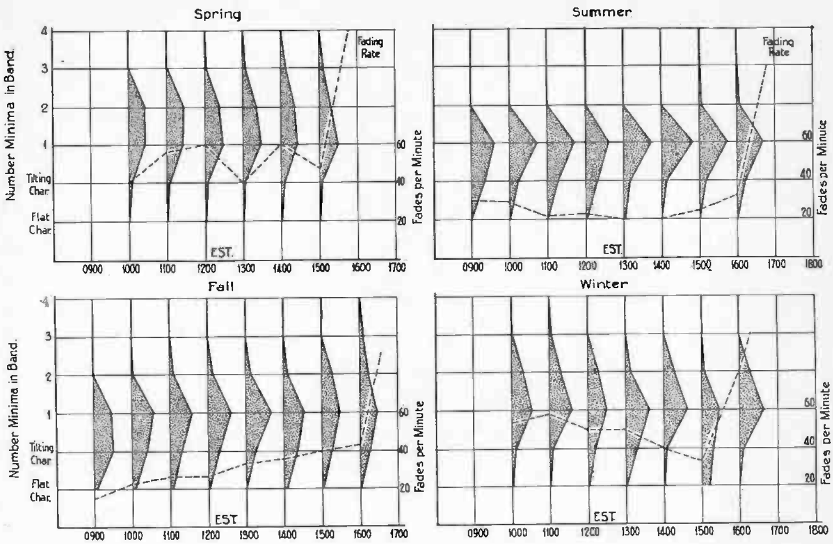

Fig. 28—Average diurnal variation of number minima in band and fading rate for 18 megacycles.

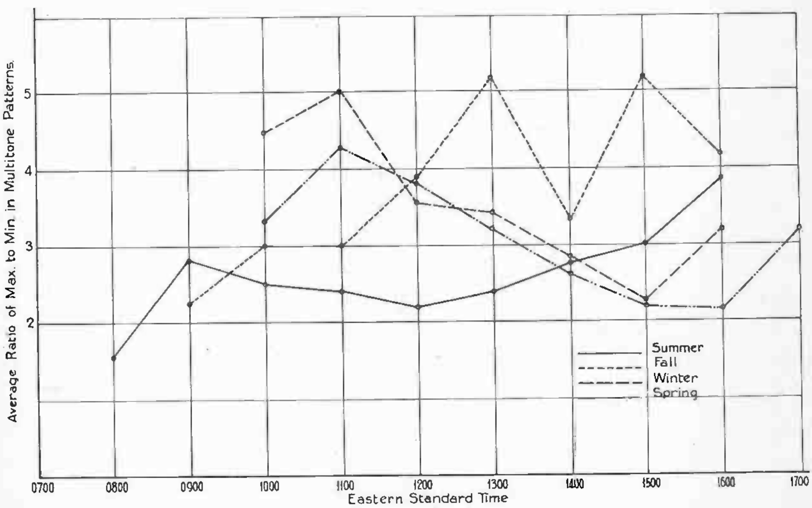

Fig. 29—Average selective fading for different seasons of year at 18 megacycles.

and it would be a minimum when there is only one wave path from transmitter to receiver. In Fig. 29 is shown the average diurnal variation in the depth of selective fading for the different seasons of the year. The depth of the fading is here shown as the average ratio between the amplitudes of the maxima and minima in the multitone band. These values are based upon estimates by the observer viewing the patterns on the cathode-ray tube. The curves of Fig. 30 show the average diurnal variation in received field strength for the seasons. (Although these fields have not been corrected for variation in power radiated they represent the average diurnal changes reasonably well). A comparison of Figs. 29 and 30 indicates that the most selective fading generally occurs when the fields are high. This suggests that

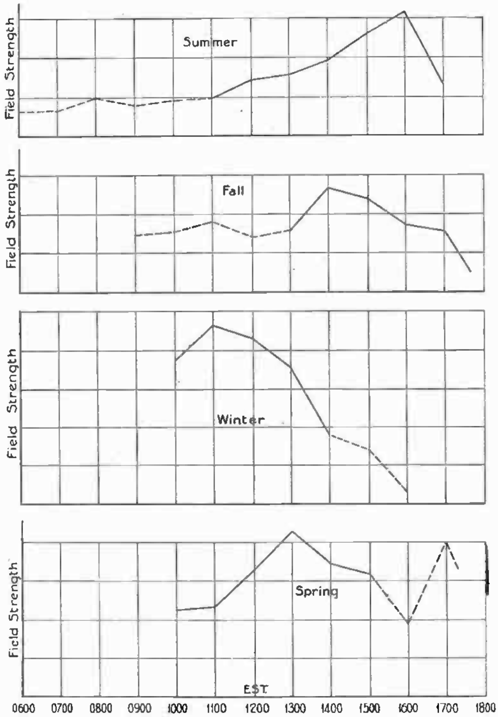

Fig. 30—Diurnal variation in field strength at 18 megacycles for period corresponding to data on Fig. 29.

the average field as measured at the receiver may be the result of a focusing of two or more ray paths rather than a decrease in the attenuation along a single path. As was previously stated these resultant field-strength curves are probably made up of three or more relatively simple individual curves representing the variation of the components which produce the selective fading. Therefore, the diurnal field-strength variation curve, such as we take at present, will probably appear somewhat complicated until we are capable of analyzing the contributing factors separately. A satisfactory method of making such an analysis is not at present apparent.

"Harmonic" Distortion

Thus far the discussion has concerned largely the fundamental distortion or distortion produced by selective suppression or exaggeration of frequencies sent out from the transmitter. As a result of this fundamental distortion harmonic distortion may occur during the process of detection at the receiver. Second harmonics of the signal are accentuated at times when a minimum of the interference patterns occurs at the carrier frequency. As has been previously stated, the effect is approximately the same as if over-modulation were occurring at the transmitter. This type of distortion is very easily recognized. The voice becomes high-pitched, seeming to slide up the frequency scale an octave when the signal falls into a fade.

The second harmonic products appearing at the receiver for the case in which the signal follows three paths from the transmitter are equal to

$$E_{2q} = m^2\sqrt{C^2 - D^2} \tag{14}$$

where

$$C = 1 + 2k_2 \cos\beta_2 \cos\alpha_2 + k_2^2 \cos 2\beta_2 + 2k_3 \cos\beta_3 \cos\alpha_3$$
$$+ k_3^2 \cos 2\beta_3 + 2k_2k_3 \cos(\beta_2+\beta_3)\cos(\alpha_2-\alpha_3)$$
$$D = 2k_2 \cos\alpha_2 \sin\beta_2 + 2k_3 \cos\alpha_3 \sin\beta_3 + k_2^2 \sin 2\beta_2 + k_3^2 \sin 2\beta_3$$
$$+ 2k_2k_3 \cos(\alpha_2-\alpha_3)\sin(\beta_2+\beta_3).$$

Definitions of the various factors entering into these equations are given under the previously discussed case for the fundamental tones.

In Fig. 31, the series (b) represents the relation between the fundamental and harmonic audio characteristics as determined by (12) and (14). These are for the case in which equal components of the signal arrive over three paths, two of which are respectively 200 and 167 km longer than the third. The series illustrates the successive changes during a portion of a fading cycle at one point in which the carrier is reduced to zero. The phase relation of the three-carrier components is shown opposite the corresponding patterns under (a). The amplitudes of the tone patterns are plotted in decibels (i.e., equal to 20 log(E_x/E_o) where E_o is arbitrarily taken as the maximum audio-frequency output on a single tone). The assumption was made that there was 50 per cent modulation by each individual audio frequency. The second harmonic pattern is shown shaded in order to distinguish it from that of the fundamental.

At the beginning of series (b) in Fig. 31 it will be noted that the harmonic is some 20 db below (i.e., 1/10 the amplitude of) the fundamental. In the vicinity of the point where the resultant carrier fades out, the harmonic approaches the amplitude of the fundamental. When the carrier fades out completely, the fundamental tones must also disappear, but the harmonic remains since the side-band compo-

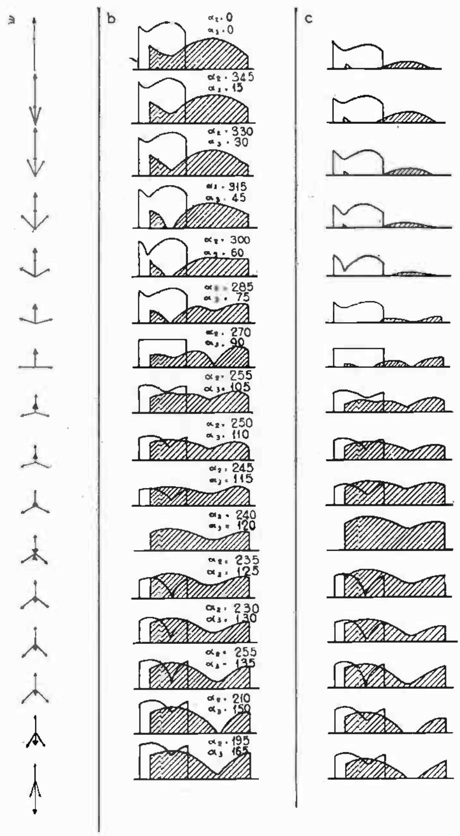

Fig. 31—Synthetic characteristics of fundamental and second harmonic distortion accompanying selective fading:
(a) variation in carrier amplitude
(b) normal receiver output
(c) output of receiver with automatic gain control

nents producing them are still present. Therefore, very near the fading-out point, the harmonic may be much greater than the fundamental.

Of the 360-deg. fading cycle there is only some 5 deg. during which the fundamental is below the harmonic; that is, the duration of this poor quality interval is relatively short. It will be noticed also that as the signal approaches a fade, both the fundamental and harmonic tone patterns change their shape. The change is quite abrupt, and is easily recognizable when listening to multitone signals. There is a sudden alteration in the sound of the tones, somewhat like that which occurs when a circular saw strikes a knot in a log.

In series (c) of Fig. 31 is shown the effect of automatically regulating the signal output by means of the carrier amplitude. This is the familiar method of reducing signal variations due to fading. When the carrier is high the radio receiver amplification is reduced, and when it becomes low the amplification is increased to some limiting value. The effect of this increased gain during periods when the carrier is low is to amplify greatly the harmonic distortion which without such gain regulation would with the fundamental signal remain somewhat in the background.

The automatic gain control operates most effectively when the minima in the wave-interference pattern are widely separated, or

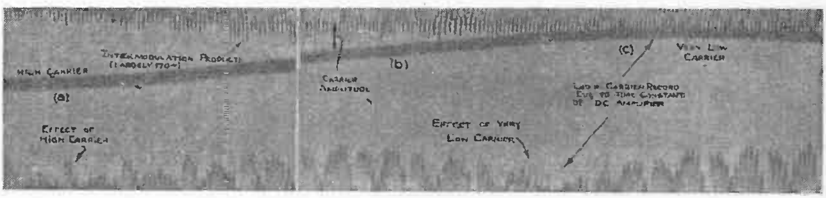

Fig. 32—Effect of automatic gain control upon audio output and intermodulation products when selective fading is present.

the variation in amplitude is about the same over the whole high-frequency signal band. Such is the case, for example, when patterns similar to those under (a) of Fig. 9 are present. If the "selective" fading is such that the side bands fade opposite to the carrier there may be a low audio output when the carrier is a maximum, a higher audio output as the carrier amplitude fades, and a low output again when the carrier fades out. This is well illustrated by the record of Fig. 32 which shows the variation in carrier and the multitone-pattern amplitude when the automatic gain control was used. The two parts of the record were taken from a single long record covering a period of several seconds. The carrier record here shown is simply the d-c component of the rectified high-frequency signal which for normal modulation and that part of the selective fading cycle where the carrier is increased in relation to the side band, is amply representative. When the carrier fades to a point where its amplitude is comparable to that of the side band, the amplitude of the field as determined by this curve is no longer accurate. For this reason the carrier amplitude, as indicated by the "field" record at the bottom of a fade is higher than the actual carrier amplitude.

At (a) in Fig. 32 the field is high and the general amplitude of the multitone patterns is low. As the field fades down to an average value at (b) the multitone patterns increase very noticeably in general amplitude. When the carrier amplitude decreases further to a point where it is approaching zero, the multitone fades out again.

On the upper edge of this record is shown the amplitude of the side-band intermodulation components appearing below 350 cycles. These were separated from the audio signal by means of a 350-cycle low-pass filter. These modulation components consist largely of a 170-cycle wave equivalent to the multitone spacing. It will be noticed that these modulation components increase as the carrier decreases.

Fig. 32 is in fact an illustration of the change in apparent percentage modulation produced by selective fading. The function of the automatic gain control, as commonly used, is to maintain effectively a constant level of carrier into the final detector of the receiver. When the percentage modulation is altered by a selective suppression or exaggeration of the carrier, the gain control is unable to maintain a constant audio output over its operative range. The result is the same as if the percentage modulation were varied over a wide range at the transmitter. Those components of the side band which fade in and out with the carrier can be maintained at what approaches a constant level by means of the automatic gain control, but the variations of those which fade oppositely are actually magnified by controlling the receiver gain through variations in the carrier. This condition will be most pronounced when the minima spacing is comparable to the width of the signal band.

The Effect of Frequency or "Phase" Modulation upon Signal Quality

It has been recognized for some time that change in signal frequency with amplitude modulation results in distortion when selective fading occurs. Frequency modulation is not recognizable on the output of a radio receiver near the transmitter, but the distortion appears when the receiver is moved away to a point where fading takes place (indicating the existence of more than one path between transmitter and receiver). At a distance of 50 miles from a short-wave transmitter the distortion produced by frequency modulation may be as pronounced as it is at several thousand miles.

Even deviations from normal phase in the order of 90 deg. or less during amplitude modulation may produce considerable distortion in a double side-band and carrier-transmission system if selective fading is present. Such distortion results when the difference in group time of the interfering paths which cause the selective fading is comparable to the period of the modulation frequency. Assume, for example, the carrier is modulated by a 1000-cycle tone and there are two interfering paths which differ in transmission time by 1/2,000th of a second (a common difference in path time). If phase modulation occurs, the carriers received over the two paths will be varying oppositely in phase. When the vectors representing the two interfering carriers are nearly equal and opposed, corresponding to the minimum of a fade at the receiver, the distortion produced by phase deviations of 90 deg. or less with amplitude modulation is approximately proportional to

$$e^2[\sin\ (\Delta\phi)]^2$$

where e = amplitudes of opposing carriers and $(\Delta\phi)$ = phase deviation.

Since the distortion due to phase modulation is most pronounced during the fades it easily may be confused with distortion due to side-band intermodulation ("harmonic" distortion). It is similarly selective in character in that the harmonics which appear most prominently will depend upon the path-length difference.

The distortion produced by intermodulation of the side bands is proportional to

$$k_m{}^2e^2$$

where k_m = percentage modulation.

The ratio of the distortion produced near the minima of the fades by phase modulation and by side-band intermodulation is then approximately

$$\frac{[\sin\ (\Delta\phi)]^2}{k_m{}^2}$$

Assuming a percentage modulation of 70 the ratio becomes

$$1-\cos 2(\Delta\phi)$$

Therefore, when the deviation in phase over the amplitude-modulation cycle is 45 deg. the distortion near the bottom on the fades is comparable to that resulting from side-band intermodulation.

Deviations in phase with amplitude modulation may be produced in a transmitter by varying reaction of the amplitude-modulated power stages back upon the unmodulated high-frequency stages between the modulator and the control oscillator. It may also be produced in any high-frequency stage of the transmitter where plate or grid resistances across reactive circuits are caused to vary over the modulation cycle.

Since one of the principal limitations in realizing the full advantage of an automatic gain control is imposed by the distortion which often appears so prominently in the fading minima it is desirable to at least reduce phase modulation to a point where side-band intermodulation is the limiting factor.

In the foregoing only the case of normal transmission with both side bands and carrier has been considered. For the same amount of phase deviation, the distortion will be much less on single side band than on double side band with carrier. Although it will be present at all times when the selective fading minima are in evidence, it will be largely confined to harmonics of those fundamental frequencies at which the minima appear.

Rapid Fading

There appears at times on the short-wave circuit between Deal and New Southgate a certain distinctive type of fading to which has become attached the descriptive term "rapid fading." At 18 megacycles it usually occcurs toward the end of the useful day both in summer and winter. At 13 megacycles the occurrence in the winter time is not associated with any particular part of the useful period, but in summer the tendency is again toward the end of this period. Approximately, the same may be said of 9 megacycles, although there is more of an inclination toward random occurrence in the summer time. At 6 megacycles the periods during which rapid fading was observed do not appear to depend upon the time of day either in summer or winter.

In Fig. 33 is shown the monthly variation in susceptibility of the circuit to rapid fading expressed in terms of the percentage occurrence during test periods when the field was above 3 μv per meter. During the months from January to August the susceptibility is much lower than between August and January. Since this type of fading is undoubtedly regulated by circumstances associated with the ionized layer, it is apparent that a rather abrupt change takes place in this region of ionization between August and October. Probably this might be accounted for as due to an increase in the effective layer height. Carrying this conjecture further, we might anticipate from the appearance of these curves that the layer height is a maximum around October and a minimum around April or May. It also appears that the decrease in effective height, as the summer months approach, is much less abrupt and regular than the increase between August and October. This argument is, however, pure speculation, since we are not sure that other factors than effective layer height might not play an important part in the production of rapid fading.

This so-called "rapid" fading seems to fall outside the category of the type which has thus far been discussed in connection with the multitone tests. It is too rapid to be investigated by the test

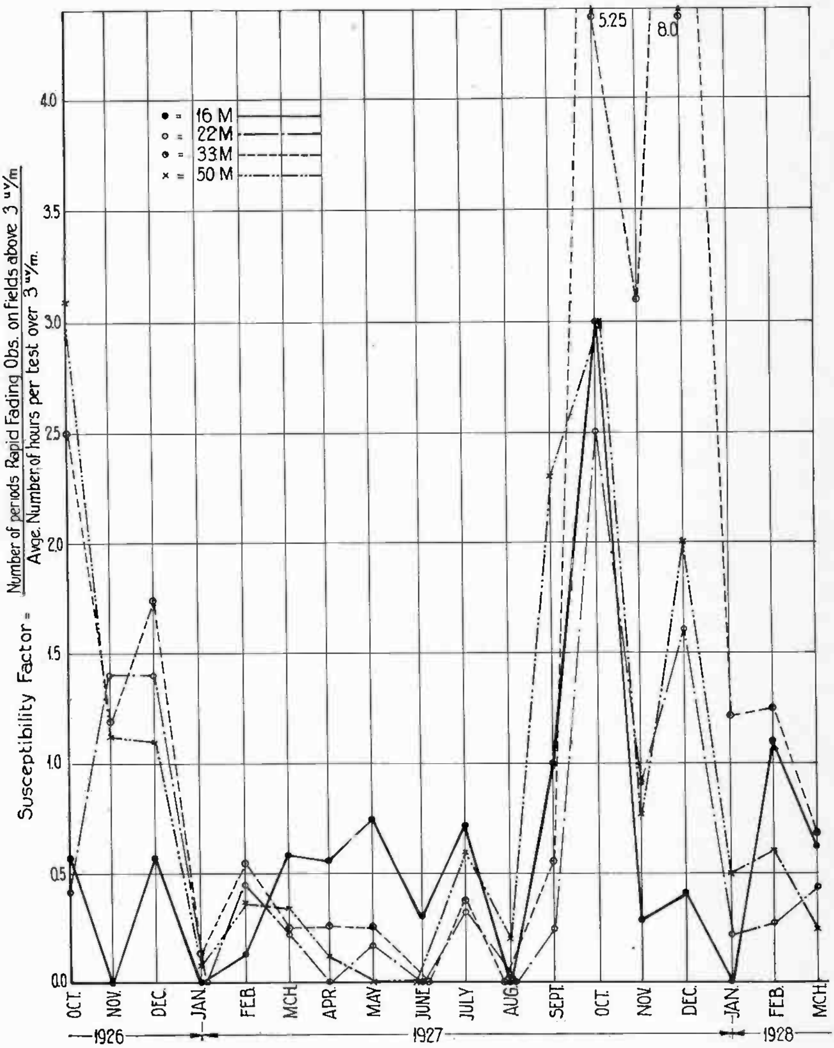

Fig. 33—Susceptibility to "rapid fading" on Deal-New Southgate short-wave circuit. (Data at 6, 9, 13, and 18 megacycles.)

method in which commutation is employed. Fig. 30 shows the distribution of normal fading rates of tone transmitted between Deal and New Southgate on frequencies ranging between 6 and 21 mega-

Fig. 34—Single side-band record of "rapid" fading on frequencies spaced 170 cycles taken at 18-megacycle Deal-New Southgate circuit at 1950 and 2025 E.S.T., May 14, 1928.

cycles. These data were taken from oscillograph records made at intervals covering about four months during the early part of 1928. They show that the normal fading rate falls somewhere between 5 and 100 fades a minute. The average rate extends from approximately 20 to 50 fades a minute, depending upon the radio frequency. For the lower radio frequencies, the average fading rate is higher and, as the distribution of values indicates, less regular. Oscillograph records of rapid fading often show fading rates ranging between 500 and 10,000 a minute. These rapid variations, when they become pronounced, cause a decided tremolo in the voice which gives to it a suggestion of pathos as if the speaker were sobbing into the microphone. At the same time the quality becomes harsh.

Rapid fading usually appears first in small quantities superimposed upon the normal, relatively slow variations. At the bottom of the slow fades the percentage variation in amplitude produced by the rapid fades makes the presence of the latter most conspicuous. For this reason the report often appears in the log sheets that "traces of rapid fading were noticed at the bottom of the slow fades." (In the single side-band record strips 6, 7, and 8 of Fig. 34 this effect is clearly shown). At the maxima of the slow fades the rapid variations may amount to only 1/10 of the average amplitude, while during the minima of the normal fades the signal appears to drop to zero between the maxima of the rapid fluctuations. Incidentally, the use of the automatic gain control at such times has the effect of magnifying these rapid changes since the set gain is increased during the normal depression. The gain control is incapable of following the faster amplitude changes.

Although it was not possible during "rapid" fading periods to make commutated multitone records of the variations such as were obtained for normal fading, it was possible to record the tones continuously to give an undistorted picture of these variations. Fig. 34 includes records of this kind. The number of tones recorded was limited by the number of oscillograph elements available to three. These are single side-band records of tones spaced 170 cycles apart. In fact they actually represent the amplitude variations of three 18-megacycle carrier waves spaced 170 cycles apart in the frequency spectrum. Despite the very small separation of these frequencies a casual examination will show the fading to be apparently unrelated. The fact that depressions occasionally appear at the same time on the two outside frequencies when the maximum is present on the middle one suggests that the minima separation is at least comparable to twice the 170-cycle spacing. It seems very likely that the fading would appear unrelated on frequencies separated by much less than 170 cycles during the rapid fading periods.

There appears in these records evidence that "rapid" fading is due to a wave-interference effect rather than to an irregular fluttering in and out of a signal which is barely refracted to earth. The superimposed fades conform in shape at both high and low levels to those which would be produced by interference. Such a small separation of the minima would, it seems, involve considerable differences in length of the interfering paths. At the extreme this difference in path-length might be equal to the earth's circumference, the interference taking place between direct and around-the-world signals. Since both the transmitting and receiving arrays on the Deal-New Southgate circuit are directional, the interfering signal would doubtless go completely around the earth in the same direction as the normal signal before being received. The difference in length of path would then be such that the minima spacing would be of the order of 10 cycles. Due to the great difference in path length, the fading rate would presumably be proportionately high.

If the cause of this high-speed fading is attributable to "around-the-world" signals, we should expect to find echoes on normal speech transmission. Due perhaps to conditions which will be explained later there is available among the data of these tests only one definite piece of evidence that this is the case. During the course of some tests on the circuit in May, 1928, remarkable echo effects were observed on single side-band speech transmission at 2050 E.S.T. Twenty minutes later, when the normal transmission of both side bands and carrier was resumed, the "rapid" fading was pronounced and the echoes were still recognizable though they were much more difficult to detect. (Probably they would not have been noticed except for the distinct occurrence on single side band). Later, on single side-band transmission again, the echoes were once more pronounced and accompanied by the "rapid" fading. Although no records were made from which the echo interval could be determined, the time lag was such that it might reasonably be attributed to around-the-world transmission. The evidence obtained from these few observations (which unfortunately are all that are immediately available) indicates that the echoes are actually present during the normal transmission of carrier and two side bands, but that the rapid fluctuations in carrier producing correspondingly rapid fluctuations in the audible signal tend to mask its presence. When a single side band is transmitted and the carrier is supplied locally the general fading would (according to the argument previously given under a consideration of the fading reduction accomplished by single side-band transmission) be largely overcome. When the minima are very close together, the average side-band amplitude would remain practically constant, which with the introduction of a constant carrier at the receiver would result in a constant audio-frequency output. Therefore, during periods of "rapid" fading, we might expect to find easily recognizable echoes and practically no apparent rapid fluctuation in the audio-frequency output of a single side-band signal. The normal transmission of both side bands and carrier would at such times be badly cut up by the high-speed fluctuations of the carrier, and though echoes might be present they would be difficult to recognize due to the excessive distortion. Records taken at the receiver of short-wave trains spaced about a fifth of a second during times when "rapid" fading is present would probably serve to determine whether around-the-world signals are responsible for this effect.

Incidentally, the high rate of change in relative path length indicated by "rapid" fading might, of course, be designated as a Doppler effect. Assuming that the length of one of the paths does not change materially, it may be considered that the other is changing at a rate which would result in an effective frequency at the receiver of $(f_c \pm f_x)$ where f_c is the normal carrier frequency and f_x is the frequency of the fades. The existence of such effects introduces the possibility of a type of distortion which may appear on single side-band transmission at the very high radio frequencies. There would be a change in pitch of the voice as a result of a change in frequency of the side band (due to transient changes in side-band path length) although the frequency of the carrier supplied at the receiver remains constant. While this type of distortion was not noticed on the Deal-New Southgate circuit during the single side-band tests at 18 megacycles herein described, it is possible that it would have been evident at other times or at other frequencies.

Normal-Fast Fading

In addition to the "rapid" fading which has been described above, there usually is observed toward the end of the useful period a decided rise in the normal fading rate. This is shown in the "Fading Rate" curves of Fig. 27. An example of such fading is shown in the oscillograph records of Figs. 24 and 25. These were taken toward the end of the normal useful period (1500 E.S.T.) on March 14, 1928. The field at this time was unusually high for this hour. Such fading is distinguishable from "rapid" fading both by its lower rate and the fact that the minima are spaced normally. It may be due to the approach of a critical relation between the interfering paths. Toward the end of the day, in particular, it seems reasonable to presume that the interference is not the result of earth reflections since the higher angle ray necessary for earth reflections would not return to earth. It may be interference between two rays which would be refracted toward the receiving point from the two levels where the rate of change of ionization with height above the earth would be effectively the same. By making use of the basic assumptions employed in the paper by W. G. Baker and C. W. Rice, mentioned earlier, it is possible to form some approximate ideas concerning the group path-length relation between the two overhead rays at the time when their intensities are comparable. To do this it is necessary to determine the phase length of path by an integration of the product of the physical path length and the refractive index over the ray path. From data concerning the phase length of path for different frequencies over the same range between transmitter and receiver, it is possible to determine the group path length. The equations to be derived are for the case of a "flat earth."

Starting with equation (33) of the above-mentioned paper as the general differential equation of the ray path, we have,

$$dx = \frac{\cos \beta dz}{\sqrt{\mu^2 - \cos^2 \beta}} \tag{15}$$

where β = the angle that the ray path makes with the lower boundary of the electron layer

μ = the refractive index of the medium
x = the horizontal distance
z = the vertical distance

For the physical distance along the ray path we have

$$ds = \sqrt{(dx/dz)^2 + 1}\, dz. \tag{16}$$

Substituting (16) in (15)

$$ds = \frac{\mu dz}{\sqrt{\mu^2 - \cos^2 \beta}} \tag{17}$$

The "phase length of path" may be defined such that

$$dL_p = \mu ds = \frac{\mu^2 dz}{\sqrt{\mu^2 - \cos^2 \beta}} \tag{18}$$

where μ is the refractive index of the medium. The phase-length dL_p in a vacuum where the velocity is c is the same as that of ds in a medium of refractive index μ. Since μ changes along the ray path, it is convenient to express the path length in terms of its equivalent in vacuum.

Using the assumption of the Baker-Rice paper, that the distribution of ionization in the refracting medium may be represented by

$$\mu^2 = 1 - \frac{\sigma N_0}{\omega^2} \sin^2 \left\{ \frac{(Z-b)\pi}{2(B-b)} \right\} \tag{19}$$

where b = height of lower layer boundary from the earth

B = height of the region of maximum ionization above the earth

N_0 = maximum ion density in number per cc

$\omega = 2\pi$ times frequency of transmitted wave

$\sigma = 4\pi\, e^2/m = 3.2 \times 10^9$ cgs. (esu) for electrons

equation (16) becomes

$$dL_p = \frac{\left[1 - \frac{\sigma N_0}{\omega^2} \sin^2 \left\{ \frac{(Z-b)\pi}{2(B-b)} \right\}\right] dz}{\sqrt{\sin^2\beta - \frac{\sigma N_0}{\omega^2} \sin^2 \left\{ \frac{(Z-b)\pi}{2(B-b)} \right\}}}. \tag{20}$$

Equation (20) may by some manipulation be converted to the form of an elliptic integral as follows:

$$L_p = \frac{C_1}{\sin\beta} + C_2 \cdot K(\sin\alpha) - C_3(K-E)(\sin\alpha) \tag{21}$$

in which the phase length of path is expressed in km.

K and E are the complete elliptic integrals, values for which may be obtained from tables.

$$C_1 = 2b$$

$$C_2 = \frac{1.415 \times 10^2 f_{mc}(B-b)}{\sqrt{N_0}}$$

$$C_3 = \frac{1.117(B-b)\sqrt{N_0}}{f_{mc} \times 10^2}$$

$$\sin\alpha = \frac{1.11 \times 10^2 \times f_{mc}}{\sqrt{N_0}} \sin\beta$$

f_{mc} = the transmitting frequency in megacycles.

The "range" equation which will be used is the one for the "flat earth" case, namely

$$R = C_1 \cos\beta + C_2 \cos\beta \cdot K(\sin\alpha) \quad \text{(km)} \tag{22}$$

If we consider the paths followed by two slightly different frequencies from transmitter to receiver, we may write for the number of wavelengths in each path,

$$N_1 = L_1/\lambda_1 = L_1 f_1/c$$
$$N_2 = L_2/\lambda_2 = L_2 f_2/c\,.$$

The number of group waves along these paths between transmitter and receiver is then

$$N_g = N_2 - N_1 = \frac{1}{c}(L_2 f_2 - L_1 f_1)\,.$$

Let $L_2 = L_1 - \Delta L$ and $f_2 = f_1 - \Delta f$

Then, neglecting second-order quantities

$$N_g = \frac{1}{c}(L_1 \Delta f + f_1 \Delta L)$$

Since the group frequency is $(f_2 - f_1) = \Delta f$, the group time is $N_g/\Delta f$ and the group length of path is

$$L_g = N_g c/\Delta f = L_1 + f_1 \frac{\Delta L}{\Delta f} \qquad (23)$$

Although it is difficult to determine the change in phase length of path with frequency by direct differentiation, we may determine phase length of path and corresponding range values from (21) and (22) for frequencies separated by a relatively small interval, and from these values construct curves showing the variation in group length of path with range. In Fig. 35 curves (A) and (D) show the horizontal "range" of rays launched from the transmitter at different vertical angles. The assumptions concerning layer height, dimensions, and maximum density are given with the curves. The transmission represented by that portion of the curves (A) in the vicinity of (b) and on toward (a) is that in which we are at present interested. From (21) the phase length of path was computed for frequencies sufficiently separated to give reasonable numerical differences. In order to show clearly the change in phase length of path with frequency, a difference of two megacycles was used in computing the curves (B) and (E) of Fig. 35. Similar computations using a much smaller differential show that the results have not been materially altered (except at the critical point near (b) in Fig. 35-C) by using the two megacycles. Assuming different values for the vertical angle of the ray path leaving the transmitter, values of the phase length of path L_p and the range R were computed. In curves (B) and (E) are plotted the phase length of path minus the range against the range for the differential frequencies of 18 and 20 megacycles, and 10 and 12 megacycles, respectively. In these curves we have the values necessary to determine the group length of path from equation (23). Curves (C) and (F) show the change in group length of path with range for the two cases.

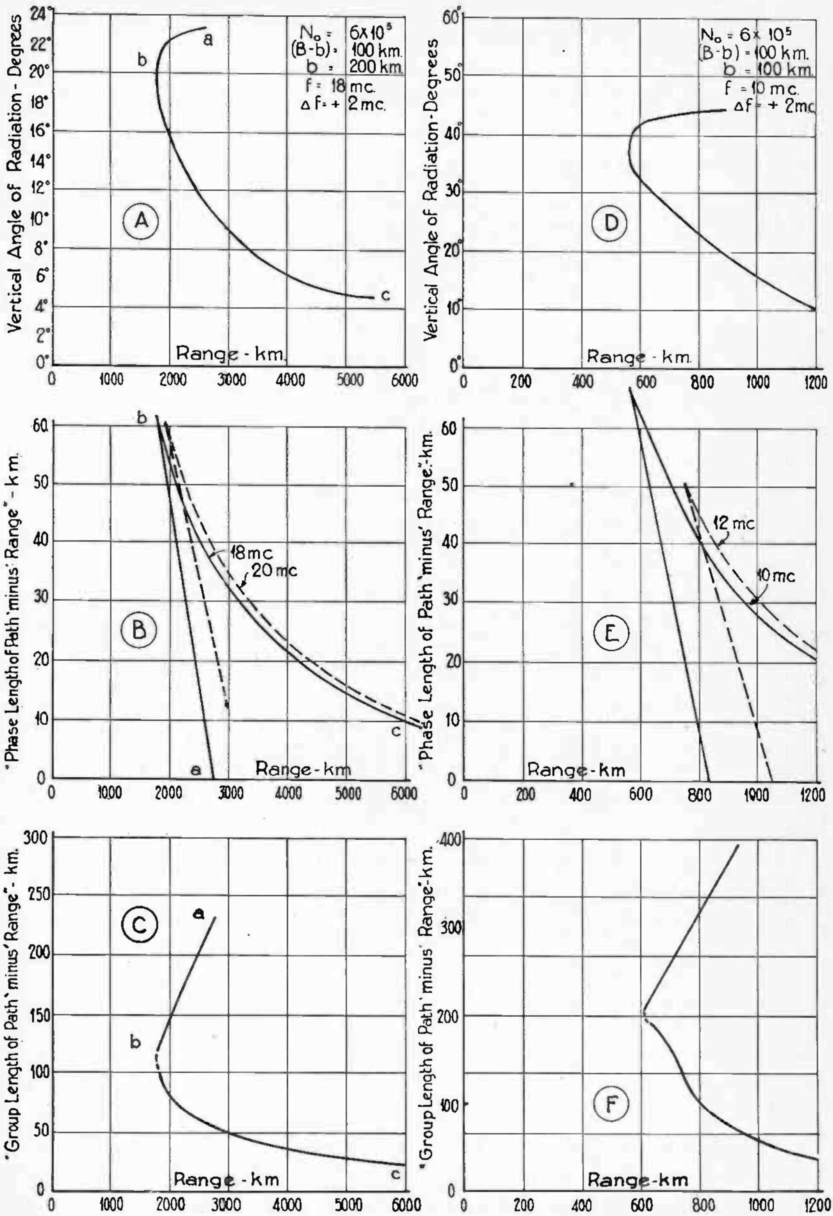

Fig. 35—Some calculated curves showing relation between vertical angle of radiation, phase length of path, group length of path, and range for "flat earth" case.

It will be noted that the group length of path increases very rapidly in the vicinity of the minimum range at (b) in curves (C) and (F). The point (b) is a critical point in the group path relation. At (b) there exists, a condition under which two components of a wave group cannot both reach the receiver. The higher frequency would not be sufficiently refracted. Let us presume that, due to dimensional or density changes (or both) in the refracting layer, the curve (a, b, c) in (C) is moved to the right past a particular range point. When point (a) reaches this receiving range, there will be two wave components present. The difference in group length of path will be considerable, and due to the steep gradient of the "group path length-range" curve at this point the path-length difference between these two components will change rapidly. This change will cause correspondingly fast fading. The depth of the fading minima will increase as the ratio between the upper and lower rays approaches unity. Normally the intensity of the upper ray is much less than that of the lower but as point (b) on the "group path length-range" is approached the two approach equality, and rapidly diminish in intensity. The fading rate would increase steadily due to the continual increase in the combined rate of change of path length. According to this line of reasoning the spacing of the minima would increase as the fading progressed, since the difference in the group path lengths would be decreasing rapidly. Although the increase in fading rate does generally occur toward the end of the useful period in accordance with this theory, it is not certain that this increase in fading rate is always accompanied by an increase in minima spacing. Unfortunately the end of the period is so confused by the relatively high noise, and by distortion of the multitone patterns due to the abnormal fading rate, that reliable data are difficult to obtain.

If some such effect as has been described does account for the rather abrupt increase in fading rate at the end of the day, it appears that the distribution of ionization must be quite different during the transient period at the beginning of the useful interval, for at this time there is rarely any evidence of fast fading.

Conclusions

The cause of fading on a short-wave, long-range circuit appears to be of a more or less orderly nature when the fading is observed on a band of frequencies rather than upon one alone. The relative simplicity of the selective fading patterns suggests that the contributing factors are limited in number. Diurnal and seasonal variations in the amplitude and character of selective fading are fully as orderly as field-strength variations. The patterns are in general most simple for the higher radio frequencies, indicating that a smaller number of components are involved as the frequency increases. The average fading rate is correspondingly lower for the higher frequencies.

Normally the minima spacing in the selective fading patterns observed on the Deal-New Southgate circuit was more than 500 cycles. In extreme cases unlike fading on radio frequencies spaced 170 cycles apart was recorded. It appears probable that the minima spacing at these times was considerably less than 170 cycles. Such conditions were always accompanied by very rapid changes, and on at least one occasion (when single side-band signals were transmitted) by distinct voice echoes presumed to travel around the earth in the direction transmitter-to-receiver. The susceptibility of the circuit to this very rapid fading (which appears to be distinctly different from normal fading in character) varies considerably with time of year, and is a maximum between September and January. Fading rates intermediate between these extremely rapid changes, and normal variations may be due to a critical condition along one or more of the paths such that the group length of path may undergo a rapid change accompanying normal changes in dimensions and height of the ionized region.

Since the fading as observed on signals received with vertical antennas is selective, and other observers have found fading of a single frequency to differ in the horizontal and vertical planes, it seems very likely that components of the signal band are in various states of polarization when they arrive at the receiver. Approximate calculations indicate that for transmission in the direction of the earth's magnetic field the planes of polarization of the components of long-range, short-wave signals will be so selectively rotated at the receiver as to produce distortion when received on an antenna in a single plane. Intermediate earth reflections would also accentuate the distortion produced by selective rotation of the polarization plane over the signal band. The magnitude of such selective rotation of the polarization plane over the signal band would decrease rapidly with frequency. Observations on single and double side-band 18-megacycle signals at times when the patterns were extremely simple indicate that this is not the major cause of the distortion at this frequency on the Deal-New Southgate circuit. It may be a contributing factor of some importance at the lower frequencies.

The presence of distortion on both single and double side-band signals indicates that the cause cannot be assigned to side-band asymmetry.

A study of single and double side-band patterns obtained at times when the patterns were simple suggests that a considerable part of the distortion is due to wave interference between signals arriving over paths of different group length. Normally the difference in group length of the interfering paths seems to be between 50 km (or less) and 300 km for the different components. Except in unusual cases it is necessary to assume three or more paths to account for the pattern shapes and sequence of changes observed. This is particularly true of the lower frequencies.

To account for the different paths (assuming that more than two do normally exist) there is the possibility of paths through different levels of the refracting medium where the rate of change of ionization with height is effectively the same. Two such paths are possible in a layer based upon simple assumptions. More than two might exist if the rate of change of ionization with height is actually not so simple. This latter case would be equivalent to the idea that there may be more than one layer. The apparent decrease in number of paths with frequency does not seem to adapt itself to this theory since the lower frequencies would be less inclined to penetrate to the higher layers.

A number of paths might be the result of "earth" reflections. There is apparently some substantiation of this theory in the fact that the number of paths seems to decrease with frequency. Higher frequencies would be less apt to return to earth at the higher radiation angles.

The fact that the selective fading patterns were found to be practically the same on a vertical antenna and an array directive within some 10 deg. in the horizontal plane apparently precludes any possibility of widely divergent paths in this plane.

Observations of single side-band multitone patterns at 18 megacycles show generally what appears to be a progressive change in relative path length superimposed upon which are transient variations in either direction.

The diurnal change in pattern shapes and depth of fading suggests a similar diurnal change in the various components. The diurnal field-strength curves obtained by measuring average fields are probably a composite of simple diurnal variation curves representing the contributions of different paths.

The distortion appearing in the audio-frequency signal is due to intermodulation of the side bands as the carrier is suppressed ("harmonic distortion"), and to a selective suppression or exaggeration of fundamental audio frequencies ("fundamental distortion"). The former may be reduced by a decrease in percentage modulation at the transmitter when using double side band, or eliminated by the use of single side band. The fundamental distortion cannot be corrected by either of these methods.

On the fading maxima, corresponding to a wave interference maximum at the carrier frequency, the distortion due to selective fading on a normal double side-band signal is about the same as that on a single side-band signal. Therefore, as far as the reduction of distortion is concerned, it seems that a double side-band receiving system of distributed receivers and means for continually selecting the highest output would be as effective as the use of single side band. This statement should perhaps be limited to normal or slow fading periods when the rate of selection in the double side-band distributed receiver case is within practical limits. When the fading rate is very high—indicating, as a rule, the existence of closely spaced minima—there seems to be little doubt that single side-band transmission is most effective in reducing distortion.

An automatic gain control which regulates receiver amplification in accordance with carrier amplitude changes cannot maintain a perfectly constant audio-frequency output due to the fact that the percentage modulation of the received signal effectively undergoes a continual change when selective fading occurs. The use of an automatic gain control apparently emphasizes the distortion due to selective fading since the maximum distortion occurs during the fades. Without the automatic gain control this distortion fades with the signal so that it is less obvious though none the less present.

In conclusion it should be repeated that the multitone tests so far described encourage a closer study of fading on short waves at long ranges on the ground that they indicate the cause to be specific rather than accidental.

Acknowledgment

Obviously, tests of such a character as those which have been described could not be made single-handed. They involve the cooperative effort of a large number of individuals. This cooperation by engineers of the Bell Telephone Laboratories and the American Telephone and Telegraph Company is appreciated. Acknowledgment is particularly due H. B. Coxhead, who had charge of the multitone sending and local monitoring equipment in New York, N. Y.; A. G. Jensen, who, while in charge of the receiving equipment at New Southgate, England, cooperated in the accumulation of the multitone data; and Dr. R. Bown, and Dr. G. C. Southworth, who contributed much through their criticisms and suggestions.

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SUMMARY OF PROGRESS IN THE STUDY OF RADIO WAVE PROPAGATION PHENOMENA*

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Summary: *Recent progress in the study of radio wave propagation phenomena is surveyed in the light of the history of the art. The paper is divided into three parts: (A) an historical review; (B) recent developments; and (C) conclusions and outlook for future development.*

Part A. *The historical development of the art from its inception to 1927 is considered. The discussion includes an outline of early isolated sphere hypotheses, their limitations and the development of the modern Kennelly-Heaviside layer theory of radio transmission. Early experimental progress, echo signals, magnetic correlations and the relation of the science of radio direction finding are also considered.*

Part B. *(On recent advances) reviews the progress of the last year or 18 months and includes a discussion of publications on the Störmer-van der Pol echoes and their theoretical interpretation. Progress in Kennelly-Heaviside layer height determinations and experimental studies in transmission and magnetic and solar correlations are also considered.*

Part C. *The rapidity of the advance during the last year is noted, but the need of further consistent observations and other means of investigation before anything approaching a complete satisfactory theory of radio transmission can be evolved is pointed out.*

WHILE IT is the primary purpose of this summary to survey recent developments in wave propagation phenomena, some brief review of historical development is perhaps not inappropriate, inasmuch as such a review furnishes a desirable background against which current development may be viewed.

Part A. Historical Development

1. The Isolated Sphere Hypothesis.

Not long after the successful transatlantic radio transmission experiments of Marconi in 1901[59]† mathematical physicists became interested in comparing the results of his experiments with classical theory. These early investigators considered the earth to behave as an isolated conducting sphere, and the problem to be that of determining the electric field at any point on the surface of such a sphere due to an oscillating doublet located at a point on its surface.

Prominent in this group of investigators were‡ MacDonald,[54,55,56,57] Poincaré,[77,78,79] March[60], Rybeynski,[83] and Love.[53]

* Dewey decimal classification: R113.
† References will be found in the bibliography at the end of this paper.
‡ It is the purpose of this summary to indicate only the salient points in the development and the bibliography included makes no pretense of completeness.

The results of the investigations of these competent workers indicated field strengths at distant points on the earth's surface much smaller than those required to explain experimental results. The analytical problem, however, had proved to be one of no inconsiderable difficulty which required the use of series expansions and subsequent approximations for its solution. Various investigators, proceeding by slightly different methods and approximations, were thus led to somewhat different results. While these results were in agreement inasmuch as they all indicated field strengths much too small, they were by no means identical, and investigators were, hence, encouraged to seek an explanation of the discrepancy between theory and experiment rather in the mathematical details of the solutions than in any fundamental error in hypothesis. Examples of investigations of this type, directed to a consideration of the effects of earth resistivity, are to be found in the work of Zenneck[100] and Sommerfeld.[87]

The isolated sphere hypothesis commanded the interest of analytical workers in the field of radio transmission until most of the discrepancies between the results of the various mathematicians were reconciled and the inadequateness of the results to explain the observed phenomena definitely shown by the work of Watson[97] and van der Pol[95] in 1919.

The results of this survey established the essential correctness of the MacDonald formula as a solution of the problem on the hypothesis of the earth as an isolated sphere. According to this hypothesis, the ratio of field intensities at any two points on the earth's surface is given by

$$\frac{E_r}{E_0} = \sqrt{\frac{\sin\theta_0}{\sin\theta_r}}\; E^{\frac{-0.00375(\rho_r - \rho_0)}{\sqrt[3]{\lambda}}} \tag{1}$$

where ρ = distance along the surface of the earth in kilometers.

θ = angle subtended at the center of the earth by the transmission path.

λ = wavelength in kilometers.

E = field intensity in microvolts per meter.

Although the results of the isolated sphere hypothesis were quite inadequate to explain observed phenomena, particularly with the rapid development of the art and the advent of the complex phenomena associated with high-frequency transmission, they are nevertheless worthy of note, for they represent substantial contributions to physical optics and also furnish a solution of a part of the problem, i.e., the effect associated with the so-called "ground wave."

2. Early Suggestions of the Effects of Atmospheric Conductivity. Experimental Advance. Observations of Magnetic Correlations.

While most of the analytical development of the first decade of the twentieth century was devoted to the isolated sphere hypothesis as outlined in the previous section, this period was not devoid of suggestions that this point of view was inadequate and failed to consider the factors of prime importance.

Balfour Stewart in 1882 and Arthur Schuster in 1886 had explained certain phenomena of terrestrial magnetism by postulating a conducting layer in the upper atmosphere. The first definite suggestion that such ionization might play an important part in radio wave propagation was made by Kennelly early in 1902[45] and shortly thereafter by Heaviside.[38] Kennelly and Heaviside considered only specular reflection from a rather sharply defined ionized layer. The effects of the conductivity of gaseous ions on the propagation of electromagnetic waves was pointed out by J. J. Thomson about this time.[94] The effects of the ionization of the air by sunlight on radio wave propagation were also early suggested by J. E. Taylor[93] and J. A. Fleming.[31] Eccles in 1912 showed that radio waves might also be bent back to earth by refraction, as the wave velocity in the electronic atmosphere would be different from that in the relatively un-ionized lower atmosphere.[25] The effect of atmospheric ionization was also discussed by Nagaoka a few years later.[64]

In 1913 Kennelly gave a qualitative explanation of the diurnal variations in long-distance radio communication, based upon the varying ionization of the atmosphere by solar radiation, which fitted the then-known facts so well as to leave little doubt not only of atmospheric ionization as an important factor in radio transmission, but also that the principal ionizing agent was of solar origin.[46]

It remained for Pickard in 1926 (after the advent of the vacuum tube had permitted precise and persistent measurements of field intensity to be made) to establish quantitatively the correlation with solar phenomena by a series of observations of radio transmission in the broadcast band.[74,75] Similar correlations for the low-frequency region have been established by the work of Austin[9,10,99] and by observations of engineers of the American Telephone and Telegraph Co.[1,28]

Beginning in 1915, Austin began systematic measurements of a group of European and American stations, which have continued down to the present time. From 1915 to 1922, these observations were made by audibility meter measurement of signal strength, but from 1923 to date by the telephone comparator, with a great gain in accuracy. These measurements, which have extended through fourteen years or over a sunspot cycle, have recently shown very significant correlations with solar activity.

The first definite correlation between radio transmission and a geophysical element was made by Fessenden[32] in 1908, when he found that night transmission over the north Atlantic was severely depressed during magnetic disturbances. More recently Austin and Pickard from statistical studies of day and night fields over long periods, have found striking correlations between reception, temperature, sunspots, solar constant, and terrestrial magnetism. In general they found that day and night reception were inversely related, day fields over long east-west paths increasing with solar activity, with disturbances of terrestrial magnetism, and with cold waves, whereas night reception was markedly depressed at times of magnetic storms and large sunspot groups, but increased with rising air temperature. Similar relations were pointed out qualitatively by Espenschied, Anderson, and Bailey in 1926.[28]

The earliest work in the measurement of field intensity was that of Duddell and Taylor in 1905, where the current in the receiving antenna was directly measured by a sensitive thermo-galvanometer. In 1906 Pickard published a description of a method in which the received signal was directly compared with a locally generated signal of known strength, which he later (in 1921) developed into the present-day method of introducing a measured and attenuated comparison signal into the receiving aerial. The outstanding work of this period was the field-intensity measurements of Austin[7] over sea water, upon which the Austin-Cohen transmission formula was based.

With the rapid growth of the broadcasting of radio programs for entertainment purposes, numerous surveys have been made during the last few years from which the distribution of field strength over metropolitan areas as a result of signals transmitted from a nearby broadcast station have been determined.[15,58,23] The field strengths observed are of course mainly due to ground-wave transmission and are hence relatively independent of time and of meteorological or solar elements. However, marked evidence of shielding effects resulting from large buildings and topographyare evidenced, which usually result in rather irregular contours which are difficult of prediction. In numerous cases of stations located in congested districts evidence is found for heavy local absorption of frequencies of from 0.5 to 1.5 megacycles in nearby buildings, and further justification for the present practice of locating stations in the outlying city districts (apart from the primary considerations of interference) is hence secured. Actual changes of contours during the progress of particular contemporary building projects are in some cases reported. The effects of trees and terrain are also considered by a recent worker.[14]

3. Radio Direction Finding.

With the advent of consistent observations and an appreciation of the importance of the atmosphere in radio transmission, came an increasing realization of the close relation of the art of radio direction finding to the science of radio transmission and its associated "night effect" and polarization phenomena. Many difficulties (which would not have appeared had the isolated sphere hypothesis been correct) confront the radio direction-finding engineer. Thus, the loop antenna and other devices widely utilized in this art give correct maximum and minimum bearings only in the absence of abnormal polarization. The presence of abnormal polarization (resulting from transmission phenomena) therefore represents a problem in radio direction finding which has as yet found no satisfactory solution. The presence of the "night effect" was early recognized,[32] although its interpretation became clear only with the development of the Kennelly-Heaviside layer theory.[46,90,26]

4. Analytical Development of the Layer Theory. Prediction of Skip Distance Phenomena.

Perhaps one of the most notable early analytical contributions to the Kennelly-Heaviside layer transmission theory was that of Watson[97,98] just after his analysis had shown the inadequacy of the isolated sphere hypothesis. On the suggestion of van der Pol, Watson then derived the law of propagation between two concentric conducting shells and showed that the law of attenuation corresponding to this hypothesis could be written in the form expressed earlier by the (empirical) Austin-Cohen formula. Watson's method of analysis consisted in a straight-forward solution of Maxwell's equations subject to appropriate boundary conditions. This attack, however, led to analytical complications which rendered it not well adapted to extension to a consideration of other than sharply defined boundaries of ohmic conductivity; a consideration of other types of boundaries is essential to an explanation of high-frequency transmission phenomena. Recently it has been shown that a formula of the Austin-Cohen type may be obtained on Watson's hypothesis from the usual point of view (now adopted) of reflected (or refracted) rays. A suggested modification of the coefficient in the Austin formula is also suggested by this analysis which was implicitly but not explicitly contained in Watson's work.[47]

The rapid development of interest in high-frequency phenomena in the early '20's led to a rapid development of a transmission theory in which the behavior of the Kennelly-Heaviside layer was studied by means of an application of the ray theory for non-homogeneous media (borrowed from physical optics). According to this point of view the electronic conductivity in the upper atmosphere produces a gradually varying change in effective dielectric constant and hence in index of refraction (which could be exactly determined analytically if the true distribution of electron density, temperature, pressure, etc., were known for the upper atmosphere). In the absence of such data writers have usually assumed some plausible distribution (which at the same time proves convenient analytically) and proceed by use of the Snell law to deduce the differential equation for the ray path from which critical angles, etc., may be predicted. A start on such a theory is to be found in the work of Eckersley[26] in 1921 and of Larmor[52] in 1924, while a more complete development of the point of view adopted by recent workers in the field is to be found in the work of Taylor and Hulburt[91] in 1926. By the critical angles associated with such trajectories (and appropriate assumptions of layer height and electronic distribution) Taylor and Hulburt were able to explain most of the skip-distance phenomena experimentally observed. Meanwhile, Nichols and Schelleng[66] had evolved a theory for the effective change in dielectric constant of the upper atmosphere (taking into account the earth's magnetic field), and pointed out the importance of this effect on radio transmission, (particularly at frequencies near 1 to 2 megacycles).

5. Layer Height Determinations.

As pointed out in the previous section, an exact quantitative determination of ray paths in the upper atmosphere requires a knowledge of the physics of the upper air beyond that now available. In the absence of such data, numerous investigators have evolved ingenious radio experiments with a view to furnishing such information by observations of radio transmission phenomena. Early experiments of this type were carried out by Appleton[4] and Hollingworth[41] in England, and by Breit and Tuve;[20] Brown, Martin, and Potter;[16] and Heising[39] in the United States. The methods of these investigators each possess peculiar advantages and disadvantages. The methods of Appleton[4,5,6] and Hollingworth[41] consist in observing the phase reinforcements and oppositions introduced by multipath transmission. In Appleton's method, a fixed base is employed and rapid changes from reinforcement to opposition obtained by appropriate frequency variations at the transmitter (the frequencies employed have in general been confined to the broadcast range, i.e., of the order of 1 megacycle). Hollingworth's determination consisted in observing these changes by recording field strengths at varying distances from a low-frequency station operating on a fixed frequency.

The method of Breit and Tuve[20,21] consists in the oscillographic reception of radio pulses of the order of 10^{-4} seconds duration. In the high-frequency region where these observations are carried on, these pulses appear at the receiver as groups corresponding to a ground wave and a series of reflected rays.

Appleton's methods, with the balanced antenna and loop systems employed, permit measurements of polarizations and other phenomena not directly disclosed by oscillographic studies alone such as obtained by the classical Breit and Tuve methods (utilizing an antenna only). There is, however, no apparent reason why loops and directional antenna arrays may not be employed to advantage to obtain additional information in applications of the pulse methods even though much of the information thus obtainable requires measurements of relative amplitudes, etc., to which the setups of Appleton have been peculiarly well adapted. There appears to be no inherent limitation of pulse methods, however, which prevent their extension to a consideration of the more difficult amplitude variations as well as purely time relations. The phase interference results are complicated by effects produced by waves corresponding to more than two paths. This difficulty also applies to Hollingworth's method. In general these limitations are of less importance at low frequencies where phase relations are less subject to rapid variations.

The methods of Breit and Tuve are largely free from this difficulty and are well adapted to studies in the high-frequency region, but may be extended to relatively low frequencies (say 0.3 megacycle) where the length of the desired pulse begins to approach the natural period of the circuit. After this, difficulties introduced by transients and other obvious modulation limitations govern. Heising employed both methods in his investigations. The method of Brown, Martin, and Potter in which selective side-band fading was noted, is similar in principle to that of Appleton.[15]

In a brief historical review appropriate to a summary of this sort, space hardly permits a more detailed quantitative discussion of the methods outlined in this section for which the reader is referred to articles mentioned in the accompanying bibliography. Appleton's development of appropriate loop and antenna measurements to determine angles of polarization, etc., are worthy of notes as important tools for use in further investigations. In their 1926 paper,[20] in addition to presenting experimental results, Breit and Tuve prove an important theorem widely used by other workers, i.e., it is proved that

"In the absence of dissipation, a ray departing with an angle ϕ_0 in a medium of variable index of refraction is subject to a group retardation equal to that encountered by a ray traversing with the velocity of light a triangular path of the same base and initial angle of departure."

6. Pedersen Summary.

Readers interested in a more extended quantitative and historical summary of radio wave propagation may well refer to a book recently published by P. O. Pedersen[68] in which an analytical summary and survey of the development of the field is outlined. While some of the material presented, particularly as to the constitution of the upper atmosphere, is of necessity highly controversial and subject to Pedersen's own interpretation, nevertheless this book, by virtue of its completeness and the important original contributions of Prof. Pedersen in the course of the presentation, unquestionably constitutes an outstanding recent contribution to the subject of wave propagation phenomena.

7. Echo Signals.

With the advent of short-wave communication, a new series of phenomena came into prominence, *i.e.*, the so-called echo signals apparently first reported by E. Quäck[80,81] and subsequently frequently known as the Quäck effect. As originally observed, these signals consisted of echoes of the original dots and dashes with retardation times corresponding to transits of the earth (not only once, but in later observations, several times). Extended observations by Taylor and other investigators of the phenomenon, however, subsequently disclosed many echoes corresponding to time intervals not simply related to the time for an earth transit along a great circle path.[92] A more extended discussion of these phenomena will be given at the beginning of the next section outlining recent advances.

Part B. Recent Advances

In Part A salient points in the development of the study of radio wave propagation phenomena from the inception of the art to about one year ago have been briefly outlined. In Part B the rapid development of the art reported from the latter part of 1928 to the present will be discussed in relation to its importance in the fields previously surveyed.

1. Echo Signals.

Perhaps the most remarkable and puzzling phenomena in wave propagation to come to light recently are echoes of really enormous retardation time running into many seconds and even into minutes. These echoes were reported by Hals, Störmer, and van der Pol[89,96] in November, 1928. As yet the explanation of echoes of this type is not by any means satisfactory. Two possible hypotheses suggest themselves; either the signals encounter an electron distribution in the Kennelly-Heaviside layer such as to produce an extremely small group velocity over part of the ray path, or the echoes may escape through this layer at nearly normal incidence to be returned from a layer of extreme height (i.e., a diameter comparable with the moon's orbit). Both of these hypotheses are open to serious difficulties. The first hypothesis was advanced by van der Pol; and Breit has shown that an expotential distribution of electron density may give extremely small group velocities. Appleton[3] and other investigators have, however, emphasized the extreme difficulties associated with the attenuation encountered by a ray passing over such a trajectory.

An important contribution to the second hypothesis, which was advanced by Störmer, is found in the recent paper by Prof. Pedersen[69] in which he considers the attenuation encountered when the group velocity is small for numerous assumed types of propagation in the Kennelly-Heaviside layer. He arrives at the conclusion that the attenuation is in every case so excessive as to render an explanation by this means quite unsatisfactory. Pedersen thus definitely allies himself with those who would explain the observed phenomena by electronic or ionic clouds in interplanetary space. Evidence for the existence of such layers due to the electrons emitted from the sun in the earth's magnetic field (according to the theory of Störmer) is found, but great difficulties still remain as a result of the extreme variability of retardation intervals reported, and the rigorous requirements for focussing made necessary in order to overcome the excessive inverse square attenuation which would otherwise appear over a path of such enormous dimensions.

Distinct from the van der Pol-Störmer echoes of extreme retardation time, numerous investigators[81,40,92] have reported further observations of the Quäck effect or "round-the-world signals" and further studied their diurnal variations and occurrence. These signals are distinguished from the previous group by retardation times corresponding to that required for one or more transits around the earth, although many workers have reported echoes with retardation times not simply related to this interval.[92,27,49] The investigators of these phenomena in general seek an explanation of the observed effects in multiple transits of the earth along a great circle path or from signals reflected back from the irregularities of the earth's surface or from the sea or by signals scattered by the atmosphere. The possibility remains, however, that some of these phenomena may be less marked manifestations of the van der Pol retarded echoes. Thus, a 5,000-km equivalent path difference on 4,435 kc again introduces difficulties in attenuation and size of reflector when an echo produced by terrestrial reflection is sought as an explanation of the observed phenomena. It thus appears difficult at present to draw a sharp line of demarcation between all these phenomena, although the existence of distinct effects seems unquestioned.

In a recent (1929) comprehensive paper T. L. Eckersley has presented important further contributions to the field of retarded echoes in the form of numerous observations of the bearings obtained on a high-frequency direction-finding system.[26] These bearings are found in general to be correct in the case of distant stations (which are not beam transmitters). The bearings from beam transmitters are, however, found to be grossly in error (the bearing usually corresponding more nearly with the direction of the intercepting station of the beam transmission). Triangulations on very limited available base lines are made, and considerable evidence for the existence of scattering or reflecting sources at distances of from 2,000 to 3,000 km is found. The bearings of non-beam (perhaps appropriately termed "broadcast") transmitters operating within the skip distance are quite indeterminate, the energy apparently arriving from all directions.

An extended hypothesis of scattering from ionic clouds is evolved to explain the observed phenomena, and the dimensions of the clouds are predicted by the absence of observed scattering phenomena above 50 meters. While the evidence deduced for the existence of scattering is considerable, that for the existence of ion clouds of certain discrete sizes appears less complete, and worthy of further careful consideration.

2. Kennelly-Heaviside Layer Studies.

The last few months have marked a period of rapid advance in both theoretical and experimental studies of the height of the Kennelly-Heaviside layer. Notable in this development have been the theoretical papers of Schelleng,[84,85] Eckersley,[26,27] Hulburt,[43,61] and Appleton,[6] and the experiments of Eckersley[27] and Tuve and Hafstad.[36,37] Kenrick and Jen[48,49] have also contributed further data taken at Philadelphia and a further theoretical discussion of wave trajectories and retarded echoes, while Mirick and Hentschell have contributed an interesting determination of layer height by the Hollingworth method applied to the 3-megacycle frequency range.[63]

Schelleng's papers have furnished an interesting method by means of which the difference in wave number between two paths is obtainable for a frequency f_0 in terms of an integral involving the group time retardation for all frequencies less than f_0, i.e.

$$(N_1 - N_2)_{f0} = \frac{1}{f_0} \int_{f=0}^{f=f_0} (Tg_1 - Tg_2) df. \tag{2}$$

Schelleng finds the height of a triangle having the wave numbers N_1, N_2, etc. (vacuum velocity of propagation assumed) and obtains an approximation to the height of the Kennelly-Heaviside layer by this means which is applied to the world data available (as a function of frequency) to obtain a revised height curve.

Appleton[6] has discussed the ratio of true to virtual heights on several assumptions of electron density distribution, and shown for any given distribution that the same group retardation times are obtainable by either the pulse method of Breit and Tuve or the wave number method utilized in his investigations.

Kenrick and Jen,[48] in their theoretical discussion, have considered the estimates of height of Schelleng in their relation to the true height and also the ratio of true to virtual heights for various electron distributions. (Some of this latter discussion closely parallels the work of Prof. Appleton, although it represents an independent development prepared before Prof. Appleton's results appeared in print*). Kenrick and Jen also present layer height determinations showing diurnal variations as observed at Philadelphia on transmission of multivibrator signals from NKF in three distinct tests.

Tuve and Hafstad have presented similar height determinations as observed at the Department of Terrestrial Magnetism and also reported an application of a new method by which the phase of the outgoing and incoming echo signals are compared, and accurate determinations of layer movement thereby obtained. The transmitter crystal phase is used as a system of reference. This paper represents an ingenious and interesting further development of the pulse method for a study of phase relations.[37] It appears, however, that layer measurements have hardly yet reached a state of refinement to warrant the extended application of such methods for the production of significant results.

The effects of magnetic storms upon layer heights and movements have also been observed and reported.[36]

Eckersley's recent contributions to the Kennelly-Heaviside layer problem are to be found in two papers.[26,27] The contributions contained in the first of these papers have already been in part discussed. Important among the later conclusions contained in this paper are the

* Prof. Appleton's paper was presented at the U.R.S.I. meeting at Brussels on September 13, 1921, and appeared in print in January, 1929.[6] The Kenrick and Jen paper was presented at a meeting of the Philadelphia Section of the Institute of Radio Engineers on November 23, 1928; see bibliography (No. 48) at end of paper.

author's reaffirmation of the variation of attenuation with angle of departure rather than electron limitation as the major cause of the observed phenomena of skip distance. Objection is raised to the electron limitation hypothesis because of alleged observations of the reception of 10 mc waves returned at nearly normal incidence and of local scattering at 21 mc. The absorption attenuation theory of an earlier paper[26] is further discussed and developed. Another important question as to the validity of the ray theory when applied to waves of greater length than 1.5 mc is raised and Prof. Pedersen's discussion of low-frequency propagation from this point of view termed "entirely unwarranted." The use of Watson's theory in the treatment of low frequencies is recommended.

The discussion of the validity of the ray theory thus raised is indeed interesting, and it is to be hoped that Eckersley will further support his contentions by a more adequate and complete theoretical discussion which will serve to disclose more exactly the range of validity of the wave theory and the errors to be expected by its use in the low-frequency region, beyond the statement that "it is difficult to trace the transition between the two methods and therefore determine what modification of the ray theory is necessary." Failure of the author to include such a discussion is no doubt due to the great length of his paper and it is to be hoped that it may be soon included in another communication.

It is generally recognized that the ray theory represents but an approximation for the treatment of problems in the propagation of radio waves, but the exact order of the approximation and the range of its validity do not appear to be generally known. It yet remains to be definitely established that these approximations are seriously in error for the low-frequency region, as would be indicated by Mr. Eckersley's formulas and graphs. It should not be overlooked, however, that Watson's formulas were derived on the assumption of a sharply defined bounding surface for the layer, and that similar conclusions for this case have been found to be derivable by the use of the ray theory.[47] Watson's theory is thus definitely limited if questions of depth of penetration or the lack of sharp definition of the surface of the layer are to be considered.

In his second paper,[27] Mr. Eckersley presents interesting evidence of multipath long-distance communication on the high frequencies as obtained from high-speed facsimile reception, and deduces figures for the height of the Kennelly-Heaviside layer. Close accord is found with the figures for height obtained by Kenrick and Jen in observations on 4435 kc and the agreement termed "more than fortuitous." The point of view adopted, however, differs from that of these latter investigators in that several rather sharply defined gradients of electron density are pictured. The waves are thus postulated as first refracted from the lower layer and later in the night from the upper layer. Apparently the gradients in each layer are supposedly so rapid as to cause the observed heights to be nearly independent of frequency. Support of this point of view is found also in some of Prof. Appleton's observations and the results of some American observers.*

The point of view of Kenrick and Jen, however, was not extended to several layers but rather considers a continuous and gradual changing electron density with height. This apparently proves sufficient to explain the gradually and continuously varying virtual heights they observed during the evening periods. Such changes are supposedly due to a variation in virtual height due to redistributions of electron densities during the night period over a wide range of height in the upper atmosphere. From this point of view a close agreement in height between observations made over widely different distances on widely different frequencies would be largely fortuitous even when the possibility of several rather sharp maxima is duly considered.

Hulburt's interesting estimate of the Kennelly-Heaviside layer on Mars proceeding from the known physical constants, etc., is worthy of note.[42]

We are also indebted to Hulburt for a recent contribution to the Kennelly-Heaviside layer theory in which the problem of the ionization in the upper atmosphere is further considered from the point of view of the physicist.[43] Difficulties encountered in a previous paper where the layer was calculated as lower during the night period as a result of thermal effects are reconciled by noting an opposing (probably predominant) factor in the form of a difference in electrical potential produced by a circuital ionic current. This effect produces a force causing the ions on the night side of the earth to tend to rise. The observed facts, as obtained from radio observations, are found to be in accord with those predictable by this theory when the best available assumptions of physical constants for the upper atmosphere are made. The constants involved are, however, so much in question as to render a quantitative agreement hardly conclusive.

Breit has recently contributed a further theoretical discussion of echoes of long retardation times in which he produces an exponential form of electron distribution consistent with the observed results but still subject to difficulties of excessive attenuation.[18] It is possible, however, that a close study of the form of electron collisions and the

* loc. cit.

mechanism of the dissipation may disclose relations consistent with a satisfactory theory. It is to be hoped that Dr. Breit will consider this phase of the subject in a subsequent communication. Kenrick and Jen[49] have applied a modification of Breit's distribution in discussing a possible explanation of observed echoes of moderate retardation of some 5000 km retardation on 4435 kc.

Another recent paper of Dr. Breit's considers the theoretical aspects of the phase-echo experiments of Hafstad and Tuve.[19]

3. Transmission Studies. Experimental Advances.

Observations of field strengths and a study of their variation have been continued during the past year to an increasing extent. Results of such studies have been reported in papers by Austin,[11] Sreenivasan,[88] and Wymore[99] in the low-frequency range and by Parkinson in the broadcast band.[67] Magnetic and meteorological correlations have been studied and discussed in these communications including the effect of magnetic storms.

Kenrick and Jen have also reported the results of a limited series of observations in the low-frequency region at Philadelphia, and compared the results with simultaneous reception of the same station (WCI) by Pickard at Newton Center, Mass. Evidence for a consistent progressive change from a direct to inverse correlation of the receptions is found, but the interval of the observations is not considered sufficient to render such conclusions final.[49]

A rich store of Kennelly-Heaviside layer height determinations have also been contributed as outlined in a previous section, but many more data of this sort are necessary before anything approaching a complete and consistent picture of the phenomena involved can be obtained. Some means of automatic recording which will enable such observations to be continued over long periods would doubtless furnish many data of interest and enable interesting correlations to be established. Such observations over a wide range of frequencies are evidently needed.

Valuable supplementary data of related skip distance phenomena have been contributed by the work of Clapp[22] and Krüger and Plendl.[50]

Eve and co-workers have also reported interesting observations of underground reception which have opened up a further interesting field for research and discussion.[29,30]

The results of these observations have already been the subject of discussion contributed by Englund and others.[29] Suitable carefully controlled radio experiments underground thus give promise of considerably extending our knowledge of ground conductivity effects at very high frequencies, which is a subject still very little understood.[30] Practical applications to the location of ore bodies or other earth conductivity discontinuities are also suggested.

A knowledge of effective earth conductivities would also be of great assistance in other branches of the art, such as the prediction of antenna characteristics, etc.

4. Radio Direction Finding.

Further data from radio direction-finding observations as to the variation of apparent bearings resulting from radio transmission polarization phenomena are to be found in a comprehensive paper by Smith-Rose[86] on radio direction finding, while further interesting light is found in the published discussion of this paper.[86]

Conversely, observations of the type contributed by Eckersley[26] and Parkinson[67] in papers already reviewed are of direct bearing on the problem of high- and intermediate-frequency direction finding. These problems are rapidly becoming of paramount importance in this art due to the demands of aerial navigation for radiobeacons.

The possibility of ultra frequencies of the order of 30 to 100 megacycles or higher (which are apparently not in general returned from the Kennelly-Heaviside layer) remains, however, as a very interesting and let us hope fruitful field of current development and research in aerial navigation, where line of sight communication over considerable distances is available for the operation of directed ray beacons or general communication services.

The use of frequencies of from 1 to 30 megacycles for radio direction finding remains at present a rather unsatisfactory problem because of disconcerting effects introduced by the violent polarization changes encountered on these frequencies and the short range of the ground wave.

A fruitful method for the investigation of short-wave polarizations is opened up by the work of Friis, in which phases of received waves on antennas located at several points are studied by means of a cathode-ray oscillograph.[33]

Part C. Summary and Conclusion—Outlook for Future Development

The published developments in wave propagation phenomena during the past year have perhaps been more voluminous and varied in scope than in any other period of similar duration. However, the progress recorded represents but a start toward anything approaching a reasonably complete quantitative theory of radio transmission.

The Störmer-Hals-van der Pol echoes, (opening up a quite unsuspected field of research), have further served to emphasize how far we still are from even a complete qualitative picture of all of the factors involved. Kennelly-Heaviside layer studies, and observations in nearly all fields of the subject, have emphasized the extreme variability of the observed phenomena and the necessity of extended observations before general conclusions may be drawn. With an ever increasing number of workers interested in this field of research, however, it appears that the coming year should be even more productive of fruitful results.

Theoretical progress is much handicapped by lack of accurate quantitative data as to the actual conditions in the upper atmosphere, and workers in this field hence view with much interest the progress of such experiments as those now being carried on by Prof. R. H. Goddard of Clark University, with a view to devising a rocket which would render a direct observation of the conditions existent in the upper air possible. Meanwhile, many data of importance may be contributed from consistent observations along the lines outlined above and by further theoretical discussion and interpretation of the results thus obtained. It is to be hoped also that new experiments and lines of investigation may be devised which will further serve to separate and clarify the complex factors which contribute to the phenomena of wave propagation. A further study of the magnetic factors entering into wave propagation, and a completely satisfactory theoretical explanation of the phenomena associated with magnetic storms appears also to rest largely in the future, as does a wholly satisfactory explanation of the Störmer-Hals-van der Pol* echoes.

Bibliography

1. Anderson, C. N., "Correlation of long-wave transatlantic radio transmission with other factors affected by solar activity," PROC. I.R.E., **16**, 297–347; March, 1928.
2. Anderson, C. N., "Transatlantic radio transmission," PROC. I.R.E., **17**, 1528–1535; September, 1929.
3. Appleton, E. V., *Nature*, **122**, 879; 1928.
4. Appleton, E. V., "On some direct evidence for downward atmospheric reflection of electric rays," *Proc. Royal Soc.*, **109**, 621; 1925. See also *Proc. Royal Soc.*, **113**, 450, 1926; **115**, 305, 1927; **115**, 291, 1927. *Electrician*, 398, April 3, 1925. *Proc. Camb. Phil. Soc.*, **22**, Part 51, 672–675; 1925.
5. Appleton, E. V., "On a method of determining the state of polarization of downcoming wireless waves," *Proc. Roy. Coe. A*, **117**, p. 576–588. "Study of signal fading," *Jour. I.E.E.*, (London) 872–885; August, 1928.
6. Appleton, E. V., "Some notes on wireless methods of investigating the electrical structure of the upper atmosphere," *Proc. Phys. Soc.* **41**, 43, (London) December 15, 1928.
7. Austin, L. W., Bulletin of the Bureau of Standards, Washington, **7**, No. 3, 315; 1911.
8. Austin, L. W., "A suggestion for experiments on apparent radio direction variations." PROC. I.R.E., **13**, 3-4; February, 1925. (Dr. Austin published

articles on long-wave reception tests in nearly every issue for several years at about this period.)
9. Austin, L. W., "Long-wave radio measurements at the Bureau of Standards in 1926 with some comparison of solar activity and radio phenomena," PROC. I.R.E., **15**, 825–843; October, 1927.
10. Austin, L. W., "Long-wave radio receiving measurements at the Bureau of Standards in 1927," PROC. I.R.E. **16**, 1252–1260; September, 1928.
11. Austin, L. W., "Experiments in recording radio signal intensity," PROC. I.R.E. **17**, 1192–1205; July, 1929.
12. Baeumler, M., "Recent investigations of the propagation of electromagnetic waves," PROC. I.R.E., **13**, 5–29; February, 1925.
13. Baker, W. R. G. and Rice, C. W., "Reflection of short radio waves in the upper atmosphere," *Jour. A.I.E.E.*, **14**, 535–539; June, 1926.
14. Barfield, R. H., "The attenuation of wireless waves over land," *Jour. I.E.E.* (London), 204–218; February, 1928. Discussion *Jour. I.E.E.* (London) 931; July, 1929.
15. Bown, R., and Gillett, G. D., "Distribution of radio waves from broadcasting stations over city districts," PROC. I.R.E., **12**, 389–409; August, 1924.
16. Bown, R., Martin, D. K., and Potter, R. K., "Some studies in radio broadcast transmission," PROC. I.R.E., **14**, 57–131; February, 1926.
17. Breit, G., "A suggestion of a connection between radio finding and small fluctuations in the earth's magnetic field," PROC. I.R.E., **15**, 709–723; 1927.
18. Breit, G., "Group velocity and retardations of echoes," PROC. I.R.E., **17**, 1508–1512; September, 1929.
19. Breit G., "The significance of observations of the phase of radio echoes," PROC. I.R.E., **17**, 1815–1821; October, 1929.
20. Breit, G., and Tuve, M. A., "A test of the existence of a conducting layer," *Phys. Rev.*, **21**, 554–576; 1926.
21. Breit, G., Tuve, M. A., and Dahl, O., "Effective heights of the Kennelly-Heaviside layer in December, 1927, and January, 1928," PROC. I.R.E., **16**, 1236–1239; September, 1928.
22. Clapp, J. K., "Some experiments in short distance short-wave radio transmission," PROC. I.R.E., **17**, 479–493; March, 1929.
23. Cherry, R. O., "Signal strength measurements of 3L0," 1928 Specialty Press, Ltd., Melbourne, Australia. (Two papers).
24. Dobson, G. M. B., Harrison, D. M., and Lawrence, J., "Measurements of the amount of ozone in the earth's atmosphere and its relation to other geophysical conditions," *Proc. Roy. Soc.* **110**, 660; *Proc. Roy. Soc.* **114**, 521.
25. Eccles, W. H., "On the diurnal variations of the electric waves round the bend of the earth," *Proc. Roy Soc.*, **87**, 79–99; 1912. Also see *Electrician*, **71**, 969–970; 1913.
26. Eckersley, T. L., "The effect of the Heaviside layer on the apparent direction of electromagnetic waves," *Radio Review*, **2**, 60–65, 231–248; 1921. "An investigation of short waves," *Jour. I.E.E.* (London), 992–1032; August, 1929. See also *Jour. I.E.E.* (London), 85–128; June, 1927.
27. Eckersley, T. L., "Multiple signals in short-wave transmission," PROC. I.R.E., January, 1930.
28. Espenschied, L., Anderson, C. N., and Bailey, A., "Transatlantic radio telephone transmission," PROC. I.R.E. **15**, 7–56; February, 1926.
29. Eve, A. S., Steel, W. A., McEwan, A. R., Thompson, J. H., and Olive, G. W., "Reception experiments in Mount Royal tunnel," PROC. I.R.E., **17**, 347–376; February, 1929. Discussion, PROC. I.R.E., **17**, 892–894; May, 1929.
30. Eve, A. S., Keyes, D. A., and Lee, F. W., "The penetration of rock by electromagnetic waves and audio frequencies" (preliminary report), PROC. I.R.E., **17**, 2072–2074; November, 1929.
31. Fleming, J. A., "Principles of electric wave telegraphy," Longmans and Co., 1st Edition, 1906.
32. Fessenden, R. A., "Wireless Telephony," *Proc. A.I.E.E.*, **27**, Part 1, 553–629; see pages 610–611.
33. Friis, H. T., "Oscillographic observations of the direction of propagation and fading of short waves," PROC. I.R.E., **16**, 658–665; May, 1928.

34. Goddard, R. H., "A method of reaching extreme altitudes," Smithsonian Institution, 1919, publication 2540.
35. Guyot, Lt., "Etude sur la propagation des ondes courtes," *L'Onde Électrique,* 7, 509–528.
36. Hafstad, L. R., and Tuve M. A., "Further studies of the Kennelly-Heaviside layer by the echo method," Proc. I.R.E., **17**, 1513–1523; September, 1929. See also "Note on Kennelly-Heaviside layer observation during a magnetic storm," *Terr. Mag. and Atmos. Elec.*, 39–44; March, 1929.
37. Hafstad, L. R., and Tuve, M. A., "An echo interference method for the study of radio wave paths," Proc. I.R.E., **17**, 1786–1792; October, 1929.
38. Heaviside, O., "Telegraphy," Encyclopedia Britannica, (ninth edition, published 1902), **33**, 215.
39. Heising, R. A., "Experiments and observations concerning the ionized regions of the atmosphere," Proc. I.R.E., **16**, 75–99; January, 1928.
40. Hoag, J. B., and Andrew, V. J., "A study of short time multiple signals," Proc. I.R.E., **16**, 1368–1374; October, 1928.
41. Hollingworth, J., "The propagation of radio waves," *Jour. I.E.E.* (London), 579–595; May, 1926.
42. Hulburt, E. O., "Ionization in the atmosphere of Mars," Proc. I.R.E., **17**, 1523–1527; September, 1929.
43. Hulburt, E. O., "Ions and electrical currents in the upper atmosphere of the earth," *Phys. Rev.*, **31**, 1018–1039; 1928. *Phys. Rev.*, 1167–1183; October, 1929.
44. Jelstrup, H. S., "Essai d'explication de l'écho Störmer—Hals sur les ondes de 31.4 metres de PCJJ," *L'Onde Electrique*, 7, 538–540.
45. Kennelly, A. E., "On the elevation of the electrically-conducting strata of the earth's atmosphere," *Elec. World and Eng.*, 473; May 15, 1902.
46. Kennelly, A. E., "The daylight effect in radio telegraphy," Proc. I.R.E., **1**, 3–16; July, 1913.
47. Kenrick, G. W., "Radio transmission formulae," *Phys. Rev.*, **16**, 1040–1050; June, 1928. *Phil. Mag*, 289–304; August, 1928.
48. Kenrick, G. W., and Jen, C. K., "Measurements of the height of the Kennelly-Heaviside layer," Proc. I.R.E., **17**, 711–733; April, 1929.
49. Kenrick G. W., and Jen, C. K., "Further observations of radio transmission and the heights of the Kennelly-Heaviside layer," Proc. I.R.E., **17**, 2034–2052, November, 1929.
50. Kruger, K., and Plendl, H., "The propagation of low power short waves in the 1000-kilometer range," Proc. I.R.E., **17**, 1296–1312; August, 1929.
51. Laporte, O., "Zur Theorie der Ausbrietung Elektromagnetischen wellen auf der Erdkugel," *Annallen der Physik*, **70**, 596–616; 1923.
52. Larmor, Sir Joseph, "Why wireless electric rays can bend round the earth," *Phil. Mag.*, **48**, 1025–1036; 1924.
53. Love, A. E. H., "The transmission of electric waves over the surface of the earth," *Philosophical Transactions*, **215**, 105–131; 1915.
54. MacDonald, H. M., "The bending of electric waves round a conducting obstacle," *Proc. Royal Soc.*, **71**, 251–258; 1902–03.
55. MacDonald, H. M., "The bending of waves round a conducting obstacle:—Amended results," *Proc. Royal Soc.*, **72**, 59–68; 1903.
56. MacDonald, H. M., "The transmission of electric waves around the earth's surface," *Proc. Royal Soc.*, **90**, 50–61; 1914.
57. MacDonald, H. M., "The transmission of electric waves around the earth's surface," *Proc. Royal Soc.*, **98**, 409–418; 1920–1921.
58. MacIlwain, Knox, and Thompson, W. S. "A radio field strength survey of Philadelphia," Proc. I.R.E., **16**, 181–192; February, 1928.
59. Marconi, G., "On the progress of space telegraphy," *Electrician*, **49**, 392; 1902. *Proc. Royal. Inst.*, **17**, 208.
60. March, H. W., "Über die Ausbrietung der Wellen der drahtlosen Telegraphie auf der Erdkugel," *Annallen der Physik*, **37**, 29–50; 1912.
61. Maris, H. B. and Hulburt, E. O., "Wireless telegraphy and magnetic storms," Proc. I.R.E., **17**, 479–493; March, 1929. See also *Terrs. Mag. and Atmos. Elec.*, **17**, 55–58; March, 1929.
62. Mesny, R., "Les ondes électrique courtes," *Presses Universitaires de France,* Paris, 1927.

63. Mirick, C. B., and Hentschel, E. R., "Height of the Kennelly-Heaviside layer," PROC. I.R.E., 17, 1034–1041; June, 1929.
64. Nagaoka, H., "Effect on radio telegraphy of atmospheric ionization," *Math. Physical Soc.* (Tokyo) *Proc.*, 7, 403–412; October, 1914.
65. Nagaoka, H., "Effect of solar eclipse on wireless transmission," *Math. Physical Soc.* (Tokyo) *Proc.*, 2, 428–430; December, 1914.
66. Nichols, H. W., and Schelleng, J. C., "Propagation of electric waves over the earth," *Bell Sys. Tech. Jour.*, 4, No. 2, 215–234; April, 1925.
67. Parkinson, T., "Observations of short period fading," PROC. I.R.E., 17, 1042–1061; June, 1929.
68. Pedersen, P. O., "The propagation of radio waves," published by "Danmarks Naturvioenskabeliage Samfund," Copenhagen, 1928.
69. Pedersen, P. O., "Wireless echoes of long delay," PROC. I.R.E., 17, 1750–1785; October, 1929.
70. Pickard, G. W., "Determination of wireless wave fronts," *Elec. Rev.* (N. Y.) 494–495; October, 1908.
71. Pickard, G. W., "Short period variations in radio reception," PROC. I.R.E. 12, 119–158; April, 1924. (Like Austin, Pickard published his results in this field at very frequent intervals in the PROC. I.R.E. from 1924–1928. Several articles will be found in nearly every volume. A complete bibliography of these articles is not given here.)
72. Pickard, G. W., "Polarization of radio waves," PROC. I.R.E., 14, 205–212; April, 1925.
73. Pickard, G. W., "The effect of the solar eclipse of January 24, 1925 on radio reception," PROC. I.R.E., 13, 539–569; October, 1925.
74. Pickard, G. W., "Correlation of radio reception with solar activity and terrestrial magnetism," PROC. I. R. E., 15, 83–97, February, 1927; 15, 749–766, September, 1927. See also discussion byDellinger, PROC. I.R.E., 15, 326–329; April, 1927.
75. Pickard, G. W., "The relation of radio reception to sunspot position and area," PROC. I.R.E., 15, 1004–1012; December, 1927.
76. Pickard, G. W., "Some correlations of radio reception with atmospheric temperature and pressure," PROC. I.R.E., 16, 765–772; June, 1928.
77. Poincaré, H., "Sur la diffraction des ondes électriques: a propos d'un article de M. MacDonald," *Proc. Royal Society*, 72, 42–43; 1903.
78. Poincaré, H., "Sur la diffraction des ondes hertziennes," *Rindiconti di Palermo*, 29, 169–259; 1910.
79. Poincaré, H., *Comptes Rendus*, 54, 795; 1912.
80. Quäck, E., Ballantine, S., "Propagation of short waves around the earth." Ballantine reviews Quäck article in PROC. I.R.E., 15, 341–345; April, 1927. Original article in *Zeitschrift für Hochfrequenztechnik*, 28, 177; 1926.
81. Quäck, E., and Mögel, H., "Double and multiple signals with short waves," PROC. I.R.E., 17, 791–829; May, 1929.
82. Rayleigh, Lord (Strutt, J. W.), "On the bending of waves round a spherical obstacle," *Proc. Royal Soc.*, 72, 40–44; 1904. *Jahr d. drahtl. Tel.*, 3, 445; 1910. *Rend d circ mat de Palermo*, 169–261; 1910.
83. Rybczynski, W., "Über die Ausbreitung der Wellen in der drahtlosen Telegraphie auf der Erdkugel," *Annallen der Physik*, 5, 191–208; 1913.
84. Schelleng, J. C., "Note on the determination of ionization in the upper atmosphere," PROC. I.R.E., 16, 1471–1476; 1928.
85. Schelleng, J. C., "Further note on the ionization in the upper atmosphere," PROC. I.R.E., 17, 1313–1321; August, 1929.
86. Smith-Rose, R. L., "Radio direction finding by transmission and reception," PROC. I.R.E., 17, 425–475; March, 1929. Discussion, PROC. I.R.E., 17, 1440–1453; August, 1929. Discussion PROC. I.R.E., 17, 1897–1898; October, 1929.
87. Sommerfeld, A., "Über die Ausbreitung der Wellen in der drahtlosen Telegraphie," *Annallen der Physik*, 28, 663–736; 1909.
88. Sreenivasan, K., "On the relation between long-wave reception and certain terrestrial and solar phenomena," PROC. I.R.E., 17, 1793–1814; October, 1929. See also discussion PROC. I.R.E., 15, 155–157; February, 1927. See also discussion PROC. I.R.E., 15, 1002–1003; December, 1927.
89. Störmer, C., "On an echo of short electromagnetic waves arriving several

seconds after the emitted signal and its explanation from the theory of aurora borealis," *Nature*, **122**, 681, 1928; **123**, 16, 1929. *C. R.* **187**, 811; 1928. *Ent.* **5**, 483; 1928. *L'Onde Electrique*, **7**, 531–532; 1928.

90. Taylor, A. H., "Variation in direction of propagation of long electromagnetic waves," Bureau of Standards Scientific Paper No. 353, 1919.
91. Taylor, A. H., and Hulburt, E. O., "The propagation of radio waves over the earth," *Phys. Rev.*, **27**, 189–215; 1926.
92. Taylor, A. H., and Young, L. C., "Studies of high frequency radio wave propagation," Proc. I.R.E., **16**, 561–578; May, 1928. Proc. I.R.E., **17**, 1491–1507; September, 1929.
93. Taylor, J. E., "Characteristics of earth-current disturbances and their origin," *Proc. Royal Soc.*, **71**, 225; 1903.
94. Thomson, J. J., "On some consequences of the emission of negatively electrified corpuscles by hot bodies," *Phil. Mag.*, 253; August, 1902.
95. van der Pol, B., "On the propagation of electromagnetic waves around the earth," *Phil. Mag.*, **38**, 365–380; 1919.
96. van der Pol, B., "Short wave echoes and the aurora borealis," *Nature*, **122**, 878, 1928. *L'Onde Electrique*, **7**, 534–537; 1928.
97. Watson, G. N., "The diffraction of electric waves by the earth," *Proc. Royal Soc.*, **95**, 83–99; 1918–19.
98. Watson, G. N., "The transmission of electric waves round the earth," *Proc. Royal Soc.*, **95**, 546–563; 1918–19.
99. Wymore, I. J., "The relation of radio propagation to disturbances in terrestrial magnetism," Proc. I.R.E., **17**, 1206–1213; July, 1929.
100. Zenneck, J., *Ann. der Physik*, **23**, 846; 1907.

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CASCADED DIRECT-COUPLED TUBE SYSTEMS OPERATED FROM ALTERNATING CURRENT*

By

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Summary—*An outline is given of the characteristics which are desirable in an audio amplifier or detector-amplifier. A description is given of some direct-coupled cascaded tube systems operating from a-c supply. Among the features which are discussed are: the reduction of current drain on the filter, the elimination of "motor-boating", stabilizing against drift of plate current, the elimination of hum and the provision of automatic change of grid bias with change of carrier input. The paper gives circuit constants and amplification-frequency characteristics for certain circuit arrangements.*

Statement of Problem

IN ANY audio amplifier or detector-amplifier the following characteristics are desirable:

1. minimum frequency discrimination
2. minimum wave-form distortion
3. minimum hum if a-c operated
4. reasonably high gain from the tubes used
5. low cost
6. permissive large tolerance in manufactured parts

In a-c operated direct-coupled cascaded tube systems the characteristics depend upon or are influenced by the following features:

1. maintaining the operation of all tubes at the midpoint of their operating or output current curves, or what may be termed stabilizing against "drift" tending to arise from—
   (a) changing tubes (they are not all alike),
   (b) change of constants or conditions due to—
      (1) aging of resistors,
      (2) temperature coefficient effects in resistors,
      (3) line voltage variations,
      (4) grid emission from tubes,
      (5) gas current in output tubes, and
      (6) manufacturing tolerances.
2. feed-back phenomena at audio frequencies
3. the hum problem
4. motor-boating

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5. trigger action
6. maximum gain of tube
7. providing current for auxiliaries, such as speaker field
8. increase to very high gain, such as that required by photoelectric cell operation.

Since the direct-coupled cascaded system is usable as a most effective detector-audio-amplifier it is well to keep in mind that the following additional essentials can be secured in this system:

1. low grid bias for weak carrier currents and high grid bias for strong carrier currents, automatically self-adjusting.
2. supply of potentials for the radio-frequency tubes sufficiently filtered to prevent modulation hum.

Some Developments in A-C Operation

Some of the inherent difficulties which had to be overcome in making the direct-coupled cascaded system stable and practical are discussed in a prior paper[1] by the authors, but owing to lack at that time of commercial a-c tubes having sufficiently high amplification constants for satisfactory direct-coupled operation our discussion was confined to battery-operated systems. The a-c work had to be commenced and carried on in large part with commercially non-available a-c high-μ tubes such as could be constructed on special order, and they were secured in both the heater-type and filament-type cathodes having values of μ ranging from 16 to 80. In the case of the filament type for raw a-c heating it was found practically desirable to go as low as 1/4 volt on a heavy filament, since the excellent amplifying ability of the system at 120 cycles makes even very slight filament hum troublesome.

It is thought that the technical and practical features encountered in our research and experiences that have led to an extremely simple, efficient, and remarkably hum-free a-c operated system will be more certainly understood and appreciated if we follow through some of the developments that have resulted in success in one way and another.

An early workable a-c operated system employing our specially constructed a-c high-μ tubes is shown in Fig. 1. A current large compared to that required for the plate circuit of tube VT_3 flows through potentiometer R_1 from source S to develop the grid and plate potentials required by the tubes. In our early experience we found a large current in R_1 necessary to avoid what might be termed a "trigger

[1] Edward H. Loftin and S. Young White, "Direct coupled detector and amplifiers with automatic grid bias", Proc. I. R. E., 16, 281–286; March, 1928.

action," an effect not wanted in amplifiers and amplifying detectors, but which may be otherwise turned to good account.[2]

This trigger action is peculiar to direct-coupled systems and, unless harnessed, may operate to prevent operating the last tube at the midpoint of its plate-current curve, so essential to good amplification. It is apparent in the arrangement of Fig. 1 that if the plate current of VT_3 is a substantial fraction of the total current through R_1 there is possibility of changes in this plate current so effectively modifying the bias of preceding tubes as to result in snapping the plate current of VT_3 to one or the other end of the curve and holding it there in an effective blocked or saturated condition of the last tube, and there-

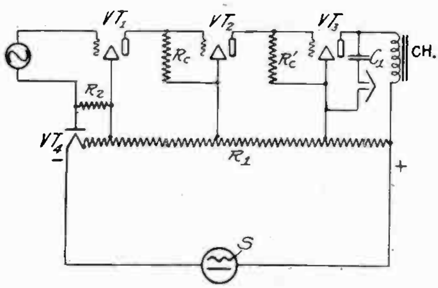

Fig. 1—Direct-coupled cascaded tube system having potentiometer potential distribution, and thermionically-controlled drift correction.

fore render the system ineffective until something is done to reestablish original conditions.

Continuing with Fig. 1, the output of the last tube comprises a choke coil and condenser combination which tends to localize audio signal current flow (except in the case of lowest frequencies), thus limiting audio signal current in arm R_1 where, if present, it can cause regenerative phenomena owing to its ability to act on the grids and plates of preceding tubes.

The system of Fig. 1 is prevented from drifting (is stabilized) by the inclusion of the filament of tube VT_4, the 199 type for example, in the potentiometer R_1. The emission from this filament flows through the resistance R_2, and with the filament operated at a critical point for emission, a slight change in current through the filament changes the plate current and therefore the potential across resistance R_2. This potential across R_2 is the biasing potential for tube VT_1, and with a proper choice of constants a relatively small change in plate current of VT_3 produces a large change in the grid bias of VT_1.

[2] Nicholas Minorsky, *Jour. Franklin Institute,* **203**, No. 2, 181–209; February, 1927.

Obviously the degree of plate current of tube VT_3 is dependent upon its grid bias, but since its grid bias is obtained from the flow of plate current of tube VT_2 through resistance R_c', and so on through the system to tube VT_1, a change in the grid bias of VT_1 will carry through the system; that is, the grid bias of VT_1 is the controlling factor in determining the amount of plate current of VT_3.

Thus, the tying together of the plate current of VT_3 and the grid bias of VT_1 by a means opposing any change in the plate current of VT_3, the system is corrected against drift and the plate current of VT_3 can be set to a desired value and be maintained at substantially that value.

In using the 199 type of tube as the stabilizer VT_4, we prefer to operate at a temperature at which the filament is just on the threshold of emission (32 ma), so that the thermal inertia is great and requires an appreciable length of time for noticeable change of temperature. If the current in R_1 exceeds this amount the excess can be by-passed by a resistance shunt. With this selection of conditions any audio-frequency component flowing in R_1 alternates much too rapidly to affect the emission noticeably, but any change enduring more than a second or so will give the filament of VT_4 time enough to change temperature and emission sufficiently to correct the result of the change. Thus the arrangement is in effect a low-pass filter for everything beyond the order of several cycles per second, and consequently relieves the grid of VT_1 from any audio signal current flowing in the arm R_1.

The practical undesirabilities of high current in the potentiometer R_1 and the use of a rather costly tube as a stabilizer in the arrangement of Fig. 1 are overcome in the arrangement of Fig. 2.

In this Fig. 2 arrangement a proper choice of constants permits the substitution of a simple resistance arm R_1 for the potentiometer, and a standard output transformer can be used with the last tube, the audio circuit being completed by a condenser C_1.

The stabilizing effect is accomplished in a bridge formed by resistances R_1, R_2, R_3, and R_4. Since the object of drift prevention is to avoid any permanent displacement of the point of operation in the plate-current curve of the last tube, the plate current of the last tube is passed through resistances R_1 and R_2 to give opportunity for control thereby. The resistances R_3 and R_4, forming the other two arms of the bridge, are connected across the relatively unvarying potential of the filter supply, and the resistance values of the bridge are so chosen that with normal plate current in the output tube the potential between the balance points x and y of the bridge is of correct polarity and magnitude for a desired grid bias of VT_1. For example, R_1 may be calculated to develop 160 volts at 50 ma of current for a 250-type output tube, R_2, 10 volts at the same current; R_3, 8 volts at 1 ma; and R_4, the difference between the 8 volts of R_3 and the total potential of the supply source also at the 1-ma current of R_3. High resistance for R_3+R_4 will keep a desirable low current drain on the supply source.

With such an arrangement when anything happens to vary the plate current of the output tube the potential across R_2 likewise varies, while the potential across R_3 remains substantially constant. The result is the development of a counter grid-bias potential for VT_1 opposing a change in either direction in the plate current of the output tube. As a practical matter, the arrangement can be designed to be capable of maintaining the conditions of Fig. 2 against drift within very

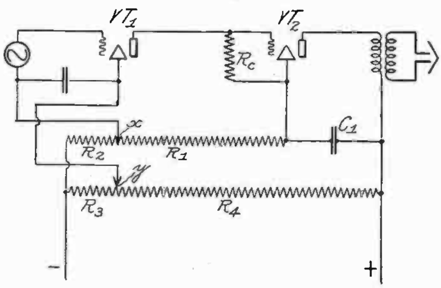

Fig. 2—Direct-coupled system with potentiometer eliminated and with bridge drift correction.

close approximation to a predetermined desired operating adjustment in the presence of a rather wide variety of conditions tending to cause drift.

One drawback of the arrangement of Fig. 2 is that hum currents, if the system is a-c operated, and audio signal currents are in assisting phase in the arms R_2 and R_3 with respect to the grid bias of VT_1, thus making it difficult to handle hum producing causes and signal current feed-back causes. Since only small resistance is needed in arms R_2 and R_3, success through by-passing of the hum and signal currents can be had only in the use of several hundred μf of by-pass condenser inserted, for example, between the points x and y. Since the difference of potential between these points is very small, it is not outside of the realm of practical possibilities that a small and cheap electrolytic condenser of sufficient capacity to be effective could be produced, but for the time being no such condenser with satisfactory life characteristics is known to be commercially available.

The hum and feed-back problems of Fig. 2 can be met by substituting for the by-pass condenser idea a thermal effect along with a re-arrangement of the bridge system, these features being included in the arrangement of Fig. 3.

Here the two major legs of the bridge are connected in parallel with respect to the plate current of the output tube, thus making the hum and audio current components in them of like direction and phase. Under these conditions if the arms R_2 and R_3 are substantially balanced for direct-current components in establishing the grid-bias potential for VT_1, likewise the hum and audio current components are substantially balanced.

In order to make attempted changes in the predetermined plate current of the output tube effective to produce a correcting change in bias potential of VT_1, a thermal effect is employed. For example, the

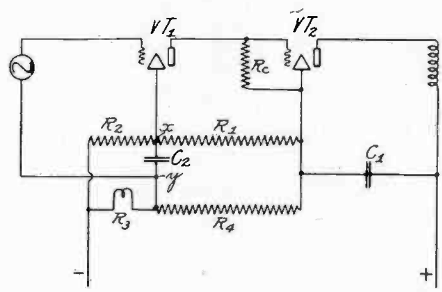

Fig. 3—Direct-coupled system having temperature-resistance drift correction.

resistance R_3 may be the filament of an ordinary 10-watt, 115-volt incandescent lamp caused to operate at a dull red heat by selecting the right amount of current for this operation in choosing the value of resistance R_4. At such a temperature the filament of the usual incandescent lamp changes its resistance pronouncedly with slight temperature changes either side of the selected point of operation. Since R_2 is an unvarying resistance, any change in the plate current of the output tube divided between the arms R_2 and R_3 will result in an unbalance to develop a correcting change in the bias potential of VT_1.

Due to the high thermal inertia of the filament of the incandescent lamp, the bridge only unbalances for effects lasting an appreciable fraction of a second, thus eliminating audio-frequency signal-current effects. For this reason no feed-back difficulty is had with the arrangement of Fig. 3. The condenser C_2 shown is merely a radio-frequency by-pass condenser which need be included only when the arrangement is intended to function as a carrier-current detector. Obviously an interchange of the grid and filament connections of VT_1 of Fig. 2 with respect to points x and y, and interchanging the lamp R_3 and resistance R_2 in Fig. 3 will reverse the action to stabilize a 3-tube or any odd-numbered tube system, the corrections shown being for even-numbered tube systems.

The hum resulting with a-c energizing of the arrangement of Fig. 3 may be made indeed low in the presence of extremely poor filtration, and the reason why such result is obtainable may be more readily explained by reference to the simple diagram of Fig. 4.

Fig. 4 is an arrangement similar to what is commonly termed the "Miller bridge," it being noted in the figure that the direct-current energizing components are supplied from the bridge arm. If attempt be made to balance out the hum of the fluctuating source S, it is found that when the grid potentiometer is moved far enough to

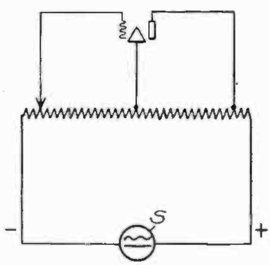

Fig. 4—Hum elimination explanatory diagram.

the left to have the grid fluctuating component neutralize the plate fluctuating component, the tube is in a practically blocked condition. However, in the present mode of operating the direct-coupled system resort is had to such high impedance conditions as to approach closely the blocked condition. In consequence the form of operation is inherently adapted to hum neutralization on the Miller bridge principle, so that the hum in the system of Fig. 3 is remarkably low.

The system of Fig. 3 has a limitation in that the amount of change of grid-bias potential of VT_1 in practical constructions is not sufficient to adequately compensate the system against the effects of strong carrier currents when using the system as a detector. The amount of compensation obtainable is however amply sufficient when the system is used as an audio amplifier where only limited cause for drift exists, such as changing from one tube to another and change in potential of energizing supply.

A system having an arrangement capable of any ordinarily required degree of stabilization is shown in Fig. 5, in this instance a screen-grid tube being used in the input position.

In the arrangement of Fig. 2, in trying to solve the signal feedback and hum current difficulties previously mentioned, attempt was made to filter these effects at the grid of the input tube by inserting therein a fraction of a megohm of resistance by-passed to the filament by a fraction of a microfarad of capacity. All these attempts were frustrated by motor-boating at the period of the filter employed. When the screen-grid tube became available it was immediately realized that the screen grid introduces hum and audio signal feed back, and like attempts to isolate this element by filtering also resulted in motor-boating.

Further investigation disclosed the fact that effective filtration without motor-boating could be obtained by inserting a filter im-

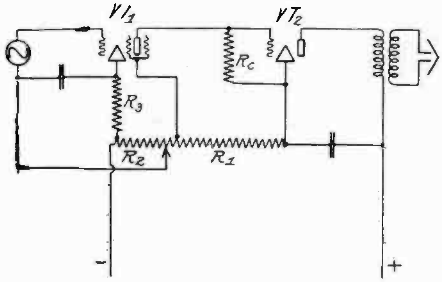

Fig. 5—Direct-coupled system including screen-grid tube, differentially acting drift correction and automatic grid-bias change.

pedance R_3 in a position common to the circuits of all three elements of the screen-grid tube, as shown in Fig. 5, the location bringing about a cancellation of the effects tending to motor-boating production.

A resistance R_3, combining as it does both the plate current and the screen-grid current, develops rather a large potential across its terminals when of a value to be effective for low-frequency current filtration. In order to prevent this fact resulting in a disadvantage and rendering the system inoperative, advantage was taken of it to form a bridge composed of resistances R_1, R_2, R_3, and the impedance of the tube combined with resistance R_c. For example, R_3 may have 20 volts developed across its terminals when the system is balanced. Then, merely for analysis, we may assume that it is desired to have the grid bias of VT_1 initially set at zero. In order to overcome the 20 volts of R_3 the grid return is made to a point on R_2 substantially 20 volts positive, thus cancelling the 20-volt potential across R_3 to leave an initial zero bias for VT_1, and to leave everything in balance. It is of course understood that any initial bias can be given to VT_1 by selecting the point of return of the grid circuit to a position on resistance R_2.

Now with the balance established, or any selected initial grid bias applied, a strong carrier current will cause pronounced rectification and consequent increase of plate current in VT_1, say of the order of 10 per cent. The potential across R_3 will consequently rise to approximately 22 volts, thus contributing 2 volts towards a negative bias on the grid in lieu of the previous zero bias. However, this is not yet the full action. There also takes place a decrease of plate current of the output tube, and since the potential across R_2 is a function of the plate current of the output tube, the differential potential developed in R_2 will be reduced. That is, where there was originally 20 volts across R_2 opposing 20 volts across R_3 to give zero bias with no incoming signal, we now have 18 volts in R_2 opposing approximately 22 volts across R_3 to give an effective bias of 4 volts. It is thus seen that the stabilizing arrangement of Fig. 5, including as it does a differential effect, permits of the development of a most powerful stabilizing reaction against drifting arising from very strong carrier currents.

While the problem of stabilizing is more than adequately solved by the stabilizing arrangement of Fig. 5 for all ordinary requirements, it isolates the grid of VT_1 from the hum source R_1, R_2, and consequently completely eliminates the Miller bridge arrangement for hum neutralization. However, because of the freedom of the direct-coupled system from phase shifting and harmonic production, it is admirably adapted to hum elimination by hum bucking. The arrangement of Fig. 6 shows one practice, and a very simple one, employed most effectively for hum balancing in combination with an extremely poor filter. It comprises merely a connection of the filament to a point of preferably variable selection on the resistance R_1 through a condenser C_{hb} of 1/10 μf, for example. If it were not for the variability in the commercial screen-grid tubes the connection to R_1 might well be once determined and left fixed.

Operational Characteristics of Some Proposed Direct-Coupled Systems

Almost an endless series of different characteristics and performances may be obtained from direct-coupled cascaded systems, through choice of elements in number and character, of circuit constants and potentials, so that the uses to which such systems may be put are manifold. In carrying out our work we have repeatedly been surprised and gratified with new and seemingly impossible results.

For example, Fig. 7 is a simple 2-tube system comprising a 224 screen-grid input tube and a 250 power-amplifier output tube, supplied with current from a single 281 half-wave rectifier tube. The general constants are shown or later stated. With this simple system over-all voltage amplifications ranging from 50 to a seemingly impossible 1000 are obtained through selection of constants and energizing potentials

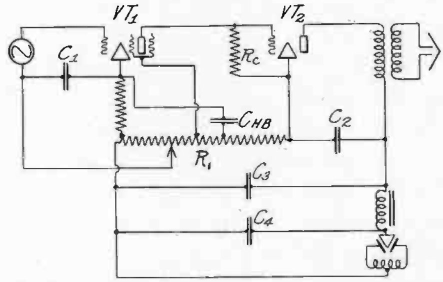

Fig. 6—Modification of figures to include hum balancing.

as later illustrated in part through two such changes in the graphs of Fig. 8. By adding a second 224 tube to make a 3-tube system the over-all amplification has been increased to 50,000 even with a 245 power-amplifier output, and there is apparently no reason why the 3-tube system cannot be worked up to a calculated over-all amplification of

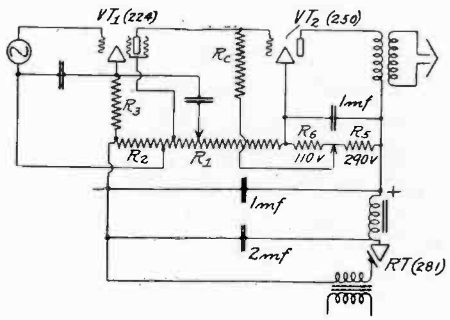

Fig. 7—Direct-coupled system designed for high potential on input tube electrodes.

250,000 with careful selection of optimum values in the case of each 224 tube, though this is a matter we have not as yet had time to determine practically.

To give a practical idea of the effectiveness of these systems, the 2-tube one gives good dynamic speaker volume on most of the New York broadcast stations at a point in the heart of the city using only antenna input, while the 3-tube one accomplishes the same result on a

3-inch coil loop reception for a number of stations. The 3-tube system, preceded only by a so-called band-pass filter, makes an extremely good broadcast receiver. In general, the 2-tube system is about 10 times as sensitive as the power detector, 1-stage audio system.

It is well to point out here that the damping of a tuned input circuit is extremely low in the direct-coupled system, and more so when the screen-grid type of tube is used because of elimination of the effect on the input circuit of the capacitive reactance of the output circuit. In other words, when using the system as a detector-amplifier good selectivity and resonant increase is had in the input circuit as compared to other forms of detection, thus lessening the amount of tuning needed in the preceding radio-frequency system if that is used. In fact, the selectivity obtained in the single circuit when coupled directly to an antenna is unusual.

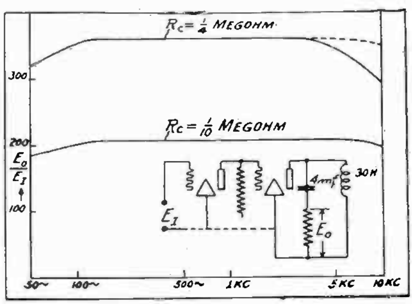

Fig. 8—Amplification frequency characteristics of two adjustments of system of Fig. 7.

In the case of three-electrode tubes the overall gain depends upon the μ of the tubes and the value of coupling resistance R_c, with the exception that with low values of R_c wide changes of μ do not make much difference. In going to screen-grid tubes the over-all gain further depends upon plate, screen-grid and grid potentials.

The two graphs of Fig. 8 show with the aid of logarithmic abscissas and linear ordinates the measured and plotted voltage gain throughout the entire audio range of the 2-tube system of Fig. 7, the system being the same for the taking of both graphs except for change in the value of coupling resistor R_c and suitable change of resistance of R_3 and screen-grid potential, 1/10 megohm being used in one case and 1/4 megohm in the other, as indicated on the graphs. The skeleton diagram accompanying the graphs shows and states the details of the output of the system employed in measuring for these graphs. In Fig. 7 the potential developed by the filter was 650 volts at 50 ma, 400 volts of this being across the 250 output tube and 250 volts across the arm R_2. Grid potential with the system at rest was about 2 volts, and screen-grid potentials were 45 and 30 volts respectively. A 400-μ 224 tube was used.

In order to operate on this occasion with the high potential of 180 volts on the plate of the 224 tube, the 400 volts across the 250 tube were divided into the 110-volt and 290-volt portions by high resistances R_6 and R_5 respectively, as shown, the high resistances not noticeably increasing the current drain on the filter. R_c was connected at this division, thereby adding 110 volts to the 250 volts in R_1 and R_2, a total of 360 volts to divide into 180 volts across coupling resistance R_c and the plate of the 224 tube, this equal division being what we term "symmetrical operation." Of course the 180 volts across R_c are too much for grid bias of the 250 tube, but the opposed 110 volts in R_6 reduces the overall grid bias to a satisfactory 70 volts. It might be added that the systems can be operated with a potential distribution on plate and across R_c equal to the normal bias potential of the succeeding power amplifier tube, as in Fig. 6, thereby not requiring the R_5 and R_6 resistances of Fig. 7. In this case only 140 volts are required across the resistance arm, thus making the filter output 540 volts for 250 tube operation.

The 1/10-megohm graph shows the most useful gain of 208 substantially uniform from 140 cycles to 5 kc with a loss of but 10 per cent at the low point of 50 cycles and a loss of but 6 per cent at the extreme range of 10 kc. These end droops can in large part be accounted for in the frequency-reactance relations of the output circuit, substantiating the theoretical constancy of the direct-coupled amplification *per se*.

The 1/4-megohm graph shows the much greater gain of 360 (80 per cent increase) substantially uniform from 140 cycles to 3 kc. Like the 1/10-megohm graph, it shows a 10 per cent loss at 50 cycles, indicating that the increase of R_c has no effect upon the low-frequency side. However, the 10-kc point shows an increase of loss to 16 per cent. This fact requires a little consideration, for it is obvious that if R_c be increased to the megohms order frequently used the high-frequency may become of serious proportions.

This fall-off is due in part to a feed-back effect. In the direct-coupled system the increasing of the resistance of R_c makes the feed back through the internal capacity of the non-screen-grid output tube increasingly effective and, being a capacitively reacting plate-circuit feed back at the high-frequency end for most output systems, the feed back decreases amplification to a greater degree with increase of R_c. Of course, if a screen-grid power amplifier becomes available we need give the feed back no further attention, there being none of this action in the screen-grid input tube, but for the time being properly chosen but simple feed-back neutralizing easily overcomes this effect in large degree. By way of example, the dotted portion of the 1/4-megohm graph shows the improvement had with a hastily adjusted neutralizer arrangement.

While some explanatory examples around a zero grid bias of the input tube are cited, in usual practice an initial bias of about 2 volts allows for the fact that the emission pressure in some tubes may be such as to start a grid current at 1 volt. In general the screen-grid potential may be low, as good operation may be had with only a few μa in the plate circuit and a too high screen-grid potential will materially reduce amplification. It is also necessary to adjust the screen-grid potential to operate near the mid point of its current curve, as is done in the case of all plate electrodes, since otherwise this additional member in the system may cause some severe unwanted rectification on its own account.

From what is explained in connection with arrangements for drift correction in direct-coupled systems, it may be seen that these effects, and those of the arrangement in Figs. 5, 6, and 7 in particular, may be used to advantage in the usual detection systems, and further are capable of automatically producing large voltage differences for automatic volume-control effects without the addition of an auxiliary tube. If there should be need for it, the drift correction responsiveness may be reduced to such low frequency that the system can be made capable of high amplification for frequencies as low as 1 cycle. Usual audio work allows plenty of margin in which to obtain drift compensation without interfering with the very lowest audio tones.

One very interesting characteristic is the ability to receive unmodulated CW signals without heterodyne for printer, tape or other relay operated recording, since the high-frequency rectifying action that carries through the system is of the square-wave type and ideal for the necessary result.

The mildness of the hum difficulties is apparent from examination of the rectifier and filter system constants of Fig. 7. Here a single-wave (281) rectifier is followed by a single-stage filter of 2 and 1 μf, respectively, separated by a 20-henry choke. The 2-μf condenser is really not used because needed for filtering but to develop the required high potential from the 281 tube. Another high-voltage 1-μf condenser is used in the signal circuit of the output tube. Even with this simple filter and half-wave rectifier, the hum is well within estimate of what is commercially tolerated. When it is appreciated from

Fig. 8 that the gain at 60 and 120 cycles is practically the same as elsewhere, the result is remarkable.

There is little or no difficulty with hum from induction since there is no effective magnetic pickup in the system, and wiring loops are easily taken care of. Even in the extremely high gain systems mentioned, electrostatic shielding is all that is necessary, and electrostatic shielding is simple and cheap compared with electromagnetic. Close location of parts is not at all a troublesome feature.

Reference to Fig. 7 also makes clear that there is plenty of high potential and current for energizing the tubes of a preceding radio-frequency amplifier without increased drain on the filter, and also for energizing the field coils of dynamic speakers, the current in the arm R_1 being adequate for this. The system also lends itself to push-pull operation as two complete systems in push-pull relation, or the equivalent of simple push-pull output tubes, but in view of the extremely fine characteristics we really see no need for push-pull for the reasons it is now so generally employed. Photoelectric cell operation becomes a simple and satisfactory matter through the medium of the very high gain amplifier.

In general we feel that direct-coupled systems offer unusual possibilities in space and cost savings, our estimate being that the present radio receivers, amplifiers, and like apparatus can be reproduced with improved quality at costs well below those now existing.

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NOTE ON DAY-TO-DAY VARIATIONS IN SENSITIVITY OF A BROADCAST RECEIVER*

By

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Summary—*A series of sensitivity measurements on a highly sensitive broadcast receiver over a period of one month indicates that large variations in sensitivity may occur. The importance of these variations in sensitivity is pointed out with particular reference to intercomparison of receiver measuring equipment and production testing of radio receivers. In this particular study, a high degree of correlation between relative humidity and sensitivity was found; i.e., days of high relative humidity were also days of low sensitivity and vice versa. This effect is probably attributable to increased losses in the radio-frequency transformers during periods of high relative humidity. It is shown that changes in sensitivity may be delayed as much as four days after the corresponding changes in relative humidity.*

Importance of the Problem

FOR THE intercomparison of radio receiver measuring equipment, it is customary to have a receiver measured under standardized conditions by the various laboratories concerned. The results are then compared, usually on the assumption that characteristics have remained unchanged over the total period of time involved. In a previous paper[1] by Van Dyck and Dickey it was stated that a 10 per cent variation in characteristics of a particular set was due to changes within the set itself as it was moved from one laboratory to another. However, no data have been furnished to show how this conclusion was reached. It is obviously important to recognize the magnitude of changes in characteristics and the conditions affecting them. It is only in this way that the true magnitude of experimental and systematic errors can be determined and the results of such intercomparison properly interpreted.

Some systems of production testing of radio receivers are based on comparison, either direct or indirect, of the product with a master set of approved characteristics. The reliability of such a system is dependent to a large extent on the retention of calibration by the master set.

In both of the above instances it is difficult, if not impossible, to attribute changes in sensitivity to any specific cause. In the case of the

* Dewey decimal classification: R161. Presented at organization meeting of the Cincinnati Section, September 16, 1929.

[1] Van Dyck and Dickey, "Tests of broadcast receiving sets," Proc. I. R. E., 16, 1530; November, 1928.

receiver which has been passed about from one laboratory to another, the elements of possible mechanical damage, actual change of characteristics, and errors attributable to the various measuring equipments enter into observed differences. It was therefore thought advisable to determine whether or not variations in sensitivity could be detected from day to day under what may be called "ideal conditions"; that is, with all measurements carried on under as nearly identical conditions as possible and with all factors likely to produce changes in sensitivity removed with the exception of those encountered in normal operation of the receiver.

Causes of Variations in Measured Sensitivity

The measured sensitivity of a receiver may vary from time to time, and under various conditions for any of the following reasons:

(1) lack of precision in the measuring system
(2) inaccurate tuning of the receiver
(3) circuit instability
(4) improper operating conditions
   (a) line voltage
   (b) input and load impedance
   (c) tube characteristics
(5) uncertain operating conditions such as:
   (a) misalignment (due to mechanical damage, condenser bearing play, movable control-grid leads, etc.)
   (b) variable contact resistances
   (c) temporary effects of temperature, moisture, etc.

Variations in sensitivity attributable to improper or uncertain operating conditions may be chiefly eliminated when all measurements are carried on in the same laboratory by an experienced operator, using precision equipment and adhering to a definite procedure. Under such conditions it may be reasonably assumed that errors are entirely experimental and of small magnitude.

Experimental Errors

Tuning. Experience shows that under such conditions, errors are chiefly due to inaccurate tuning. This accuracy is affected by the mechanical "smoothness" of the tuning system and by the rate of change of frequency with movement of the control knob. In order to determine the order of magnitude of tuning errors, the following test was performed. The sensitivity of a receiver of the same type as that used in this investigation was measured ten times in succession at each of three different carrier frequencies. Retuning of the receiver to the carrier frequency was involved in each measurement. The output level of the set was adjusted to about 100 mw while tuning, since small gains in response are more apparent when larger fluctuations of the output indicating device occur. The conventional normal output level of 50 mw was used for all sensitivity determinations. Table I gives the results of this test. This would indicate that the average error in tuning the receiver for maximum response is about 1 per cent.

Procedure

The receiver used was a commercial chassis employing 3 UY-224's, 2 UY-227's, 2 UX-245's and 1 UX-280 as radio-frequency amplifiers, detector and first audio, push-pull output stage, and rectifier, respectively. Tuning was accomplished by means of a three-gang condenser. The tubes used were of normal characteristics and had been aged about 20 hours prior to the test. No tubes were removed from the sockets after the test was started with the exception of the output tubes, thus minimizing the chance of indeterminate misalignment due to shifting of the position of the control-grid leads in the radio-frequency stages and possible damage to tubes through handling. The set was handled as carefully as possible during the process of setting up the test. Following a measurement, the receiver was carefully stored to prevent mechanical injury of any sort.

TABLE I

Carrier Frequency kc per second	Mean Deviation from Mean Sensitivity per cent	Maximum Deviation from Mean Sensitivity per cent
600	0.51	1.64
900	0.45	1.05
1500	1.28	4.13

The measuring equipment used, with the exception of minor changes, was as described previously in the Proceedings.[2] Briefly, the apparatus consisted of the standard signal generator and associated apparatus which is installed in the Receiver Development Laboratories of the Crosley Radio Corporation at Cincinnati. The equipment is capable of adjustment to a high degree of precision, thus providing a signal which may be readily duplicated as to magnitude and character from time to time. No question of the absolute accuracy of measurements was involved since comparative data only was required. The test consisted of 15 sets of sensitivity measurements spread over the period of August 5, 1929 to August 31, 1929. In the earlier portion of

[2] K. W. Jarvis, "Radio receiver testing equipment", Proc., I.R.E., **17**, 664; April, 1929.

the test, measurements were taken at 11 different carrier frequencies covering the broadcast band. Later measurements were taken at 6 carrier frequencies.

Results

From the very first, large variations in sensitivity were observed. On August 21st the set began to oscillate at 1100 and 1200 kc. There had been no previous indication of instability. The set was apparently stable on August 26th and remained so for the remainder of the month.

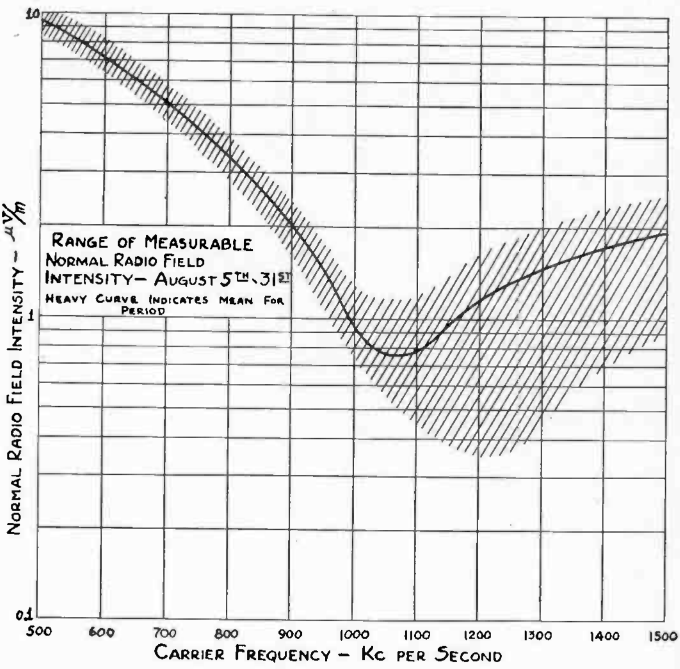

Fig. 1—Range of measurable normal radio field intensity.

Fig. 1 shows the total range of measurable normal radio field intensity for the period of the investigation. The heavy curve in the cross-hatched area represents the arithmetic mean normal radio field intensity. As can be seen, the maximum variations from the mean were from 20 to 70 per cent, being greatest over the most sensitive portions of the frequency range, that is, from about 1100 to 1500 kc. It should be remembered that the sensitivity of a receiver is inversely proportional to the normal radio field intensity.

Correlation with Humidity. Hourly readings of humidity during working days were available. From this data daily morning to morning two-day moving averages of relative humidity were computed. Considering the fact that nighttime variations in humidity were not considered and that relatively few sensitivity measurements were obtained, a rather high degree of correlation between relative humidity and normal radio field intensity was found. These data are presented in Fig. 2.

The upper group of curves represents daily humidity and field-intensity variations for frequencies of 600 and 800 kc, plotted as per cent deviation from the respective means for the month. The lower

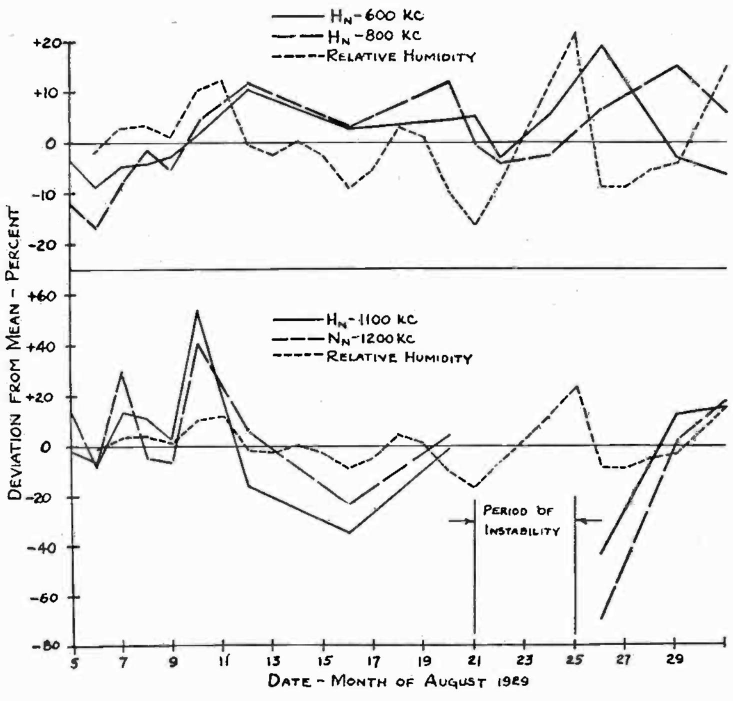

Fig. 2—Daily deviations from mean for month at 600, 800, 1100, and 1200 kc.

group of curves shows corresponding data for carrier frequencies of 1100 and 1200 kc. It should be noticed that the ordinate scale for the lower group of curves is twice that of the upper group.

Both groups of field-intensity curves follow relative humidity quite closely. In the case of the 600- and 800-kc curves, changes in field intensity are roughly proportional to changes in humidity. The effect of humidity is apparently delayed in the less sensitive portion of the range, the time-lag averaging about two days in the case of the 600-kc data and from two to four days in the case of the 800-kc data.

This time-lag is apparently very much less for the 1100- and 1200-kc group, the humidity and normal radio field intensity being practically in phase throughout the period of stable operation. It is interesting to note that the period of instability begins on the 21st of August when the relative humidity was at the lowest value for the month, and ends on the 25th when the humidity reached the peak for the month. It should be noted that the percentage changes in field intensity are from three to five times the corresponding percentage changes in humidity.

Fig. 3 summarizes the foregoing data and shows mean deviations

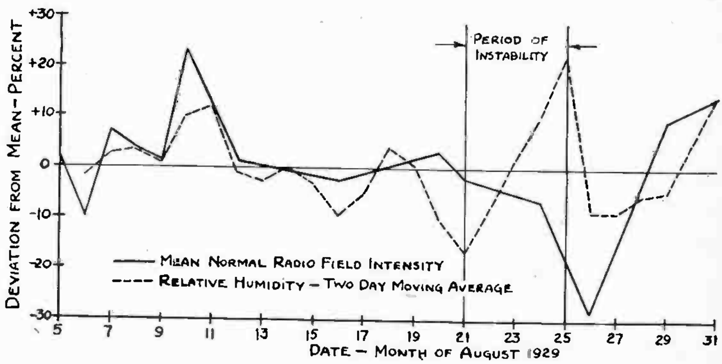

Fig. 3—Daily deviation of mean normal radio field intensity from mean for month.

from mean normal radio field intensity for the entire range of the receiver against corresponding humidity deviations.

Conclusions

The following conclusions may be drawn from the investigation:

(1) Broadcast receivers of high sensitivity may show large variations in sensitivity even when maintained under ideal conditions. The changes in characteristics may be sufficiently great to cause oscillation over the more sensitive portion of the frequency range.

(2) Changes in sensitivity appear to be highly correlated with changes in relative humidity in the negative sense: that is, periods of high sensitivity are generally periods of low relative humidity and vice versa.

(3) The effect of humidity changes may be delayed from one to four days, the time-lag being greater at frequencies of relatively low sensitivity.

(4) Changes in sensitivity with humidity are probably attributable to variable losses in the radio-frequency portion of the receiver.

(5) The observed changes in sensitivity, while highly important from the technical standpoint, are of small importance to the average listener, since usually they may be compensated for by adjustment of the volume control.

ACKNOWLEDGMENT

In conclusion, the writer wishes to acknowledge the valuable assistance of Miss Helen Klein in the taking of data and computation of results.

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CONSIDERATIONS IN SUPERHETERODYNE DESIGN*

By
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Summary—*Factors involved in the suppression of the characteristic double response of the superheterodyne are considered. Design details are given for the oscillator circuit, and oscillator-modulator coupling, as affecting the inherently uniform response characteristics. A method of aligning the circuits for single control purposes is given.*

DUE TO its inherently uniform selectivity and amplification over a tuning range, and stability of operation at high values of either factor, the superheterodyne method of selection and amplification approaches the characteristics of an ideal receiver. Notwithstanding the necessity for tubes and components which contribute nothing directly to the amplification, in practice it will be found that a properly designed superheterodyne can be built with less material, and in a smaller space, than other types of receivers for the same performance.

Suppression of Double Response

An obstacle which has, in the past, prevented the superheterodyne from more nearly approaching the ideal, is the difficulty of suppressing the double response due to the higher- and lower-frequency beats of signal and oscillator. The use of an "intermediate" frequency on the order of 400–500 kc cannot be considered as a means to this end, since it entails a sacrifice of the advantages of low-frequency amplification, as well as a reduction of the selectivity factor resulting from a reduced intermediate-frequency signal-frequency ratio. However, experience indicates that an intermediate frequency lower than 150 kc is not advisable. At this frequency, two tuned circuits before the modulator (first detector) will provide sufficient signal frequency selectivity to reduce the undesired response to a level below that of the component which unavoidably feeds through the circuit capacity to the modulator grid.

It can be seen that precautions must be taken to keep both capacitive and inductive intercircuit coupling at a low value, and the direct pickup of the modulator grid circuit must be minimized by thorough shielding. With antenna disconnected a strong signal should be barely perceptible. This condition is readily obtainable in practice.

* Dewey decimal classification: R134.75.

Even after the modulation of the interfering signal has been reduced to inaudibility, there will still remain the heterodyne whistle produced by the difference of the oscillator beats with the desired and interfering signals. If the percentage modulation of the interfering signal is low, this whistle may be of sufficient intensity to cause objectionable interference on the desired signal. It will be discerned that the frequency of the whistle thus produced can be controlled by varying the intermediate frequency slightly. In this manner, if the frequency of the whistle be made 5000 cycles, it will fall in intensity,

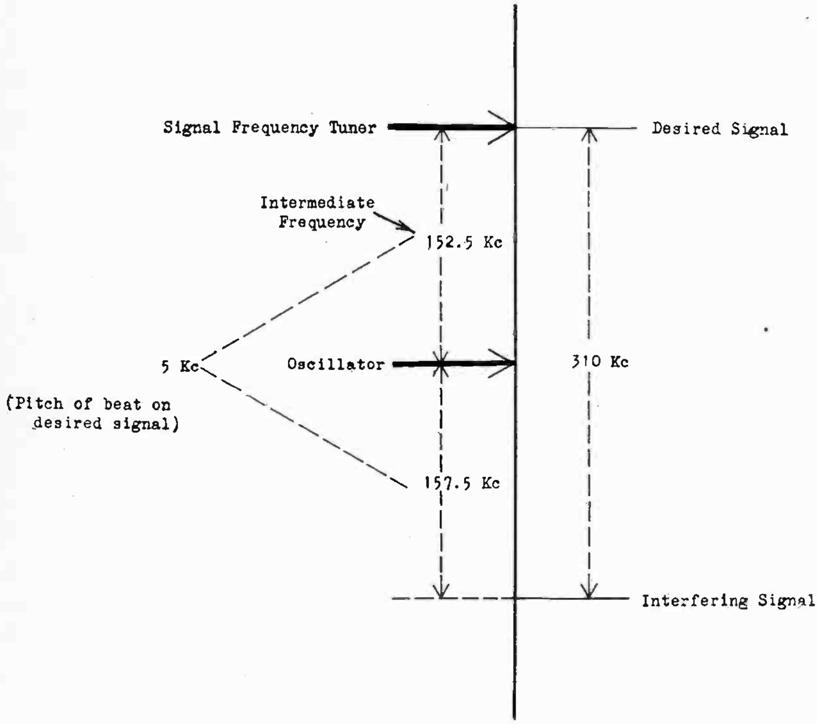

Fig. 1—Frequency relations between desired and undesired beats.

due to the drop in the sides of the selectivity curve of the intermediate-frequency amplifier. At the same time, one of the adjacent channels 10 kc from the desired channel forms another 5000-cycle beat when the oscillator is tuned to this channel. This is by virtue of the fact that on one channel the interference-frequency oscillator-frequency difference is 5 kc more than the intermediate frequency, and on the other channel, 5 kc less. The two audible beat frequencies are equal only at 5000 cycles, for a 10-kc channel separation. Any higher frequency on one channel will result in a lower one on the other. It can be seen that if the intermediate frequency is given any value ending in 2.5 or 7.5 kc, this optimum figure of 5000 cycles will result, as shown diagrammatically in Fig. 1. This procedure places the modulation of the interfering signal midway between the channels, where it is in a position to cause least interference. The high-frequency attenuation of the usual audio systems further reduces the beat-frequency interference. It is not economically practicable to reduce the interfering signal to negligible values entirely in the signal frequency tuner, due to the difficulty of reducing the circuit capacity to a favorable value. However, the interference from the highest field-strength signals which are likely to be encountered may be minimized by adjusting the intermediate frequency to the proper value, as described. Little difficulty is had in maintaining stability of the various constants, to allow effective operation of this method.

Oscillator Design

Unless the oscillator voltage on the modulator grid remains above an optimum value over the frequency range of the oscillator, the inherently uniform response of the superheterodyne will depart from normal. This uniformity can be preserved by the selection of a suitable oscillator circuit, and the proper design of coupling between it and the modulator. The oscillator level cannot be raised as a whole to compensate for a deficiency at one end of the range, as this will cause the modulator to be overloaded at the opposite end. The design of most "kit" superheterodynes in past years was defective in this respect. However, the modulator may be made capable of handling a wider range of grid voltages by providing it with automatic grid bias. An increase in oscillator voltage will then cause a corresponding increase of grid bias, and prevent the grid from swinging positive. The efficiency of the modulator is also considerably improved with automatic grid bias. The coupling between oscillator and modulator must, of course, be kept below the value at which the tuning of the latter drags the oscillator at the higher frequencies.

In Fig. 2 are shown curves of response against frequency for various oscillator circuits and coupling combinations. The response is plotted in terms of modulator plate current. Curve A is for a Hartley oscillator coupled to a few turns in the grid return of the modulator. B is the same oscillator coupled loosely to the modulator grid tuned circuit. C represents a tuned grid, and D a tuned plate oscillator with the same coupling. E shows the latter with the addition of automatic grid bias on the modulator.

The use of a properly selected grid leak and condenser is important if maximum oscillator efficiency and uniformity are to be obtained. An oscillator operating at low efficiency is more subject to frequency change from varying voltages. Better uniformity of efficiency over a frequency range will be obtained with large grid condensers; on the order of 0.005 μf.

It can be seen that the use of a non-uniform signal-frequency amplification stage will be detrimental to the over-all uniformity. It will be found, however, that the effect of one stage is negligible, even when the plate inductance is kept at a low value as a means of preventing oscillation.

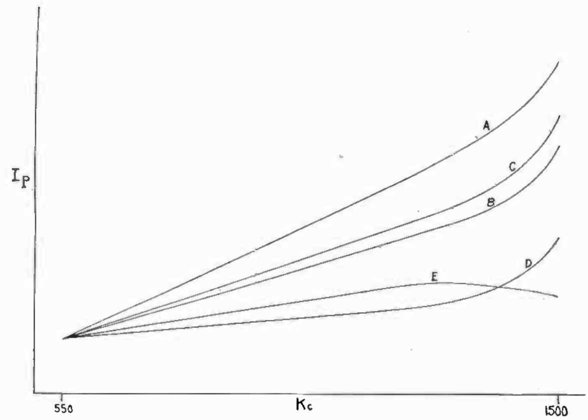

Fig. 2—Response-frequency characteristics of various coupling combinations.

While amplification before the modulator is not primarily intended to increase sensitivity, a certain amount of amplification at this point is desirable. Due to the fact that the oscillator output contains some modulation due to tube noise and supply voltage ripple, this is passed on to the demodulator (second detector) the same as the modulation of the signal, and appears in the audio amplifier as hiss and hum. The hum, which can be kept at a low value in a well-designed oscillator, is usually negligible; and the hiss is appreciable only when the ratio of signal and oscillator voltages on the modulator grid is large; i.e., when signals are weak. Since amplification before the modulator reduces this ratio, the oscillator noise is reduced in proportion. For the same reason, volume should be controlled after the modulator, so that signal voltages are as large as possible at the modulator grid.

At an intermediate frequency of 150 kc, it is practicable to operate the oscillator only on the higher-frequency side of the signal, when the oscillator range is to be aligned with that of the tuned circuits for single-control purposes. This is on account of the larger capacity ratio necessary to cover the lower-frequency beat range. The same type variable condenser is used for the oscillator as for the tuned circuits, but with a smaller inductance. The oscillator frequency range is then shortened by a fixed condenser in series with the tuning condenser until the setting for the proper beat with a given frequency coincides with that of the tuned circuits.

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THE PIEZO-ELECTRIC RESONATOR IN HIGH-FREQUENCY OSCILLATION CIRCUITS*

BY

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Part I. Motional Admittance of the Piezo-Electric Resonator†

Summary—*Cady developed theoretically the motional admittance circle diagram of the piezo-electric resonator. The object of the first part of the present paper is an experimental verification of Cady's theoretical considerations regarding motional admittance.*

The effect of an air-gap between the resonator and the electrodes upon the motional admittance is also studied theoretically and experimentally. The determination of the equivalent electrical constants of the piezo-electric resonator with an air-gap is developed by a simple mathematical treatment. The relation between motional admittance and size of electrodes is discussed, as well as the experimental arrangement when a high voltage is to be impressed upon the resonator.

1. INTRODUCTION

JUST AS it is very important to study the telephone receiver from the point of view of a motional impedance, it is also very important and convenient to treat the characteristics of the piezo-electric resonator with special reference to its motional admittance for the resonance of mechanical vibration.

From the properties of the motional admittance circle diagram of the piezo-electric resonator, we can determine its equivalent electrical constants. These equivalent electrical constants are very important for the scientific study of the characteristics of the resonator itself as well as of the electrical circuits containing the resonator, such as the piezo-electric oscillator and the piezo-electric frequency stabilizer.

Any simple and accurate method of measuring the motional admittance is so useful that the writer desires to treat in the following some new measuring methods as well as some experimental results.

The writer has studied the motional admittance of resonators for the following special cases:

(1) The apparent equivalent electrical constants of the resonator, when an air gap exists between the crystal and the electrodes, are given

* Dewey decimal classification: R214. This investigation was done in Tohoku Imperial University at Sendai, Japan, with aid from Saito Hô-On Kai (the Saito Gratitude Foundation). The remaining parts of the paper, on the piezo-electric coupler, oscillator, and frequency stabilizer, will appear in the May issue of the PROCEEDINGS.

† This part is a translation of a paper, written previously in Japanese. (*Jour. I. E. E.* of Japan, No. 466, May, 1927.)

simply by mathematical treatment of the equivalent circuit, and the result is fairly well verified by experiment.

(2) The diameter of the motional admittance circle is approximately proportional to the square of the electrode area, and the natural frequency of the resonator increases as this area diminishes.

(3) By means of two pairs of electrodes, connected diagonally, we can change the mode of the resonant vibration from its fundamental into its first harmonic, and also by the same principle, the original first harmonic vibration of a resonator made of a twinned crystal of quartz can be changed into the fundamental vibration corresponding to its length.

(4) The more the amplitude of the resonant vibration is increased, the more the mechanical loss increases with the result that the diameter of the motional admittance circle diagram decreases remarkably.

(5) When the amplitude of the mechanical vibration at resonance is intense, the stress at the node of vibration becomes so large that the electric field intensity in the air-gap between the resonator and the electrode can attain a value high enough to start there a bluish discharge. This phenomenon leads us to the idea of the production of high voltage by means of a piezo-electric resonator.

(6) Many interesting phenomena are observed in experiments with the resonator at a comparatively high voltage, such as the production of an audible sound, or of a mechanical force exerted by the resonator. The writer also describes some experiments made by means of a cathode-ray oscillograph in order to observe the dynamic characteristics of the resonator.

2. Motional Admittance of the Piezo Resonator and the Equivalent Electrical Constants

We must define first the motional admittance of the piezo-electric resonator, which is cut from a quartz crystal with the dimensions [b(width), t(thickness), l(length)] as shown in Fig. 1.

Now let us suppose that this resonator is placed freely between the electrodes without any air-gap, the electrodes being perpendicular to its electrical axis, and that any potential difference V, of a frequency which is nearly equal to the natural frequency of mechanical resonance, is applied across these electrodes.

When we consider the longitudinal vibration of the resonator, the mathematical treatment is comparatively easy, as shown by Cady[1] and others.

[1] Cady, Proc. I.R.E., 10, 83; January, 1922.

The piezo-electric stress caused by the applied potential difference V is equal to $\epsilon V/t$ and *it acts on the resonator uniformly along the length.* ϵ is the piezo-electric constant. By the law of superposition, this uniformly distributed stress may be represented by two forces acting on the ends in opposite directions with the value $(\epsilon V/t)bt$. Therefore the force making the resonator vibrate longitudinally is

$$F = 2b\epsilon V. \tag{1}$$

Letting x, z_m be the displacement and the mechanical impedance of the resonator respectively, referred to the end points, the velocity of the vibration at the end is given simply by the following equation; the

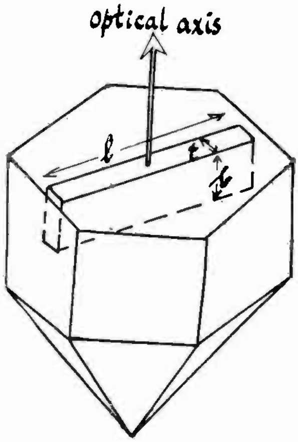

Fig. 1—Orientation of crystal plate.

symbol t for *time* in the differential expression dt must of course be distinguished from the same symbol as used elsewhere for *thickness.*

$$v = \frac{dx}{dt} = \frac{F}{z_m} = \frac{F}{r + j\left(\omega M - \frac{S}{\omega}\right)}. \tag{2}$$

In this equation r, M, and S denote respectively the mechanical resistance, inertia, and stiffness of the crystal. They correspond to Cady's N, M, and g.

The total displacement is clearly equal to $2x$ and it includes the equilibrium elongation $\epsilon lV/Gt$ where G is Young's modulus for quartz, but this value is so small compared with the elongation due to mechanical resonance that we may neglect it in the study of the motional admittance of the piezo-electric resonator. As the strain is $2x/l$, a polarization of magnitude $P_1=2\epsilon x/l$ is produced as the result of the piezo-electric converse effect. Moreover, there is another polarization due to the potential difference V, i.e., $P_2=kV/4\pi t$.

Consequently, when the impressed potential difference varies sinusoidally, the electric current in the external electric circuit is found as follows:

$$i=bl\frac{d(P_1+P_2)}{dt}. \tag{3}$$

Combining (2) with (3), we have

$$i=2b\epsilon\frac{F}{z_m}+\frac{kbl}{4\pi t}\cdot\frac{dV}{dt}=Y_m\cdot V+C_d\frac{dV}{dt}. \tag{4}$$

From this result, together with (1), we can now define the motional admittance Y_m and the normal capacity C_d of the piezo-electric resonator as follows:

$$Y_m=\frac{(2b\epsilon)^2}{z_m}, \qquad C_d=\frac{kbl}{4\pi t}. \tag{5}$$

Y_m is the motional admittance of the C_m, L_m, R_m branch in Fig. 2.

It is evident that the locus of the ends of the vectors representing the motional admittance for a variable frequency is a circle.

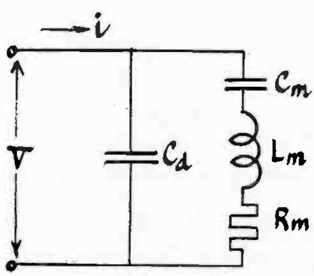

Fig. 2—Equivalent circuit of a piezo-electric resonator.

The relation between the mechanical impedance Z_m and the physical constants of the resonator is based upon the assumption that the mechanical loss is only because of the viscosity of the crystal.

$$\left.\begin{aligned} M&=\frac{1}{2}\rho blt,\\ S&=M\omega_0^2=4M\pi^2f_0^2=\frac{\pi^2Gbt}{2l},\\ r&=\frac{\pi^2Q\rho bt}{2l}. \end{aligned}\right\} \tag{6}$$

In (6), ρ is the density and Q is Cady's "viscosity" of quartz. ω_0 and f_0 refer to crystal resonance. Considering (4), we can represent the resonator by the equivalent electrical circuit (4), (5), (6) as shown in Fig. 2, where the constants of the series resonance circuit corresponding to the motional admittance are

$$\left.\begin{aligned} Z_m &= \frac{1}{Y_m} = \frac{z_m}{(2b\epsilon)^2}, \\ R_m &= \frac{r}{(2b\epsilon)^2} = \frac{\pi^2 Q\rho}{8\epsilon^2}\left(\frac{t}{bl}\right), \\ L_m &= \frac{M}{(2b\epsilon)^2} = \frac{\rho}{8\epsilon^2}\left(\frac{lt}{b}\right), \\ C_m &= \frac{(2b\epsilon)^2}{S} = \frac{8\epsilon^2}{\pi^2 G}\left(\frac{bl}{t}\right). \end{aligned}\right\} \tag{7}$$

For the quartz resonator, the equivalent capacity C_m is very small and is given approximately by

$$C_m = 0.0025\left(\frac{bl}{t}\right)\mu\mu\text{f}. \tag{8}$$

For some purposes (see below) it is more convenient to represent the C_m, L_m, R_m branch of the resonator by a capacity (positive or negative) C_m' in parallel with a pure conductance g_m. Both C_m' and g_m are thus functions of the frequency, and C_m' changes sign on passing through resonance. These two quantities are analogous to Cady's C_1'' and R_1''.*

3. Methods of Determining the Motional Admittances

It is, of course, possible to find the equivalent electrical constants of the resonator by measuring directly the current through the resonator by means of a thermojunction.[2,6] Also, the a-c bridge connection, as shown in Fig. 3, is applicable, but it has a drawback, in that a variable non-inductive high resistance is required.

In the following the writer intends to deal with some new and simple methods of determining motional admittance.

(1) Method A. Substitution method by means of the tube voltmeter.

The circuit is shown in Fig. 4. The oscillator on the left side must be a so-called constant-frequency oscillator, unaffected by any causes such as filament-current variation or plate-voltage variation.

* Cady, Proc. I.R.E., 10, 103; April, 1922.
[2] Cady, Proc. I.R.E., 2, 83; April, 1922.
[6] Dye, *Proc. Phys. Soc.* (London), 38, August, 1926.

We must first measure by the beat method the slight variation of frequency near the resonant point of the resonator corresponding to a small change of the precision condenser C of the oscillation circuit.

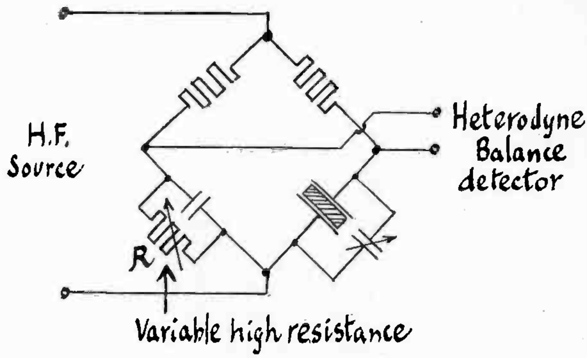

Fig. 3—High-frequency Wheatstone bridge.

Another precise tuning condenser C_2, which is connected across the main condenser C_1 of the receiving resonance circuit, must be of such value as to measure the variation of the apparent capacity of the resonator.

In the discussion below we consider the piezo-electric resonator as replaced by the equivalent parallel capacity G_m' and conductance g_m defined above, together with the geometric capacity C_d.

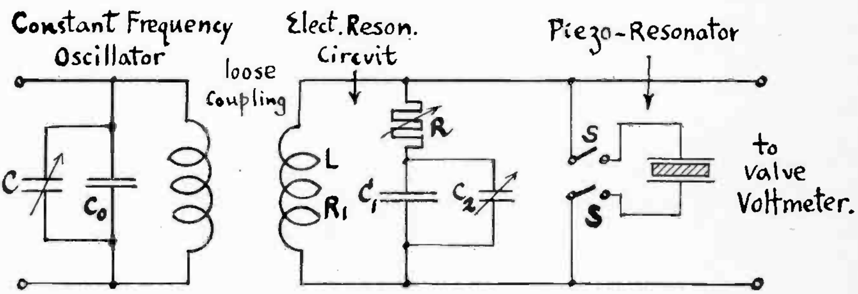

Fig. 4—Measuring circuit arrangement for method A.

The method of measurement is as follows: First, closing the switch S, that is, connecting the resonator across the electrical oscillation circuit, and adjusting the precision condenser C_2 we observe the maximum deflection of the tube voltmeter at the resonant point. Next, opening the switch, we again vary the precision condenser C_2 by the amount $\Delta C_2 = C_d + C_m'$ to obtain resonance for the new condition, and increase the variable non-reactive resistance by inserting R ohms in order to make the resonant deflection of the valve voltmeter the same as before. Thus we can find the equivalent capacity ΔC_2 from the difference between two observed values of the precision condenser C_2; and also the equivalent conductance g_m of the resonator, at the frequency employed, from the increased value of the resistance R by the following equation:

$$g_m = R\omega^2(C_1+C_2+C_d+C'_m)^2 \doteq R\omega^2(C_1+C_2)^2. \tag{9}$$

This equation is derived by equating the expressions for the total impedance to the right of LR, Fig. 4, with switch S closed and open respectively. The last part of the equation is an approximation, based on the assumption that C_d and C_m' are relatively small quantities.

Similarly, changing the frequency step by step, we can obtain the motional admittance circle diagram. As an approximation, we may use the following equation, for C_1 is usually much larger than C_2:

$$g_m \doteq R\omega_0^2 C_1^2 \tag{10}$$

Consequently we can find the value of R_m and the damping constant from the diameter $g_{\max}$ and the quadrant angular velocity respectively of the observed motional admittance circle diagram, and hence the equivalent electrical constants may be given as follows:

$$\left.\begin{aligned} R_m &= \frac{1}{g_{\max}}, \\ L_m &= \frac{R_m}{2\Delta} = \frac{R_m}{\omega_2-\omega_1}, \\ C_m &= \frac{1}{\omega_0^2 L_m}, \end{aligned}\right\} \tag{11}$$

where Δ, the damping constant $= (\omega_2-\omega_1)/2$.

A few remarks concerning this substitution method may be appropriate.

(a) One example of the experimental results is shown in Fig. 5, (A), (B). The latter is the experimentally obtained motional admittance circle diagram of resonator No. 2, the dimensions of which are $l=5.72$ cm, $b=0.78$ cm, $t=0.20$ cm, and the natural wavelength, 6070 meters approximately.

Curve I represents the relation between the tube voltmeter deflection and the frequency, under the condition that the electrical resonance circuit is kept constant. Therefore this curve represents the absorption effect of the resonator on account of its mechanical resonance, and the writer wishes to call it the *inverted resonance curve* for the piezo-electric resonator. Curve II corresponds to the case when the precision variable condenser C_2 is varied in order to hold the condition of electrical resonance. The motional admittance circuit diagram shown in Fig. 5 (B), is derived from the relation between R and ΔC_2 of the directly observed values in the experiments. Now, as $\omega_0 = 304{,}000$ and $C_1 = 2490$ $\mu\mu$f, two values of the diameters of this circle in the directions of the axes are $g_{max} = 14 \times 10^{-6}$ mho, and ω_0

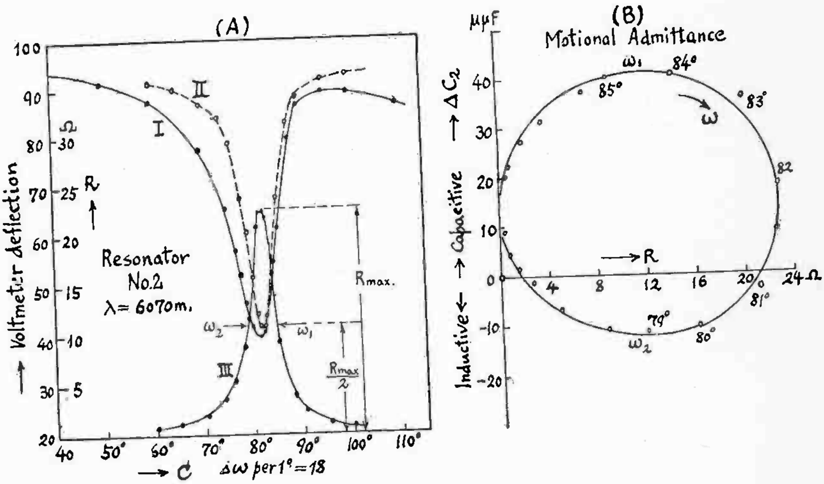

Fig. 5—Experimental result by method A.

$(\Delta C_2)_m = 15 \cdot 10^{-6}$ respectively, which shows that the observed locus is very nearly circular.

(b) While the observation of the resistance of R can be made very accurately, C_2 cannot be so precisely observed, especially when the damping at resonance is large. Therefore it appears preferable to determine the damping constant from the relation between R and ω of curve III of Fig. 5 (A), in which the ordinates are values of R, Fig. 4.

(c) As (10) shows, the smaller the condenser C_1, the larger becomes the value of R, with the result that $R\omega_0^2 C_1^2$ is equal to g_m, but there is no appreciable change in ΔC_2. In the following table, the maximum value of R at the resonant point is recorded for the different values of the condenser C_1.

(d) This method is very simple and it is unnecessary to measure the electrical constants of the inductance coil L or to calibrate the tube voltmeter. In our experiments, we use as a variable resistance Campbell's constant inductance variable resistance.

But this method has two drawbacks. First, it is necessary to use a constant-reactive or non-reactive variable resistance, and secondly, the frequency of the oscillator must be kept constant, unaffected by any causes except the variation of the condenser C, Fig. 4, for the comparatively long time required for measurement. These conditions

TABLE I

$C_1 \mu\mu$ f	2400	4200	6100
R_{max} ohms	22	7.4	3.7
g_{max} mho $\times 10^{-6}$	11.7	12.0	12.7

become more difficult as the frequency increases. It may take twenty minutes or more in order to observe the complete circle diagram of the motional admittance, and therefore even a slight gradual variation of the frequency of the oscillations is not permissible. In order to overcome these difficulties, the author devised the following second method.

(2) Method B. Inverted resonance curve method.

The circuital arrangement is very simple and is shown in Fig. 6. We must first calibrate the valve voltmeter and measure the effective resistance R_1 of the inductance coil L at a frequency nearly equal to the

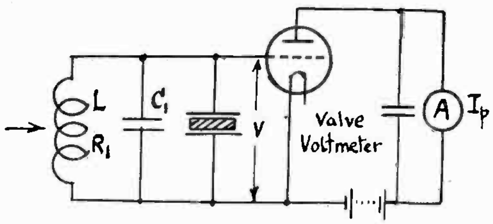

Fig. 6—Circuits for method B.

natural frequency of the resonator. In this method it is only necessary to observe as quickly as possible the inverted resonance curve of symmetrical shape as shown in Fig. 7, curve I.

Curve II is obtained by inverting curve I. Now it may be said that, within the narrow range of frequency near the natural frequency f_0 the electrical circuit of C_1 and L is approximately always in the resonance condition with the result that the terminal voltage v across the resonator is given by the following equation, which is approximately correct so long as C_1 is large:

$$v \doteq \frac{e}{j\omega_0 C_1} \cdot \frac{1}{R_1 + \dfrac{Y_m}{\omega_0^2 C_1^2}} \tag{12}$$

where e is the e.m.f. impressed on the inductance coil and may be considered as a constant unaffected by the slight variation of frequency near f_0, and R_1 is the effective resistance of the coil at the frequency f_0. Consequently we have

$$\frac{1}{v} \doteqdot \frac{j\omega_0 C_1}{e}\left\{R_1+\frac{1}{\omega_0^2 C_1^2}\left(\frac{1}{R_m+j\left(\omega L_m-\frac{1}{\omega C_m}\right)}\right)\right\} \tag{13}$$

This equation shows that curve II, representing the reciprocal of v, consists of a constant part of a value which we call c and a variable part which is similar exactly to a resonance curve and has a maximum value r.

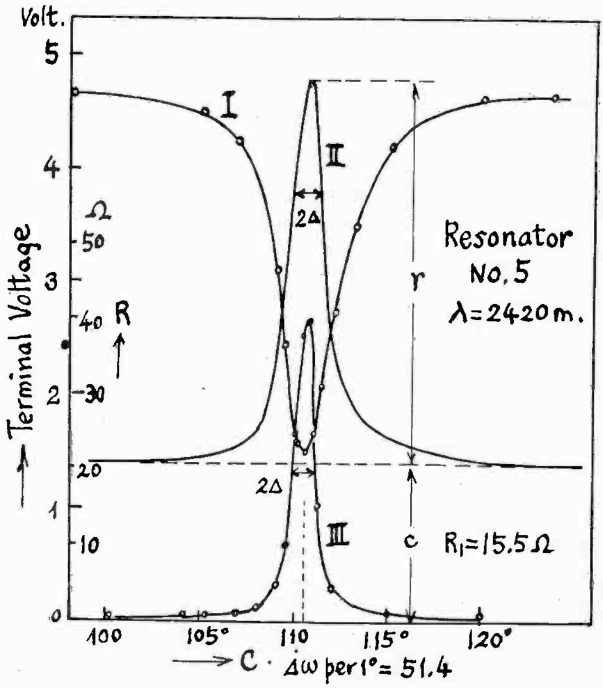

Fig. 7—Experimental result by method B.

As shown by (13), the apparent circuit resistance, which is increased as a result of the mechanical resonance of the piezo-electric resonator when close to resonance, is approximately equal to $1/R_m\omega_0^2 C_1^2$, and this value must according to Fig. 7 be equal to $R_1 r/c$, and corresponds to R_{max} in the previous method. Hence the effective resistance of the resonator is found by

$$R_m = \frac{c}{\omega_0^2 C_1^2 R_1 r}. \tag{14}$$

Moreover, the damping constant Δ may be found by the ordinary method from the shape of the resonance curve, and consequently the values of L_m and C_m are found easily by (11).

In this example of Fig. 7, $R_1 = 15.5$, and $R_1 r/C = R_{\max} = 36$ ohms; the value of the maximum R obtained by the previous method is 40 ohms, and the damping constants obtained by the two methods are in agreement.

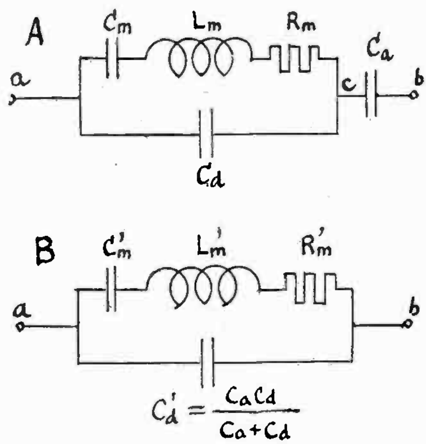

Fig. 8—Equivalent circuit of a resonator with an air-gap.

4. The Apparent Equivalent Electrical Constants of the Piezo-Electric Resonator with an Air-Gap

Dye[6] has verified experimentally that the equivalent circuit of the piezo-electric resonator with an air-gap between the electrodes and the crystal may be represented simply by the circuit shown in Fig. 8(A), where C_a is the electrostatic capacity of the air-gap.

It may be more convenient to represent it by an alternative equivalent electric circuit such as shown in Fig. 8(B).

Our problem is to find the relation between the equivalent constants of the resonator with air-gap and those of the resonator without gap, that is, the effect of the air-gap upon mechanical resonance.

(A) Letting $\alpha = R_m \omega C_m$, $\theta = 1 - (\omega/\omega_0)^2$, we have as the impedance of the resonator itself

$$Z_{ac} = \frac{1}{\omega C_d} \frac{\alpha - j\theta}{\left(\frac{C_m}{C_d} + \theta\right) + j\alpha} \tag{15}$$

[6] loc. cit.

The total impedance of the resonator in series with an air-gap becomes

$$Z_{ab}=Z_{ac}+\frac{1}{j\omega C_a}=\frac{1}{\omega C_d C_a}\frac{\alpha(C_d+C_a)-j[\theta(C_d+C_a)+C_m]}{\left(\frac{C_m}{C_d}+\theta\right)+j\alpha} \tag{16}$$

Therefore, the apparent motional admittance Y_m' is given according to Fig. 8 (B) by

$$Y_m'=\frac{1}{Z_{ab}}-j\frac{\omega C_d C_a}{C_d+C_a}=\frac{\omega C_m C_a^2}{(C_d+C_a)^2\left[\alpha-j\left(\theta+\frac{C_m}{C_d+C_a}\right)\right]}. \tag{17}$$

Consequently, the resonance point is given by the value of θ for maximum admittance Y_m'

$$\theta=1-\left(\frac{\omega}{\omega_0}\right)^2=-\frac{C_m}{C_d+C_a},$$

or

$$\omega^2=\omega_0^2\left(1+\frac{C_m}{C_d+C_a}\right),\quad \text{or } \omega\doteqdot\omega_0\left[1+\frac{C_m}{2(C_d+C_a)}\right]. \tag{18}$$

We may rewrite Y_m' in the following form

$$Y_m'=\frac{1}{Z_m'}=\frac{1}{R_m'+j\left(\omega L_m'-\frac{1}{\omega C_m'}\right)}. \tag{19}$$

Then

$$R_m'=\frac{\alpha(C_d+C_a)^2}{\omega C_m C_a^2}=R_m\left(1+\frac{C_d}{C_a}\right)^2=R_m\left(1+\frac{kl'}{t}\right)^2. \tag{20}$$

where l' = air-gap length, t = thickness of resonator.
Rewriting (17)

$$\begin{aligned}\omega L_m'-\frac{1}{\omega C_m'}&=-\theta\frac{(C_d+C_a)^2}{\omega C_m C_a^2}-\frac{C_d+C_a}{\omega C_a^2}\\&=\omega\frac{(C_d+C_a)^2}{\omega_0^2 C_m C_a^2}-\frac{1}{\omega}\left[\frac{C_d+C_a}{C_a^2}+\frac{(C_d+C_a)^2}{C_m C_a^2}\right].\end{aligned} \tag{21}$$

Consequently we get the following results

$$L_m' = \frac{1}{\omega_0^2 C_m}\left(1+\frac{C_d}{C_a}\right)^2 = L_m\left(1+\frac{C_d}{C_a}\right)^2 = L_m\left(1+\frac{kl'}{t}\right)^2 \tag{22}$$

$$C_m' = \frac{C_a^2}{(C_d+C_a)\left(1+\dfrac{C_d+C_a}{C_m}\right)} = C_m\frac{C_a^2}{(C_d+C_a)(C_d+C_a+C_m)} \tag{23}$$

$$\Delta' = \frac{R_m'}{2L_m'} = \frac{R_m}{2L_m} = \Delta. \tag{24}$$

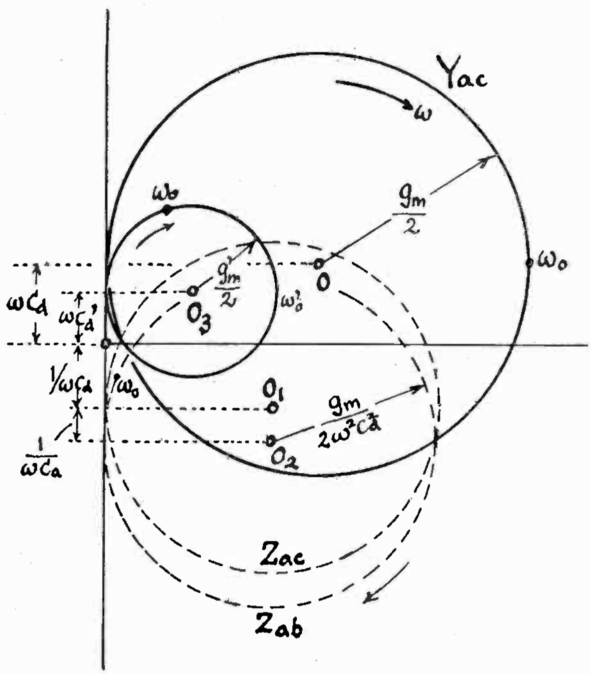

Fig. 9—Graphical method of obtaining a circle diagram of a motional admittance.*

* The circle O_1 is the locus of vectors which are the reciprocals of the vectors of circle O, that is O_1 is the circle diagram of the impedance $Z_{ac}=1/Y_{ac}$. Circle O_2 has vectors $Z_{ac}-j/\omega C_a = Z_{ab}$, that is, it is the diagram for the entire network Fig. 8(A) or 8(B). The reciprocal of these vectors, $Y_{ab}=1/Z_{ab}$, has as its locus the circle O_3. The radius of the circle O is $g_m/2$; that of circles O_1 and O_2 is $g_m/2(\omega C_d)^2$; that of circle O_3 is

$$\tfrac{1}{2}g'_m = \tfrac{1}{2}\frac{g_m/(\omega C_d)^2}{\dfrac{1}{\omega^2}\left(\dfrac{1}{C_d}+\dfrac{1}{C_a}\right)^2} = \tfrac{1}{2}g_m\left(\frac{C_a}{C_a+C_d}\right)^2.$$

As (18) and (20) show, the natural frequency of the resonator increases and the motional admittance circle diagram diminishes as the air-gap increases, and the maximum change in frequency, when $C_a=0$, is given by

$$\Delta\omega_0=\omega_0\frac{C_m}{2C_d} \tag{25}$$

(**B**) The result of (20), which shows a reduction of the motional admittance circle diagram with an air-gap, may be otherwise and graphically obtained.

It is easy by simple geometrical calculations to find that in Fig. 9* the diameter of the circle diagram O_1 of the impedance Z_{ac} is equal to $g_m/\omega_0^2C_d^2$, and then the required diameter of the apparent motional admittance is given by

$$g_m'=\frac{1}{R_m}=g_m\cdot\frac{1}{\left(1+\frac{C_d}{C_a}\right)^2}=\frac{1}{R_m}\cdot\frac{1}{\left(1+\frac{kl'}{t}\right)^2} \tag{25a}$$

From the graphical representation in Fig. 9, we note that the natural frequency is increased on account of an air-gap.

(**C**) The above relation can also be seen from another point of view.

The intensity of electric field inside the crystal due to the *P.D.* applied between the electrodes is equal to $X_c=V/(kl'+t)$, and the vibrating force is given by $F=2b\epsilon tX_c$, and consequently the polarization caused by this force is $(2x/l)\epsilon$, where it is evident from (2) that $j\omega x=F/z_m$.

The e.m.f. induced within the crystal is clearly equal to $(2x/l)\epsilon$ (bl/C_d), and the current forced by this e.m.f. through the series circuit of C_d, C_a and the external impedance, which, owing to the relatively large value of C_1 can be assumed to be negligibly small compared with the capacitive impedance of C_d and C_a, can be given as follows

$$i=j\omega\left(\frac{C_dC_a}{C_a+C_d}\right)\frac{2x\epsilon b}{C_d} \tag{26}$$

On substituting the values of x, X_c, and F (see (1) and (20)) in this equation, we get

$$i=\frac{(2b\epsilon)^2}{z_m}\ \frac{V}{\left(1+\frac{C_d}{C_a}\right)^2}=Y_m\cdot\frac{V}{\left(1+\frac{C_d}{C_a}\right)^2} \tag{27}$$

* See footnote on page 707.

From the results of an experiment as depicted in Figs. 10 and 11, the writer has derived the motional admittance circle diagrams showing dependence upon the air-gap length.

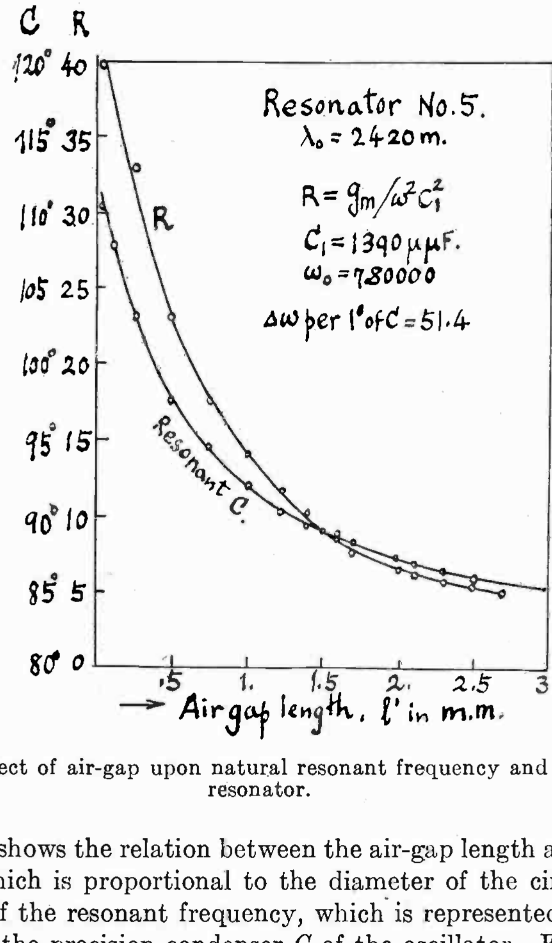

Fig. 10—Effect of air-gap upon natural resonant frequency and damping of a resonator.

Fig. 10 shows the relation between the air-gap length and the value of R_{max}, which is proportional to the diameter of the circle, and the variation of the resonant frequency, which is represented in terms of settings of the precision condenser C of the oscillator. Fig. 11 shows some of the motional admittances g_m', from which we can find the

TABLE II

l' mm	R'_{max} ohms	g_m' mho 10^{-4}	R_m' ohms	Δ'	L_m' Henry	C_m' $\mu\mu$f	C_a' $\mu\mu$f	$\frac{g'_m}{wC_a}$
0.05	41	0.50	20,000	26	390	0.0042	34.8	1.85
0.50	24	0.29	34,500	18	950	0.0017	3.48	10.4
1.0	15.5	0.19	53,000	15	1,770	0.00093	1.74	14.1
1.5	11.5	0.14	72,000	13	2,770	0.00057	1.16	12.8
2.0	10	0.12	82,500	13	3,800	0.00051	0.87	17.6
3.0	6	0.073	138,000	13	5,300	0.00031	0.58	16.2

values of R_m' and Δ', and then L_m' and C_m'. The apparent equivalent constants thus derived are shown in Fig. 12 and Table II.

While the mathematically obtained results show that the damping constant Δ' is independent of the air-gap, the experimental result shows an increase in Δ' as the air-gap length decreases. The writer believes that it may be due to the existence of damping caused by the vibration of the very thin air film. From the experiment we know that $C_m = 0.005\mu\mu f$, and $C_d = (kbl/4\pi t)\text{cm} = 1.64\mu\mu f$. Hence by (25), the

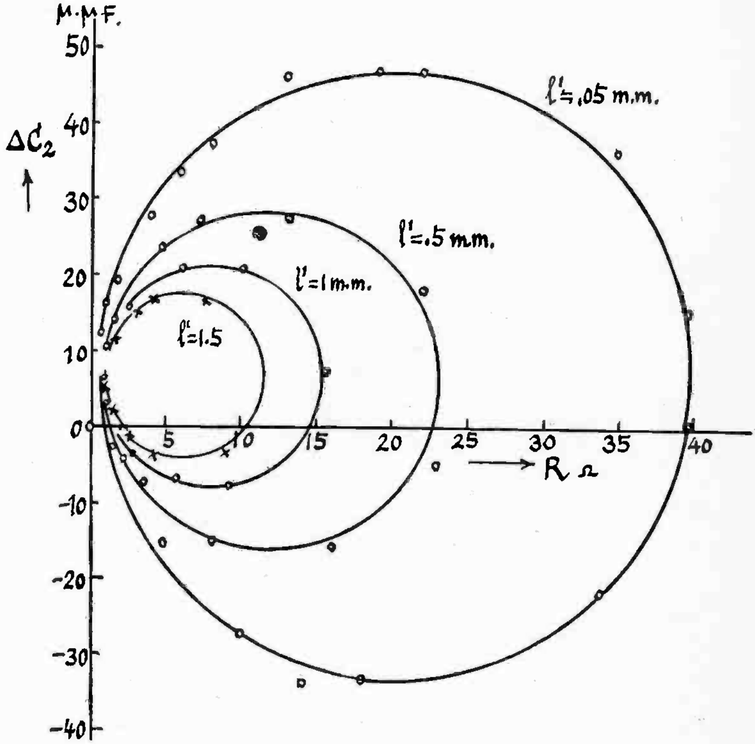

Fig. 11—Circle diagrams for various values of air-gap.

maximum variation of the resonant angular velocity is $\Delta\omega_0/\omega_0 = .005/3.28 = 0.0015$ and this value is in good agreement with the experimental result of the value $[(110-85)\ 51.4]/780{,}000 = 0.0016$.

Although the above-mentioned experimental results represent an example of a simple mode of vibration, we have often experienced the fact that the piezo-electric resonator resonates in a complicated mode of vibration.

The result shown in Fig. 13(A), (B), represents a case where two resonant frequencies are very close together.

5. Relation Between Motional Admittance and Size of Electrode

It is easy to imagine that the greater the size of the electrodes, the larger is the motional admittance of a resonator. Fig. 14 shows the relation between the inverse resonance curves and length of the electrodes, which is varied as shown in this figure.

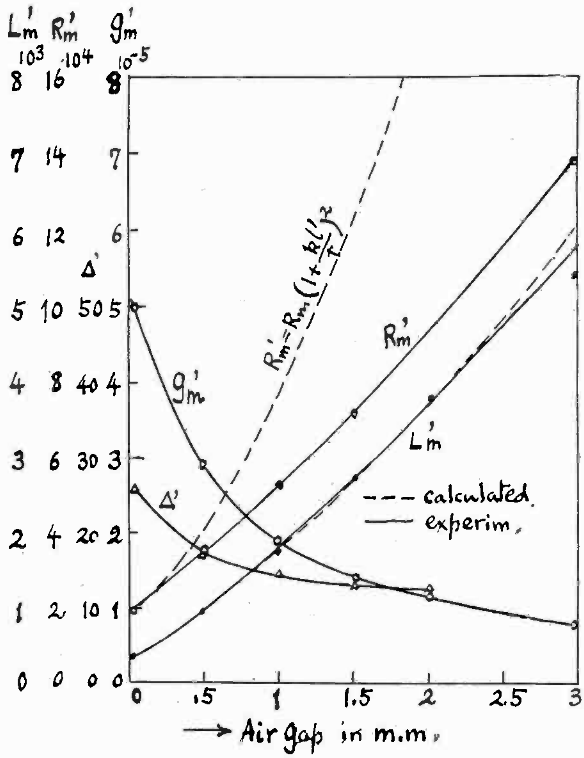

Fig. 12—Relation between the electrical constants and air-gap length.

Fig. 15, obtained with resonator No. 4, represents the dependence of the value of g_m, that is, the diameter of the motional admittance circle diagram, on the value of l_0^2. According to these results, we may say that both the resonant frequency and the effective resistance R_m of a resonator increase as the size of the electrode decreases.

6. Changing the Mode of Resonator Vibration by Means of Two Pairs of Electrodes

We can easily understand the fact that when two pairs of electrodes (ab, $a'b'$) are connected diagonally by throwing the switch to the A side in Fig. 16, then the resonator resonates at a frequency which is approximately twice that corresponding to B, which corresponds to the normal connection of two pairs of electrodes. In other

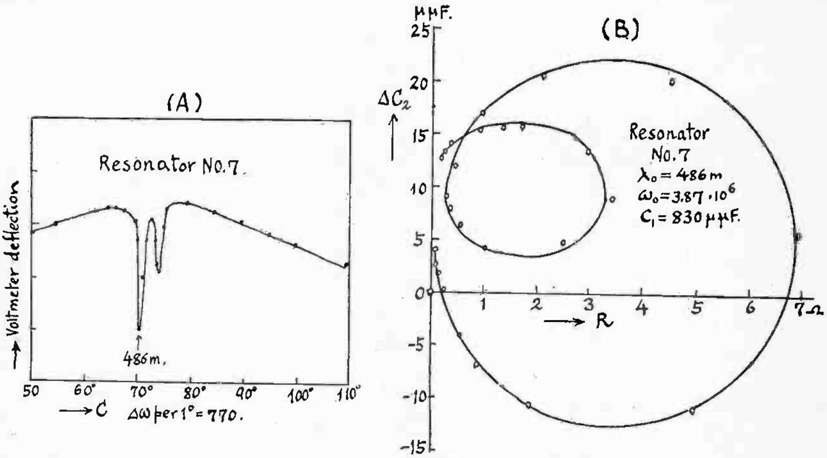

Fig. 13—One example of a somewhat complicated motional admittance of a resonator.

words, in case A, the length of the resonator corresponds to the whole fundamental wavelength.

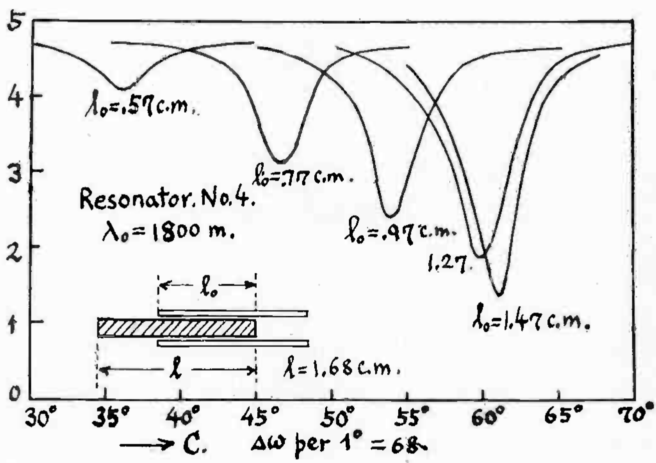

Fig. 14—Relation between inverse resonance curves and length of electrodes.

Suppose now that a piezo-electric resonator is cut out from a twinned crystal of quartz, as shown in Fig. 17. Then we can easily see that this resonator has a frequency approximately twice as high as the natural frequency of a resonator of the same size cut from normal quartz.

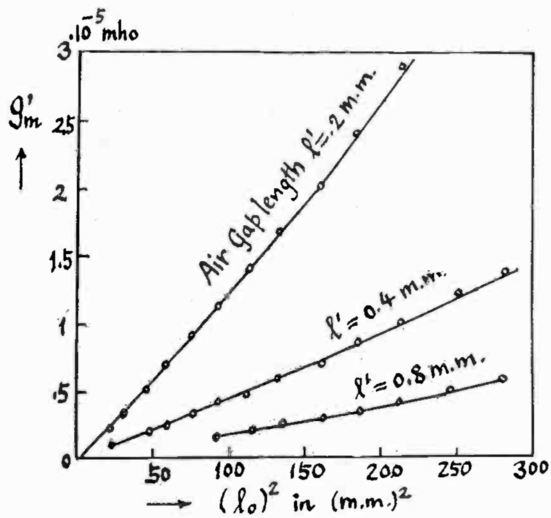

Fig. 15—Relation between g'_m and l_o^2.

Resonator No. 3 ($l=4.0$ cm, $b=1.05$ cm, $t=0.4$ cm) is such, that it has a resonant wavelength of 2160 m (not about 4400 m).

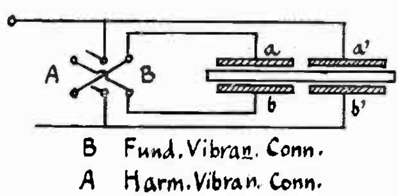

Fig. 16—Connections for two pairs of electrodes.

Such an abnormal characteristic can easily be studied by the following experiment. Placing this resonator between the two diag-

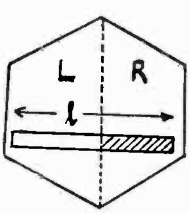

Fig. 17—Twinned crystal.

onally connected pairs of electrodes of dimensions shown in Fig. 18, and changing its relative position, we measure the effect due to resonance of the resonator at two different frequencies, 2,160 m and

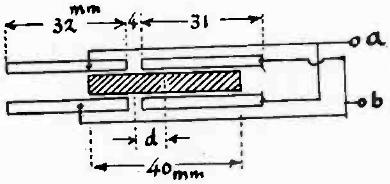

Fig. 18—Connection of electrodes to test a resonator cut from a twinned crystal.

4,300 m impressed on the resonator. Fig. 19 represents the experimental result, from which we infer that this resonator is cut from a twinned quartz crystal and moreover that the boundary of the twinning is situated at a point for which $d = -4$ mm, approximately.

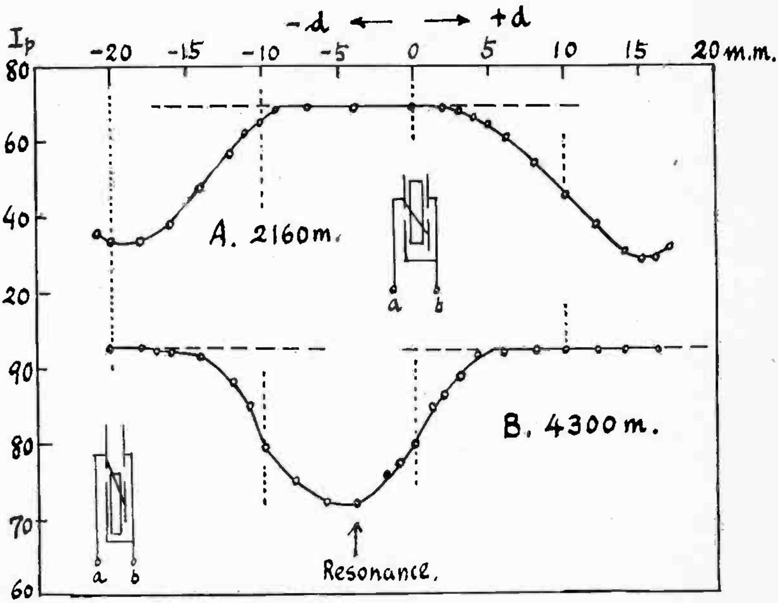

Fig. 19—Curves showing the resonance of a resonator of twinned crystal.

7. Motional Admittance under a High Impressed Voltage

The coupling between the oscillator coil and the receiving coil in Fig. 3 must be very loose, otherwise the resonance of the resonator can have an appreciable effect not only on the frequency, but also on the intensity of the oscillation. Therefore it is necessary to employ an amplifier between an oscillator and a resonator, when a high voltage is to be impressed on the resonator.

Fig. 20 shows one type of measuring circuit, where a portion of the terminal voltage V across the resonator is measured by means of a tube voltmeter. By a procedure similar to that employed in the second

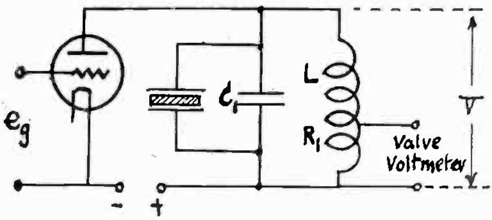

Fig. 20—Circuit to test a resonator under high voltage.

method of determining a motional admittance circle diagram, the reciprocal of the terminal voltage V as a function of the frequency is expressed by the following equations

$$\frac{1}{V}=\frac{1+\dfrac{R_i}{Z_p}}{ke_g}=\frac{1+R_i\left[\dfrac{1}{R_e}+Y_m\right]}{ke_g}$$
$$=\frac{1+\dfrac{R_i}{R_e}}{ke_g}+\frac{R_i}{ke_g}\cdot\frac{1}{R_m+j\left(\omega L_m-\dfrac{1}{\omega C_m}\right)},\tag{28}$$

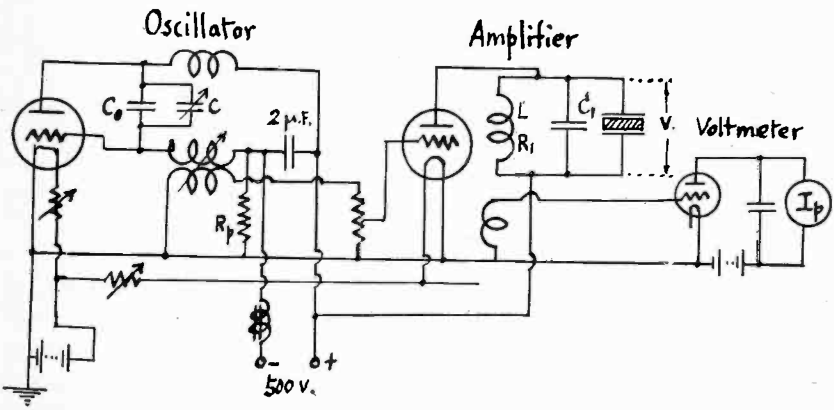

Fig. 21—Complete circuit arrangement of Fig. 20.

where $R_e = L/C_1R_1$ is the effective resistance of the oscillation circuit at resonance. From the calculated values of the latter term of this

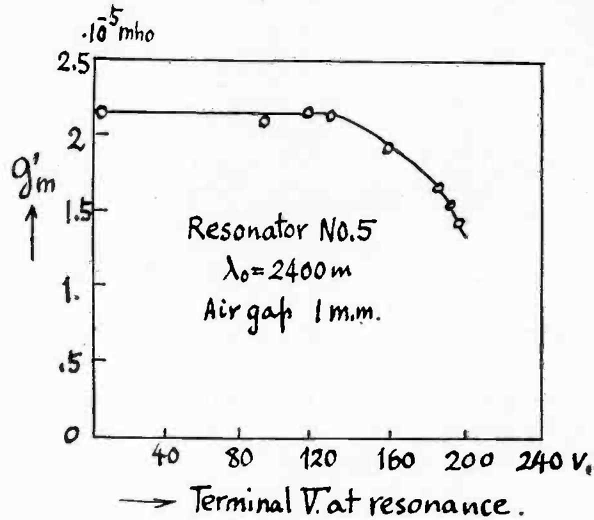

Fig. 22—Increase in damping due to high voltage.

equation for a number of frequencies near resonance we determine the equivalent constants of the resonator.

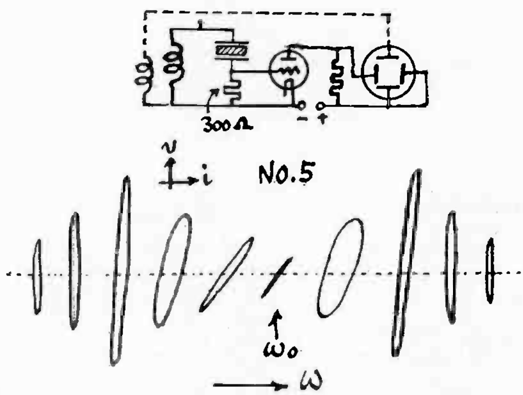

Fig. 23—Test of a resonator by cathode-ray oscillograph.

Fig. 21 shows the circuital arrangement, and Fig. 22 shows one of the experimental results, which represents the relation between the effective conductance $g_m' = 1/R_m$ and the terminal voltage across the electrodes at resonance. This experiment was performed with resonator No. 5 ($l = 2.23$ cm, $b = 0.87$ cm, $t = 0.4$ cm) with an air-gap of 0.1 cm.

When the impressed voltage is increased to more than about 100 volts, a brush discharge takes place near the middle of the resonator, and the effective conductance begins to decrease.

Here it must be noted that the potential difference across the air gap can be very much higher than the impressed e.m.f., and we can approximately represent this ratio as follows

$$\frac{V_a}{V} \doteq \frac{g_m'}{\omega C_a} \tag{29}$$

As g_m' is related according to (25a) with C_a, this ratio has the maximum value of $g_m/4\omega C_d$ under the condition that $C_a = C_d$.

The last column of Table II, shows the dependence of this ratio upon the length of air-gap.

The author has also obtained the dynamic characteristics of a resonator by means of a cathode-ray oscillograph. Fig. 23 shows the circuit arrangement and an example of the experimental results.

(To be continued in the May issue of the PROCEEDINGS)

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SOME EXPERIMENTS ON NIGHT ERRORS FOR LONG WAVES*

By

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Summary—*This paper describes the results of experiments on night errors observed for a 19.7-kc station located at a distance of 148 km, and compares them with the results of theoretical analysis. Cyclic variations of bearings, mostly two, are noticed at sunset and the same at sunrise in inverse way, the maximum shifts being about 30 deg. At the moments when the maximum shifts occur, the bearings are distinctly observed, while they are broad at others. From observations using a horizontal loop and a unidirectional antenna, polarization angles and intensities of space waves are found after Eckersley's process, assuming or empirically determining phase differences between surface and space waves, incident angles of space waves, and intensities of reflected waves on the ground. It is pointed out that the observed and theoretical values of bearings and their broadnesses are in good agreement.*

It HAS already been known that the so-called night errors can be distinctly observed by the directional reception on long waves at a distance of 150 to 700 km, and its theoretical explanation has been given by Eckersley[1] that the phenomenon is due to the polarization of space waves. It is the object of the present paper to describe some similar experiments carried out in Japan on night errors for long waves, and to compare their results with the theoretical ones.

When the transpacific station JAA (wave frequency = 19.7 kc; wavelength = 15,250 m; great circle distance = 148 km; bearing = 13 deg. east from the true north), is observed at an experimental station at Isohama near Tokio, the following shifts of the apparent bearing are noticed in general.

The bearing begins to shift towards east at three or four hours before sunset, and the shift gradually increases to a maximum when the direction of shift is reversed. The apparent bearing passes across the true bearing to a maximum towards west, and the shift is then reversed, thereby increasing until the true bearing is again observed. Another cyclic variation of this nature is generally followed without interruption, and then nighttime takes place. During night, an irregular variation continues till sunrise, when a regular shift begins to occur; and then simi-

* Dewey decimal classification: R113.3. The paper in full will be published shortly in Japanese in "The Researches of the Laboratory."

[1] Eckersley, T. L., "The effect of the Heaviside layer on the apparent direction of electromagnetic waves," *Radio Review*, II, 231; May, 1921.

lar cyclic variations as at sunset are repeated nearly in inverse way; that is, at the beginning the bearing shifts towards west and then east, until the true bearing is observed at three or four hours after sunrise. In the remaining daylight hours, no appreciable variation can be observed, the bearing being in fair coincidence with the true bearing, while the night errors sometimes reach nearly 30 deg., plus (towards east) or minus (towards west) at maxima. The results of similar observations at sunrise and sunset times have been published by Austin.[2] Similar observations have been made for some other stations of different distances and directions, but among them the station JAA gave the greatest shift for bearing.

On observations of night errors with a frame aerial which rotates about a vertical axis, the zero point of the e.m.f. induced is sometimes found distinctly, but at other times not so distinctly. In the latter case, the direction is determined by rotating the aerial through a few degrees on either side of the probable minimum point. The angle of rotation may be a measure of broadness of the minimum point. The repeated observations on the station JAA have revealed the fact that the distinct zero point was mostly found when the shift in the bearing was at plus or minus maxima. The above-mentioned shift of bearing and its broadness are, for example, as shown in Fig. 1 where curve AA is for bearing and curve BB for its broadness.

A series of experiments was conducted by the author in order to interpret theoretically the shift of bearing and its broadness. The intensity of vertical components of magnetic forces of space waves radiated from the station JAA was measured by means of a suitable horizontal loop. The results of the measurements are shown by curve CC in Fig. 1. The intensity was measured by a substitution method using a local oscillator and expressed by the e.m.f. induced in the loop, which is the product of the current I in milliamperes in the primary of the coupling coil and its mutual inductance M in microhenries.

As seen in Fig. 1, curve CC, a certain value of e.m.f. was apparently induced in the horizontal loop even in the daytime when there is little evidence of space waves. This seems to be due to the antenna effect of the loop circuit. It was, however, doubtful as to whether the variation of the e.m.f. induced in the horizontal loop, as seen in the figure, resulted from the polarization of space waves, or whether it resulted from change in the intensity of surface waves owing to the antenna effect. This question was solved by experiments using a vertical antenna and by comparing the result with that of the horizontal loop. It was ascer-

[2] Austin, L. W., "A suggestion for experiments on apparent radio direction variations," Proc. I.R.E., 13, 3; February, 1925.

tained that the variation seemed to be due to the former. In the figure, it is also seen that the e.m.f. induced in the horizontal loop varies almost directly as the bearing during the time from sunset to sunrise, and also varies above and below the daytime values. Judging from these results of experiments, the surface and space waves behaved *additively* when the values of the e.m.f. induced in the horizontal loop were above the daytime values, whereas both waves behaved *subtractively* when they were below. It is also shown theoretically that surface and space waves are to be in phase or in opposite phase at the moment when the minimum point of bearing is distinctly observed. It may, therefore, be con-

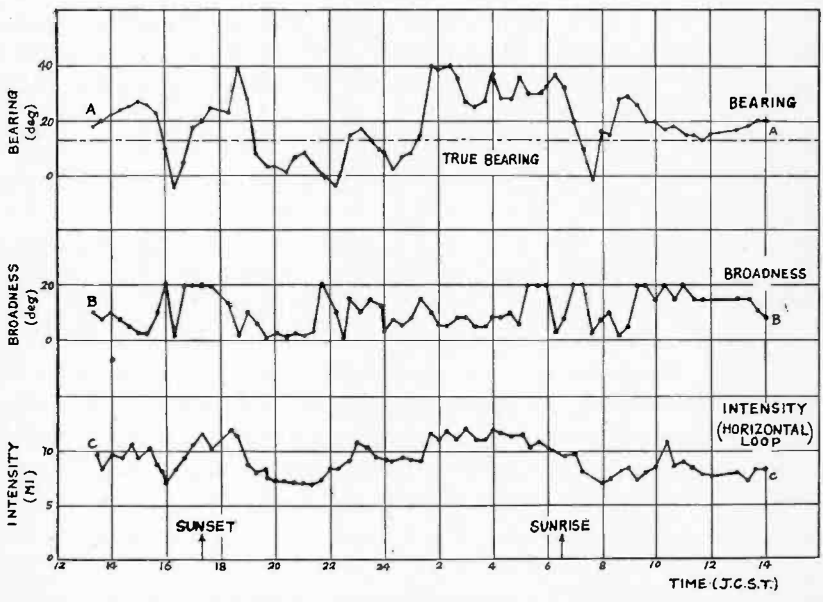

Fig. 1—Observed bearings and their broadness and measured field intensities with a horizontal loop for station JAA on February 12 to 13, 1929.

cluded in the case of sunset in the present experiments that both waves were in phase when the values of shift reached the positive maxima where the bearings were distinctly observed, whereas they were in opposite phase when the values of shift reached the negative maxima where the bearings were also distinctly observed.

By the experiments above-mentioned, the relative values of the vertical components of magnetic forces due to space waves are found by means of a horizontal loop, and the intensities of surface waves by a frame aerial with a vertical axis. Therefore, in accordance with the theory established by Eckersley, the polarization angles and the intensities of space waves can be graphically determined by assuming that, in the present case, both surface and space waves will propagate in the vertical plane including the sender and the receiver, and space waves will be plane-polarized. In this graphical solution, certain conceptions are, however, necessary as to the phase difference between surface and space waves, the incident angles of space waves, and the reflection of space waves on the ground.

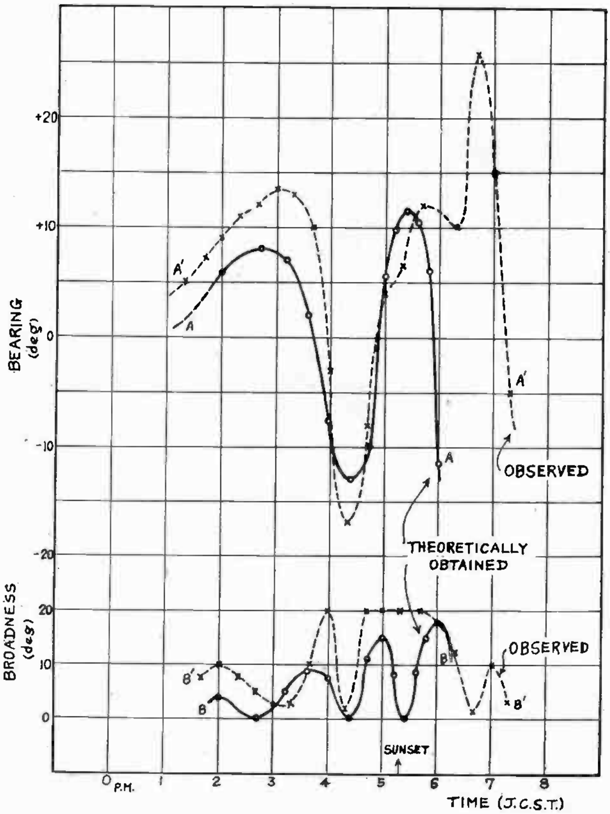

Fig. 2—Comparisons of bearings and their broadness theoretically obtained and observed for station JAA at sunset on February 12, 1929.

The phase difference between surface and space waves could be judged from the distinctness of the minimum point in the direction measurement. At the moment when the zero point can be distinctly found by a frame aerial, both waves are in phase or in opposite phase as described above. The incident angles of space waves were determined by assuming the height of the Kennelly-Heaviside layer, and it was confirmed by the experiments using a unidirectional antenna composed of a frame aerial and a vertical antenna that the assumption was fairly correct. The amount of the reflection of space waves on the ground could be made known by assuming the conductivity of the ground and by applying Fresnel's reflection equation in optics.

From the results of measurements for station JAA, the shift of bearing and the broadness of the minimum point were theoretically determined by the above-mentioned process, and those at the time of sunset were plotted in Fig. 2. In the figure, the full-line curve AA shows the shift of bearing theoretically obtained, and the broken-line curve $A'A'$ shows that observed, while the full-line curve BB shows the variation of the broadness of the minimum point theoretically obtained, and the broken-line curve $B'B'$ shows that observed. It is noticeable that the theoretical and the observed values are in fair coincidence, though not quite exactly on account of the several assumptions made.

Acknowledgments are due to E. Yokoyama under whose direction the present investigation was carried out, to E. Takagishi and T. Nakai who gave the author some valuable advice in drafting the present paper, and also to C. Asakawa, K. Kamiya, and K. Nakanishi, who all rendered the author great assistance in carrying out these experiments.

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Volume 18, Number 4 *April, 1930*

BOOKLETS, CATALOGS, AND PAMPHLETS RECEIVED

The Roller-Smith Co., 233 Broadway, New York City, has recently issued two new bulletins. Bulletin No. 300 covers various types of instruments for making resistance measurements, and No. 210 treats portable direct-current ammeters, milliammeters, voltmeters, millivoltmeters, volt-ammeters, galvanometers, circuit testers, shunts, multipliers, etc.

Ferranti, Inc., of 130 West 42nd Street, New York City, issues a booklet describing audio amplifiers, transformers and radio instruments. It may be obtained at fifteen cents a copy.

"Visitron" is the name of a photoelectric cell available from the G-M Laboratories, Inc. of Grace and Ravenswood Avenues, Chicago, Ill. Their Bulletin PE-14 describes the application, theory, and characteristics of these cells.

A price list covering a number of new transmitting type audions has recently become available from the DeForest Radio Company located at Central Avenue and Franklin Street, Jersey City, N. J. Brief descriptions of the various new audions are given in the list which comprises triodes rated from 15 watts to 5,000 watts (water-cooled), tetrodes of 7.5 to 500 watts, and two mercury-vapor half-wave rectifier tubes rated at 5,000 volts maximum peak inverse voltage and maximum peak plate currents of 0.6 and 2.5 amperes. More detailed information is available on the following tubes:

510. Triode, Oscillator and Amplifier. Output as Oscillator—15 watts.
511. Triode, Audio- and Radio-Frequency Amplifier. Undistorted Audio Output—10 watts.
503-A. Triode. R. F. Oscillator and Audio Amplifier. Output as R-F Oscillator—50 watts.
545. Linear Power Amplifier and Modulator. Undistorted Output as Audio Amplifier—20 watts.
500. Radio-Frequency Oscillator. Output—250 watts.

The characteristics of the new CeCo pentode for a-c operation are given in some data sheets recently made available by that organization which may be addressed at 1200 Eddy Street, Providence, R. I. Data on adopting the pentode to receivers now using tetrodes is also ready for distribution. In addition, a chart giving the average characteristics of the various types of tubes manufactured by CeCo will be forwarded upon request.

The three most recent additions to the many technical bulletins issued by the RCA Radiotron Co. of Harrison, N. J., describe the UX-171-A, power amplifier; the UX-222, tetrode r-f amplifier· and the UX-226 a-c operated amplifier tubes. These technical bulletins describing radiotrons were previously obtainable from Radio-Victor Company of America.

The Weston Electrical Instrument Corporation of Newark, N. J., will be glad to forward upon request copies of their literature describing various test equipment and meters suitable for radio measurements. Material on the following instruments is available:

Model 526 Direct Reading Radio Tube Tester.
Model 547 Radio Set Tester.
Model 533 Counter Tube Checker.
Portable a-c, d-c, and r-f meters.

Several diagrams showing circuit arrangements for various test setups and methods of increasing the use of meters may also be had for the asking.

Proceedings of the Institute of Radio Engineers
Volume 18, Number 4 *April, 1930*

MONTHLY LIST OF REFERENCES TO CURRENT RADIO LITERATURE

THIS IS a monthly list of references prepared by the Bureau of Standards and is intended to cover the more important papers of interest to professional radio engineers 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 scheme presented in "A Decimal Classification of Radio Subjects—An Extension of the Dewey System," Bureau of Standards Circular No. 138, a copy of which may be obtained for 10 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C. The various articles listed below are not obtainable from the Government. The various periodicals can be secured from their publishers and can be consulted at large public libraries.

R100. Radio Principles

R113 Wenstrom, W. H. More light on short-wave transmission. *Radio News*, **11**, pp. 696–700; Feb., 1930.

(Non-mathematical explanation of long distance radio transmission theory.)

R113.4 Hulburt, E. O. Ionization in the upper atmosphere: Variation with longitude. *Phys. Rev.*, **35**, pp. 240–247; Feb. 1, 1930.

(Theoretical calculations of the changes in the ionization of the upper atmosphere with longitude are given. An expression is derived giving the maximum density of electrons for the daylight hours as a function of the latitude and longitude measured from noon equinox at the equator. The value of the density obtained from the expression is shown to yield values of skip distances of short wireless waves roughly in accord with day observations (continuation of paper in *Phys. Rev.*, p. 1167; (1929).)

R113.6 Della Riccia, A. Reflecteur pour ondes hertziennes polarizees tres courtes. (Reflector for short polarized Hertzian waves.) *Revue Generale de l'Electricite*, **14**, pp. 87–90; Jan., 1930.

(The reflecting properties of surfaces are theoretically studied. The cases where the directrix of the surface is an hyperbola or a parabola are reviewed and the case where the directrix is an elipse is treated in detail. Formulas are established for use in the design of the reflector that the rays emitted by the various paths (direct and reflected) may be in phase.)

R113.7 Reyner, J. H. Some measurements in Cornwall of the signal strength from 5XX. *Jour. I.E.E.* (London), **68**, pp. 181–184; January, 1930.

(The results of an investigation carried out with the aid of portable equipment into the field strength in Cornwall of 5XX are given. Equisignal contours show what appears to be a radio shadow caused by the towers of a beam station at Bodmin. The general order of field strength is in accord with theory up to 300 km if due allowance is made for attenuation according to Sommerfeld's formula.)

R130 Moyer, J. A. and Wostrel, J. F. Radio receiving tubes (book). Obtainable from Radio World, New York, N. Y. $2.50 per copy.

(Principles and applications of vacuum tubes.)

R131 Pidgeon, H. A. and McNally, J. O. A study of the output power obtained from vacuum tubes of different types. Proc. I. R. E., **18**, pp. 266–93; Feb., 1930.

(The problems in the design of repeater tubes to operate on the common supply voltages of the Bell system and to give the maximum output power of a given quality are dealt with. The electrical characteristics and output of fundamental second and third harmonics of two of the more common telephone repeater tubes are given. The results of an experimental investigation to determine whether greater power output of comparable quality could be obtained from multi-grid tubes are presented. The reasons for the comparatively large output of certain types of such tubes are discussed.)

R133 Möller, H. G. Zur Theorie der Barkhausenschwingungen. (On the theory of Barkhausen oscillations.) *Zeits. für Hochfreq.*, **34**, pp. 201–207; Dec., 1929.

(A mathematical and graphical explanation of oscillations produced by a vacuum tube with positive grid and zero or negative plate voltage.)

R133 Freimann, L. S. Die angenäherte Theorie des magnetostriktiven Generators. (The theory of the magnetostriction oscillation generator.) *Zeits. für Hochfreq.*, **34**, pp. 219–223; Dec., 1929.

(Dynamic equations for a magnetostrictive rod and the equivalent electrical system.)

R133 Watanabe, Y. Some remarks on the multivibrator. Proc. I. R. E. **18**, pp. 327–335; Feb., 1930.

(The action of the multivibrator is described and methods are given for obtaining the characteristic curves of the same. A formula is deduced for the period of oscillation.)

R138 Reynolds, N. B. Schottky effect and contact potential measurements on thoriated tungsten filaments. *Phys. Rev.*, **35**, pp. 158–171; Jan. 15, 1930.

(Schottky's relation that log $i\alpha(V)1/2$ is verified at high fields but fails at gradients below 1000 volts per cm. This lack of saturation at low fields is accentuated by the effect of bombardment with high velocity positive ions—apparently a surface roughening and a consequent increase of field in local areas. Contact potential and the work function at the absolute zero of temperature for the thoriated surface are compared on the basis of an investigation with low accelerating and retarding voltages while varying the temperature and state of activation of the filament.)

R145 Barclay, W. A. Applications of the method of alignment to reactance computations and simple filter theory—Part 1. *Experimental Wireless & W. Engr.* (London), **7**, pp. 59–65; Feb., 1930.

(Five alignment diagrams are reproduced whereby laborious computations may be saved in determining the calculated value of the reactance of a single capacity or inductance or of a series or parallel combination of capacity and inductance at radio and at audio frequencies. A method of extending the diagrams to cover values beyond the given range is described and illustrated.)

R170 Llewellyn, F. B. A study of noise in vacuum tubes and attached circuits. Proc. I. R. E., **18**, pp. 243–265; Feb., 1930.

(The noises originating in vacuum tubes and the attached circuits are investigated theoretically and experimentally under three headings; (1) shot effect with space charge; (2) thermal agitation of electricity in conductors; (3) noise from ions and secondary electrons produced within the tube.)

R200. RADIO MEASUREMENTS AND STANDARDIZATION

R201.7 Hudec, E. Zeitproportionale, synchron laufende Zeitablenkung für die Braun'sche Röhre. (Synchronous time proportional voltages for calibrating the oscillograms obtained from Braun cathode-ray tubes.) *Zeits. für Hochfreq.*, **34**, pp. 207–219; Dec., 1929.

(Electrostatic and magnetic methods of producing such voltages for laboratory use.)

R214 Lissüten, A. Die Schwingungen der Quarzlamelle. (The oscillations of quartz plates.) *Zeits. für Physik*, **59**, pp. 265–273; Jan. 2, 1930.

(Oscillations of the rectangular quartz plate simultaneously in two directions were investigated. Mathematical.)

R214 Hitchcock, R. C. The dimensions of low-frequency quartz oscillators. *Review of Scientific Instruments*, **1**, pp. 13–21; January, 1930.

(The frequencies of the "Curie" cut quartz oscillator plates from 60 to 320 kc/sec. are shown to be discontinuous functions of the dimensions. The K, "meters per millimeter" is shown to vary from 90 to 145. It is suggested that the use of relative power measurements will insure a single frequency crystal operating at minimum damping.)

R220 Castellain, A. P. The absorption method of capacity and inductance measurements. *Experimental Wireless & W. Engr.* (London), **7**, pp. 81–84; Feb., 1930.

(The absorption method of measuring inductance and capacity is explained. The method is extended to the measurement of the self capacity and inductance of a coil. For measurements by this method a radio-frequency generator, a calibrated standard condenser and a calibrated heterodyne wavemeter are needed.)

R230 Yamamoto, I. Studies on the natural electric oscillations of coils. Science Reports of the Tohoko Imperial University, **18**, pp. 531–79; Dec., 1929.

(The solenoidal coil, the pancake coil and the conical coil are treated in a study of the natural electric oscillations of coils. Measurements are made of the fundamental and the higher natural frequencies, and the wave forms of the potential standing waves are observed.)

R300. Radio Apparatus and Equipment

R329 Amy, E. V. and Aceves, J. C. The multicoupler antenna system. *Radio Broadcast*, **16**, pp. 206–209; Feb., 1930.

(Installations for apartment houses.)

R330 Weaver, K. S. and Jones, W. J. Production testing of vacuum tubes. Proc. I. R. E., **18**, pp. 336–349; Feb., 1930.

(The procedure in the testing of vacuum tubes under commercial production, the characteristics on which tests are made and the nature of the tests.)

R342.7 Thiessen, A. E. The accurate testing of audio amplifiers in production. Proc. I. R. E., **18**, pp. 231–242; Feb., 1930.

(Method given for quickly comparing the voice frequency amplifying system of receivers, particularly those for use in broadcast reception, with a predetermined standard. Tests made on the amplification of the system within the band of audio frequencies and on the undistorted power output that it will deliver.)

R342.7 Glauber, J. J. Application of screen-grid tubes to audio-frequency amplification. *Radio Engineering*, **10**, pp. 29–33; Feb., 1930.

(Construction of proper circuits suitable to the characteristics of the typical screen-grid tube.)

R343 Lubszynski, G. Grundsätzliches über die Verwendung gemeinsamer Stromquellen für mehrere Verstärker. (Fundamental consideration on the use of the same source of current for several amplifiers). *Elek.-Nach. Tech.*, **6**, pp. 500–504; Dec., 1929.

(The mutual interference of two or more amplifiers working from the same sources of plate and filament voltage is considered, and a quantitative expression for the ratio of the interference signal to the desired signal is developed and applied to several specific cases to determine the feasibility of multiple operation.)

R343 Harris, S. Cross modulation in r-f amplifiers. Proc. I. R. E., **18**, pp. 350–354; Feb., 1930.

(The causes of cross modulation in radio-frequency amplifiers are described, particularly in connection with the use of a non-selective input circuit, and in connection with the static characteristics of the screen-grid tube. Remedies for the difficulties are suggested.)

R343 von Handel, P.; Krüger, K.· Plendl, H. Quartz control for frequency stabilization in short wave receivers. Proc. I. R. E., **18**, pp. 307–320; Feb., 1930.

(Experiments were made on the use of quartz control on receivers to stabilize high-frequency reception. The use of a quartz plate either in a self-generating detector or in a separate heterodyne to produce audible beats with the frequency of the transmitter quartz was found impractical. A successful experiment is described in which the superposition of the frequencies of the transmitter and the receiver both piezo controlled produce a intermediate frequency which is made audible in a normal generating detector.)

R343.7 Brown, H. A. and Morris, L. P. Filament supply for radio receiver from rectified 25-kc current. Proc. I. R. E., **18**, pp. 298–306; Feb., 1930.

(A method of generating, rectifying, and filtering 25-kc current for supplying filament power to ordinary d-c-amplifier tubes in radio receivers is described. The oscillator used to generate the 25-kc current was of a special design and contained one or more UX-210 power tubes. The dry contact type rectifier unit was used, and cathode-ray oscillograms of the output current were taken. Operating tests were made of the performance of radio receivers.)

R360 Thomas, H. A. A method of measuring the overall performance of radio receivers. *Experimental Wireless & Wireless Engr.* (London), **7**, pp. 78–80; Feb., 1930.

(The apparatus and method developed at the National Physical Laboratory for the Radio Research Board for measuring the overall performance of radio receivers is described. Abstract of a paper read before the Wireless Section, Institution Electrical Engineers, Jan. 15, 1930.)

R360 Farnham, P. O. A broadcast receiver for use in automobiles. Proc. I. R. E., **18**, pp. 321–26; Feb., 1930.

(The important features affecting the design of a broadcast receiver for use in automobiles, special reference made to: (1) type of collector; (2) ignition shielding; (3) electrical characteristics of the receiver; (4) physical structure of the receiver and (5) power supply. Observations with an experimental receiver show that the ignition interference is greatest at the higher broadcast frequencies, that the normal service range is from 50 to 100 miles from 50-kw stations, and that automatic volume control is desirable when the travel is through hilly country.)

R386 Uehling, E. A. Band-pass filter circuits. *Radio Broadcast*, **16**, pp. 212–214; Feb., 1930.

(Mathematical considerations in design are given.)

R388 von Hartel, H. Eine neue Braun'sche Röhre. (A new Braun tube.) *Zeits. für Hochfreq.*, **34**, pp. 227–228; Dec., 1929.

(Describes new type of Braun tube and its several advantages.)

R388 von Ardenne, M. A Braun tube for direct photographic recording. *Experimental Wireless & W. Engr.* (London), **7**, pp. 66–70; Feb., 1930.

(A Braun tube employing from 300 to 4500 volts as the anode voltage is described. At the lower voltages it is adaptable to observational measurements. At the higher voltages (above 1200) it permits the photography of aperiodic as well as periodic phenomena direct from the fluorescent screen. Photographs taken with the aid of the tube are reproduced.)

R500. Applications of Radio

R526.1 Diamond, H. Applying the visual double-modulation type radio range to the airways. *Bureau of Standards Journal of Research*, **4**, pp. 265–87; Feb., 1930. Research Paper No. 148 obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C.

(A number of circuit arrangements are described, by which a single visual-type radio range is made to serve two, three, or four courses radiating from a given airport at arbitrary angles with each other. A method of obtaining small amounts of shift by an adjustment of the receiving equipment aboard the airplanes is also described.)

R536 Geyger, W. Zusammenfassender Bericht: Die geolelektrischen Untersuchungsmethoden mit Wechselstrom. (Complete report on the methods of geoelectric investigation with alternating currents.) *Zeits. für Hochfreq.* **34**, pp. 228–233; Dec., 1929.

(Continued from *Zeits. f. Hochfreq.*, Nov., 1929 issue.)

R582 Ives, H. E. and Johsrud, A. L. Television in colors by a beam scanning disc. *Jour. Opt. Soc.*, **20**, pp. 11–22; January, 1930.

(Photoelectric cells sensitive to all colors in the visible spectrum and colored lights capable of high speed variation in intensity have made possible television in color. The details of the scanning apparatus and of the sending and receiving apparatus employed are given. Certain operational features and problems in the faithful reproduction of color are discussed.)

R800. Non-Radio Subjects

530 van der Pol, B. A new transformation in alternating-current theory with an application to the theory of audition. Proc. I. R. E., **18**, pp. 221–230; Feb., 1930.

(A mathematical transformation of the elements of an impedance is considered whereby the complex impedance of each of the constituents is multiplied by j, j^2 and j^3 and the physical meaning of such a transformed system is investigated. New circuits can be derived from the known circuits and special properties of the former are transformed into new special properties of the latter. Further, negative capacities and negative inductances are considered which are independent of frequency. Several a-c circuits are described having the property that the modulus of their impedances is independent of frequency. These permit an experiment confirming the acoustical law of Ohm.)

534 Browne, C. O. The problem of distortion in sound film reproduction. *Experimental Wireless and W. Engr.* (London), 7, pp. 71–77; Feb., 1930.

(Frequency characteristics of a recording and reproducing sound-film system are discussed independently with a view to producing a level combined-frequency response. Various recorders and the method by which their frequency responses can be brought into line with that of the reproducer are described. A recording system producing a twin wave track record of the variable width type is described in detail and the essential points of the variable density recording system are observed.)

537.1 Landon, V. D. The equivalent generator theorem. Proc. I. R. E., 18, pp. 294–97; Feb., 1930.

(It is proved that any electrical network with two output terminals may be replaced by a generator and a series impedance without changing the current in an externally connected load. The voltage of the generator is the no-load voltage of the output terminals. The value of the series impedance is the impedance of the unloaded network looking into the output terminals. The use of the theorem is illustrated, and it is pointed out that it is valid for transient as well as steady state conditions.)

621.313.3 Geyger, W. Ein komplexer Wechselstromkompensator für mittlere Frequenzen. (A complex a-c. compensator for frequencies from 500 to 5000 cycles.) *Zeits. für Hochfreq.*, 34, pp. 223–27; Dec., 1929.

(Description of a simple instrument for determining amplitude and phase of an unknown a-c voltage using the compensation method.)

Proceedings of the Institute of Radio Engineers
Volume 18, Number 4 *April, 1930*

CONTRIBUTORS TO THIS ISSUE

Clapp, James K.: Born December 30, 1897 at Denver, Colorado. With Marconi Wireless Telegraph Company, 1914–1916; U. S. Navy, 1917–1919, foreign service, 1918–1919; Radio Corporation of America, 1920, also 1922–1923. Received B.S. degree, Massachusetts Institute of Technology, 1923; instructor in electrical communications, M. I. T., 1923–1928; M.S. degree, 1926. Engineering department, General Radio Company, Cambridge, Mass., 1928 to date. Associate member, Institute of Radio Engineers, 1924; Member, 1928.

Glover, Ralph P.: Born June 15, 1906 at Lockport, New York. Received E.E. degree from University of Cincinnati, June, 1929. Thesis: "Methods and Equipment for Overall Measurements on Broadcast Receivers." With Crosley Radio Corporation from April, 1929, to date. In charge of standard measurements on receivers from June, 1929, to date. Associate member, Institute of Radio Engineers, 1928.

Kenrick, G. W.: Born May 25, 1901 at Brockton, Mass. Received B.S. degree in physics, Massachusetts Institute of Technology, 1922; M.S. in physics, M.I.T., 1922; D.Sc. in mathematics, M.I.T., 1927. Assistant, department of physics, M.I.T., 1920–1922; department of development and research, American Telephone and Telegraph Company, 1922–1923; instructor in electrical engineering, M.I.T., 1923–1927; Moore School of Electrical Engineering, University of Pennsylvania, 1927 to date. Associate member, Institute of Radio Engineers, 1923; Member, 1929.

Loftin, Edward H.: Born July 19, 1885, at Montgomery, Alabama. Graduated, U. S. Naval Academy, 1908; post graduate course at Naval Post Graduate School, Annapolis, and Columbia University with M.A. degree; closely affiliated with naval radio activities from 1910 to 1924 during which time commanded naval research ship *Bailey*, pioneered development for radio aircraft, in charge of naval communications in France during the War, liaison officer on Inter-Allied conferences, negotiations for and construction of the Lafayette station in France, in charge of naval research and development of radio for four years after war, member of Technical Committee of International Communication Conference (1921), and chairman of Inter-Departmental Radio Board. Since leaving the naval service in 1924 has been engaged in private research and development work. Member, Institute of Radio Engineers, 1926.

Pickard, Greenleaf Whittier: Born February 14, 1877 at Portland, Maine. Educated at Westbrook Seminary, Westbrook, Maine; Lawrence Scientific School of Harvard University; and Massachusetts Institute of Technology. Experimental radio work with Blue Hill Observatory, 1898–1899. Research engineer for American Wireless Telegraph and Telephone Company for several years. Radio telephony in research department of American Telephone and Telegraph Company, 1902–1906. Consulting engineer, 1906–1907. Consulting engineer for and director of the Wireless Specialty Apparatus Company of Boston, 1907 to date. Inventions in connection with radio telephony, the crystal detector, loop aerials and direction-finding systems, and various static-mitigating devices used during the war. Received Institute Medal of Honor, 1926. Member, Institute of Radio Engineers, 1912; Fellow, 1915.

Potter, Ralph Kimball: Born October 1, 1894 at Elgin, Illinois. Received B.S. degree from Whitman College, 1917. With Artillery Corps, U. S. Army, 1917–1919. Received E.E. degree, Columbia University, 1923. With department of development and research, American Telephone and Telegraph Company, in connection with broadcast and transatlantic high-frequency radiotelephony, 1923 to date.

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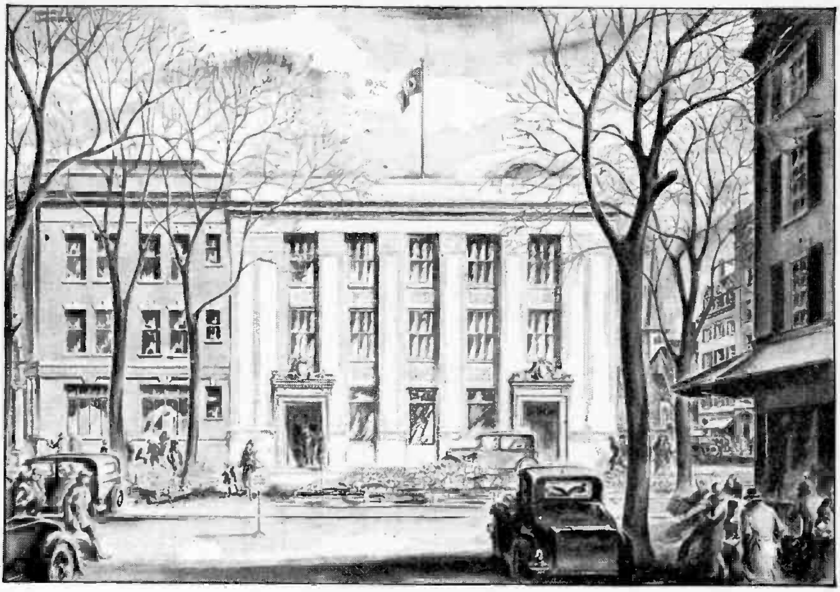
Watanabe, Yasusi: See PROCEEDINGS for February, 1930.

Watts, E. G., Jr.: Born March 2, 1907 at Long Branch, New Jersey. Amateur radio operator, 1921–1923. Florida Radio Telegraph Co., Miami, Florida, 1924–1928. Victoreen Radio Co., Cleveland, Ohio, 1928–1929. Murton Laboratories, Cleveland, Ohio, 1929 to date. Junior member, Institute of Radio Engineers, 1927; Associate, 1928.

White, S. Young: Born April 11, 1901. For some time in testing course of the General Electric Company; spent a number of years as radio operator on ships throughout the world; engaged in special work on rectifiers in the United States and Europe for several years; during the past few years has been engaged in private research and development work, particularly in amplifying circuit and radio design work. Non-member, Institute of Radio Engineers.

***Takagishi, Eijiro:** Born, 1898. Graduated from Tokyo Higher Technical School, 1918. Wireless department of Electrotechnical Laboratory, Ministry of Communications, Japan, 1918–1925. Chief of Hiraiso branch of Electrotechnical Laboratory, 1925–1929. Chief of research department, Annaka Radio Manufacturing Company, Limited, 1929 to date. Non-member, Institute of Radio Engineers.

* Paper published in the March, 1930, PROCEEDINGS.



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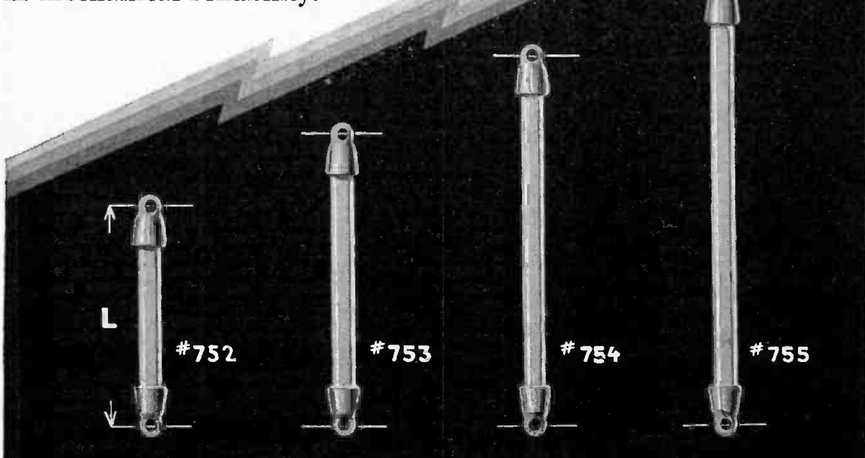

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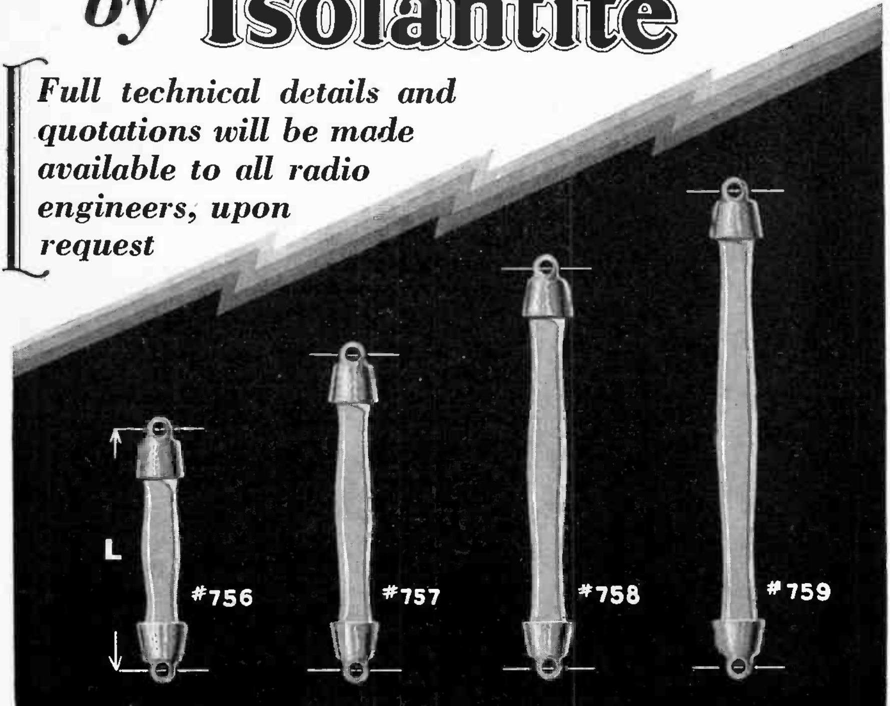

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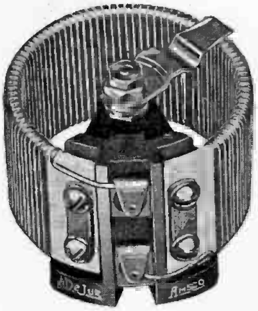

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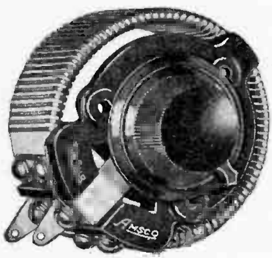

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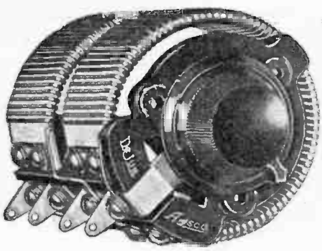

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APPLICATION FOR ASSOCIATE MEMBERSHIP

(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.

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. I furthermore 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.

Yours respectfully,

....
(Sign with pen)

....
(Address for mail)

....
(Date) (City and State)

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Address .... Address ....

Mr. .... Mr. ....

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Mr. ....

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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: * * * (d) Associates, who shall be entitled to all the rights and privileges of the Institute except the right to hold the office of President, Vice-president and Editor. * * *

Sec. 5: An Associate shall be not less than twenty-one years of age and shall be: (a) A radio engineer by profession; (b) A teacher of radio subjects; (c) A person who is interested in and connected with the study or application of radio science or the radio arts.

ARTICLE III—ADMISSION

Sec. 2: * * * Applicants shall give references to members of the Institute as follows: * * * for the grade of Associate, to five Fellows, Members, or Associates; * * * Each application for admission * * * shall embody a concise statement, with dates, of the candidate's training and experience.

The requirements of the foregoing paragraph may be waived in whole or in part where the application is for Associate grade. An applicant who is so situated as not to be personally known to the required number of members may supply the names of non-members who are personally familiar with his radio interest.

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RECORD OF TRAINING AND PROFESSIONAL EXPERIENCE

1 Name ....
(Give full name, last name first)

2 Present Occupation...
(Title and name of concern)

3 Permanent Home Address...

4 Business Address ....

5 Place of Birth.................... Date of Birth..................Age......

6 Education ....

7 Degree ....
(college) (date received)

8 Training and Professional experience to date..............................

NOTE: 1. Give location and dates. 2. In applying for admission to the grade of Associate, give briefly record of radio experience and present employment.

DATES HERE	

9 Specialty, if any..

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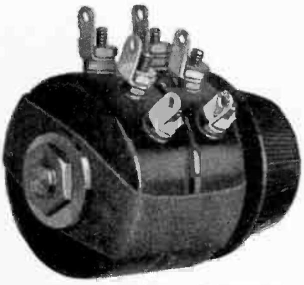
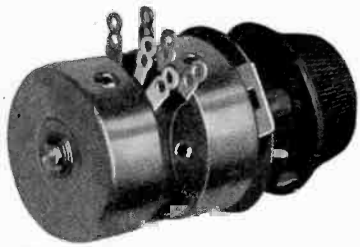


No. 2880-2880. Bakelite shell composition element only. Resistance range from 5,000 ohms to 1 megohm. All curves. Potentiometer or rheostat types. Units insulated from each other. Diameter, 1 1/2 in. Depth of shell, 1 1/8 in.

IN no field of radio manufacturing is absolute precision more essential than in the production of volume control units. Much of the satisfactory service a receiver is called upon to deliver depends on the complete dependability of these units over long periods of time, under varying conditions of temperature and humidity.

Here at Elkhart in the Frost-Radio laboratories we have established new standards of precision in the manufacture of volume controls. Old-fashioned standards will not do for tomorrow's marvelously improved receivers, for yesterday's best is far from being good enough for tomorrow's efficiency. So you will find in Frost-Radio Volume Controls an amazing precision, a new conception of noiseless, wear-proof operation, and a new standard of accuracy—all made possible by constant Frost-Radio research to the end that every product bearing this name will be better, more dependable, and longer lived.



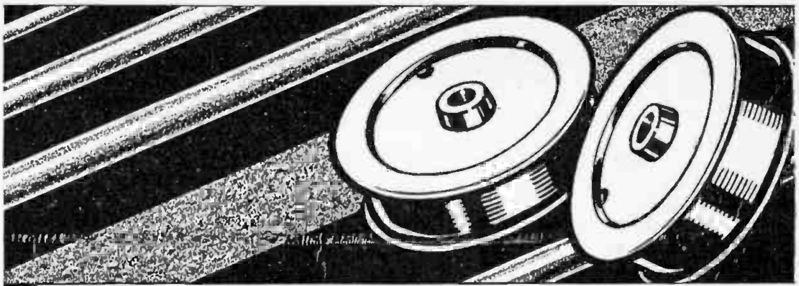
No. 200-200. Metal shell type wire wound resistors with resistances from 5 ohms to 10,000 ohms. Split windings. Rheostat or potentiometer types. Units insulated. Diameter, 1 7/16 in. Depth of shell, 1 1/2 in.

No. 590-590. Metal shell, composition element only. Resistances from 5,000 ohms to 1 megohm. All curves. Potentiometer or rheostat types. Units insulated from each other. Diameter, 1 5/16 in. Depth of shell, 1 1/8 in.

If you have a volume control problem we suggest you write or wire us for information as to its solution. Samples based on your exact specifications will be supplied promptly.

HERBERT H. FROST, Inc.
***Main Offices and Factory:* Elkhart, Ind.**
160 North La Salle Street, CHICAGO

The World's Largest Manufacturer of High Grade Variable Resistors

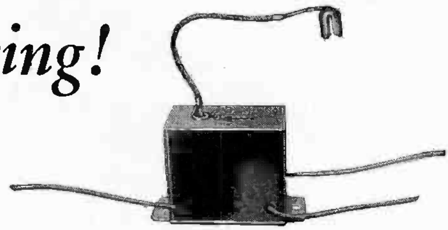


When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*

You can forget the Condensers if they are DUBILIERS

Announcing!

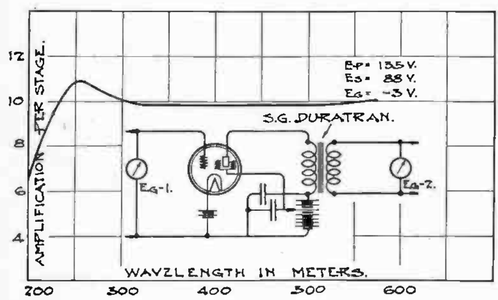
The New Dubilier Screen-Grid Duratran (Untuned Radio Frequency Transformer)



PL-2000
The New Dubilier Screen-Grid Duratran

A new development in untuned radio-frequency transformer construction, of particular interest to set-manufacturers.
Features:—

(1) An untuned interstage radio-frequency transformer for use with screen-grid tubes—Types 222 and 224.
(2) Relatively high gain per stage.
(3) Uniform amplification over broadcast wave-band.
(4) Amplification equivalent to that of a tuned radio frequency amplifier system.
(5) Practically eliminates costly shielding problems.
(6) A screen-grid duratran amplifier eliminates after assembly service charges usually encountered with unbalanced tuned R.F. stages.
(7) Savings in balancing, testing, and shielding, permit large manufacturing economies.
(8) For use in standard receiving sets for home, portable, automotive, and marine use.



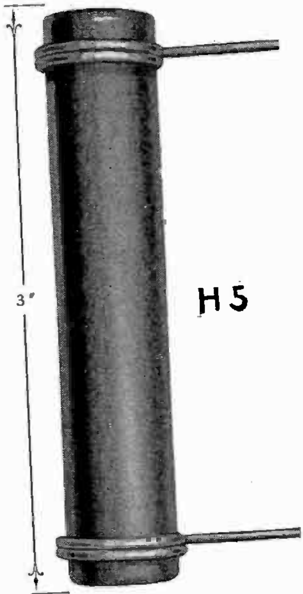
Curve of Amplification vs Frequency

Technical data and samples will be gladly furnished to set-manufacturers.

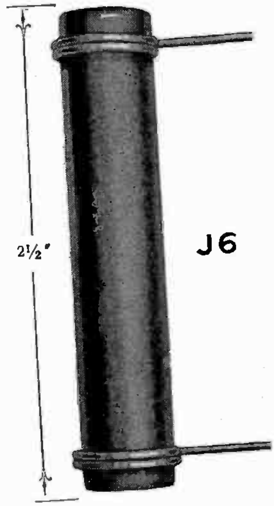
DUBILIER CONDENSER CORPORATION

342 Madison Avenue New York, N. Y.

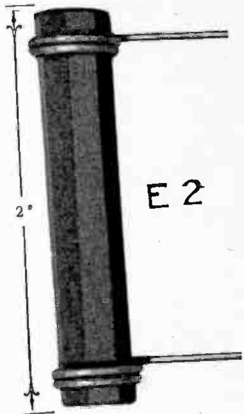
Continental Resistors



5 Watts



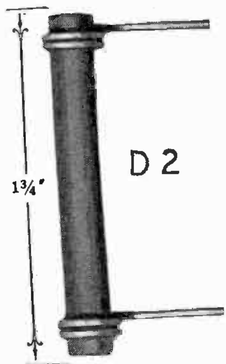
3½ Watts



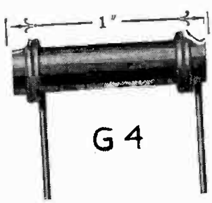
2 Watts

CHARACTERISTICS:

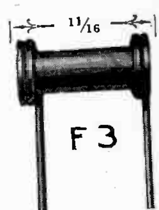
NOISELESS
RESISTANCE CONSTANT
SMALL TEMPERATURE COEFFICIENT
RUGGED
FIRMLY SOLDERED TERMINALS
DEPENDABLE
COLOR CODED



1 Watt



¾ Watt



½ Watt

Write for Information and Prices

CONTINENTAL CARBON INC.
WEST PARK, CLEVELAND, OHIO

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 any change in the listing of their company affiliation or title for the Year Book membership list.

The Secretary,
THE INSTITUTE OF RADIO ENGINEERS,
33 West 39th Street,
New York, N.Y.

Dear Sir:

Effective .... please note change in my address
(date)
for mail as follows:

FROM

....
(Name)

....
(Street Address)

....
(City and State)

TO NEW ADDRESS

....
(Street Address)

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(City and State)

Also for the membership list for next year's Year Book note change in my business address (or title) as follows, this is / is not my mailing address:

....
(Title)

....
(Company Name)

....
(Address: Street, City and State)

PLEASE FILL IN, DETACH, AND POST TO THE INSTITUTE PROMPTLY


POWEROHM
Whatever your Resistor Need We can Supply it!
Resistor units of all values for all purposes . . . . high values from 10 to several hundred megohms per unit length for photocell work, high voltage voltmeter multipliers, lightning arrestors, etc. — precision wire wound units made to accuracies of 1% and ½% . . . each one built for more dependable service and longer life. Write for bulletins, including bulletin No. 9 on the new precision wire wound resistor.
PRECISION WIRE WOUND
RESISTOR
100,000 OHM
Ranges 500 to 500,000 ohms
DURHAM
METALLIZED
RESISTORS & POWEROHMS
INTERNATIONAL RESISTANCE CO.
2006 Chestnut Street, Philadelphia, Pa.


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AS ITS
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(UNCOATED)
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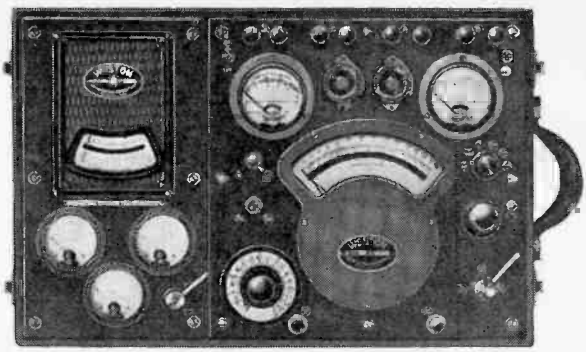


WESTON MODEL 526 - Type 7
RADIO TUBE TESTER

WESTON INSTRUMENTS help keep millions of tubes in orderly procession—safe-guarding production and insuring delivery to consumer in perfect condition.

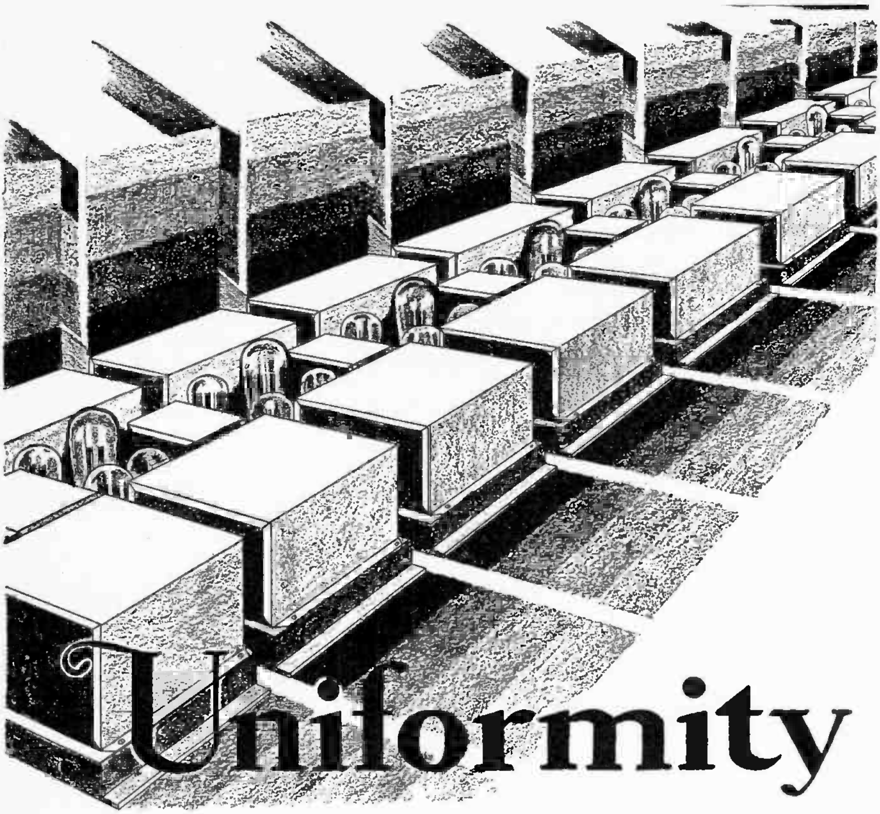
The MODEL 526 TUBE TESTER has levelled the barriers of slow-operating devices and removed the obstruction of tedious and complicated computations. With this instrument tube and set manufacturers can quickly and conveniently obtain direct readings and determinations for the following:

> *Short Test—Leakage—Gas Test. Determination of Amplification Factor, Measurement of Plate Impedance, Mutual Conductance and Plate Current.*

These Tube Testers have become Standard equipment in many of the leading tube factories—in all cases accelerating production and insuring uniformity and high quality of tube output. Enclosed in hardwood case with Bakelite panel. Size, $19\frac{3}{4}$ x $12\frac{3}{4}$ x $5\frac{7}{8}$ inches.

WESTON ELECTRICAL INSTRUMENT CORPORATION
589 Frelinghuysen Avenue Newark, N.J.

Weston
PIONEERS SINCE 1888
INSTRUMENTS



Uniformity

EVERY operation in the production of Operadio Power Amplifiers contributes to the verification of the slogan "Uniformity of Product." In specifying Operadio Power Amplifiers, you are assured of laboratory performance at production costs.

Their somewhat higher initial cost is cheap insurance for uniformity of performance and operation. 58% of the total time spent to build Operadio Power Amplifiers is used for either tone tests, power tests, or comparative tests against a standard.

OPERADIO MFG. CO.

St. Charles, Illinois

OPERADIO

ENGINEERS AVAILABLE

Advertisements on this page are available only to members of the Institute of Radio Engineers. For rates and further information address the Secretary, The Institute of Radio Engineers, 33 West 39th Street, New York, N.Y.

MANUFACTURERS and others seeking radio engineers are invited to address replies to these advertisements at the Box number indicated, care the Institute of Radio Engineers. All replies will be forwarded direct to the advertiser.

GRADUATE, Northwestern University, B.S. in 1926; Lehigh University, M.S. in 1929. Six months' experience television research and four months' study of acoustics. Desires connection in television or acoustical work. Age 27. Box 20.

RADIO ENGINEER, married, eight years' executive experience in design, operation and maintenance of broadcasting stations. B.A. degree in Science. Studied in several colleges and universities. Have travelled extensively. Desire an executive position with large broadcasting station, with talking picture industry, or allied fields. Well endorsed. Age 29. Box 15.

RADIO ENGINEER, familiar with research and design work on broadcast receivers and loud speakers as well as general laboratory work. Desires connection with broadcast receiver manufacturer or similar type of work. Age 26. Box 16.

M.I.T. GRADUATE, B.S., E.E., 1926. Experienced in research on audio amplifier equipment for radio, public address and talking movie work. Also experienced in production engineering and personnel management. Desires position with manufacturing organization, preferably as production engineer. Age 25. Box 17.

COLUMBIA UNIVERSITY GRADUATE, B.A. 1919, E.E. 1922. Six years with large engineering organization on receiver design, manufacture and service. Has experience on development, installation, test and specification of carrier current communication equipment. Two years' power company communication engineering including some aircraft radio work. Desires responsible position in radio manufacturing or as air transport communication engineer. Age 32, Box 18.

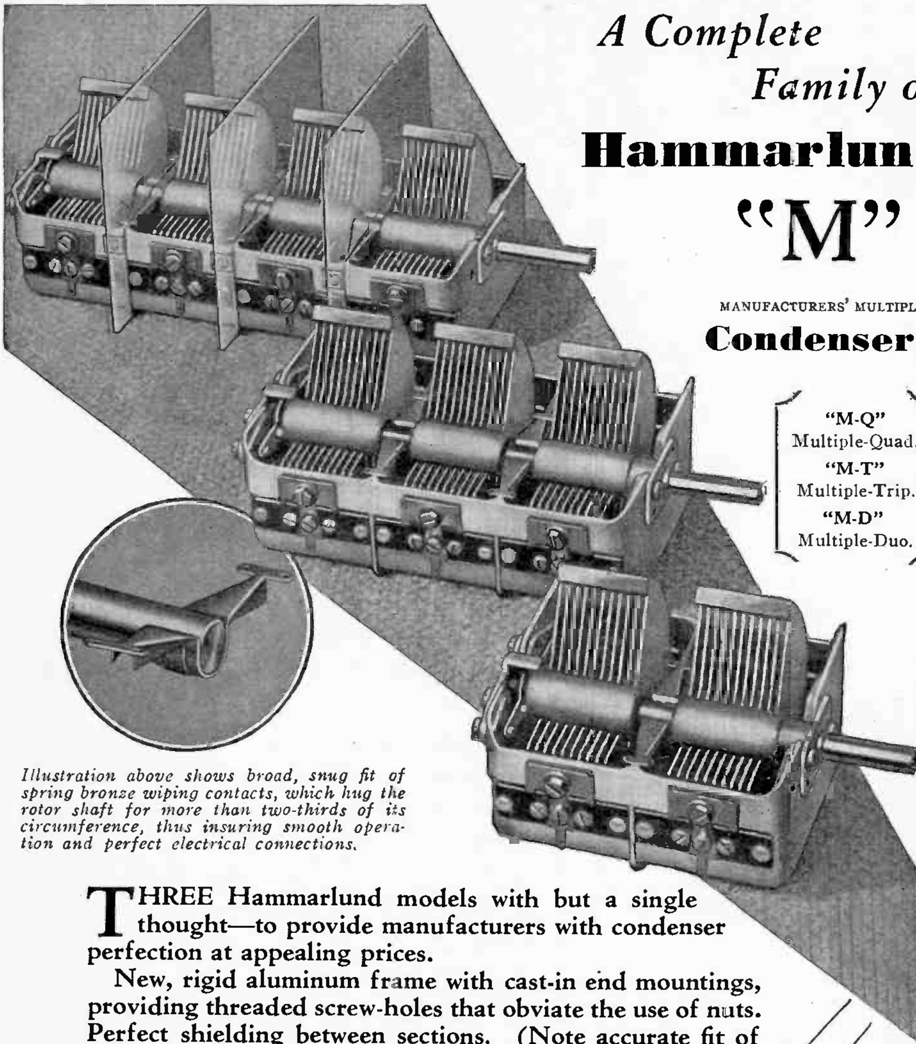
RADIO ENGINEER, college graduate with more than twelve years' exclusive experience in radio, having a thorough knowledge of the art and requirements of the receiver industry, and for the past three years chief engineer for a national manufacturer is desirous of making new connection in responsible capacity. Box 9.

ENGINEERING EXECUTIVE of thirteen years' experience desires suitable connection. From 1917 to 1922 in U. S. Navy Department on research and development, testing of radio-compass equipment and high and low-power transmitters. In charge of radio laboratory in Philadelphia for three of these years. 1922 to 1925, chief radio engineer for large manufacturer of broadcast receiving sets handling research, design, supervision of manufacture, training of personnel, and responsible for design of all apparatus sold during that period. 1925 to 1927 spent as consulting engineer. 1927 to 1929, chief engineer for an organization manufacturing parts and theatre amplifying equipment. Four months of 1929 on receiver design. 35 years of age. Box 8.

GRADUATE of University of Kiev (U.S.S.R.), B.A., '13, has built, repaired, and serviced receivers and power-supply units and has considerable experience in audio amplifiers having frequency-response characteristics better than those available in manufactured units. Is interested in work concerning the building, control, installation, and servicing of sound-amplifier systems. Age 38. Box 13.

GRADUATE of industrial electrical engineering course at Pratt Institute, also radio course at same school, is interested in experimental or test work on receivers or tubes. Experienced in factory testing and trouble shooting. Age 23. Box 10.

TEST ENGINEER, two years' college, ten years' radio manufacturing experience, six on test and design work on broadcast receivers and loud speakers. Desires position doing test or laboratory work. Age 30. Box 19.



A Complete
Family of
Hammarlund
"M"

MANUFACTURERS' MULTIPLE
Condensers

"M-Q"
Multiple-Quad.
"M-T"
Multiple-Trip.
"M-D"
Multiple-Duo.

Illustration above shows broad, snug fit of spring bronze wiping contacts, which hug the rotor shaft for more than two-thirds of its circumference, thus insuring smooth operation and perfect electrical connections.

THREE Hammarlund models with but a single thought—to provide manufacturers with condenser perfection at appealing prices.

New, rigid aluminum frame with cast-in end mountings, providing threaded screw-holes that obviate the use of nuts. Perfect shielding between sections. (Note accurate fit of demountable upper shields, shown in phantom on quadruple model). Steel shaft working in long, hand-reamed bearings. Anchored, non-microphonic, aluminum plates. Separate stator insulating strips. Large area trimmer condensers.

You couldn't ask more of any condensers than these new Hammarlunds offer.

Write us your needs. Use coupon.

HAMMARLUND MFG. CO.
424-438 W. 33rd St., New York

For Better Radio
Hammarlund
PRECISION
PRODUCTS

MAIL COUPON FOR FULL PARTICULARS

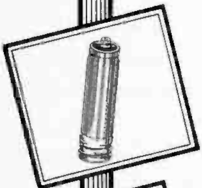
HAMMARLUND MFG. CO., Dept. PE4
424-438 W. 33rd St., New York
Please send information on "M" Condensers.
Name ....
Address ....

Alphabetical Index to Advertisements

QUALITY

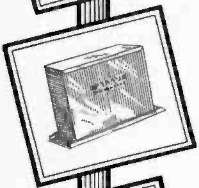
Sprague Precision Condensers are the Standard of Condenser Quality

WHEN critical engineers get together, they all agree that Sprague Condensers are superior. They know that Sprague Condensers have stood the severest tests of service — that they can be depended upon to perform their duties with unfailing faithfulness . . . Sprague Condensers are designed by the nation's foremost condenser engineers and assembled by skilled craftsmen. And here are a few reasons why Sprague Condensers are better:



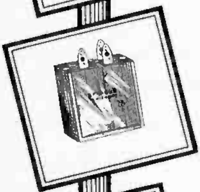
THE SPRAGUE ELECTROLYTIC CONDENSER

A single unit allowing maximum flexibility for mounting in circuit. No welded or riveted joints in its one piece anode, made of purest aluminum. A lower leakage and better power factor than any other electrolytic unit, wet or dry. Rigid construction prevents possibility of internal shorts. Screw type socket makes for ease in mounting. Edge effect 10% of spiral type.



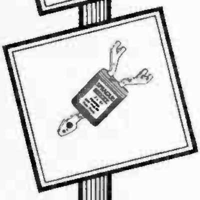
THE SPRAGUE BLOCK CONDENSER

Dielectrically superior due to patented paraffin layer process: Ruggedly protected by extra heavy sheet metal can. Impervious to moisture due to dipping of individual condensers, wrapping of assembled block in moisture-proof material, and triple sealing. Highest leakage resistance guaranteed above 5000 megohms per microfarad.



THE SPRAGUE ONE MICROFARAD UNIT

Flexible mounting — either unique stud or flange as desired . . . Correctly protected against moisture by double seal and only one small open end. Also furnished in midget assemblies using up to five sections of low capacity.



THE SPRAGUE MIDGET

A compact and unusually strong unit. Tested to high voltage breakdown — waterproofed with asphalt covering and special process of triple impregnation. Easily and quickly mounted . . . Dual type of winding if desired.

SPRAGUE SPECIALTIES COMPANY
QUINCY, MASSACHUSETTS

SPRAGUE ELECTROLYTIC AND PAPER CONDENSERS
WILL SOLVE YOUR CONDENSER PROBLEMS

SPRAGUE

FRAME or PICTURE?

No priceless painting is coveted by the connoisseur because of a gilded frame, but many an atrocious smear finds a guileless friend that way.

Experts select CARDWELL condensers because they are mechanically sound and fundamentally right, their worth *proved* over a decade of hard, exacting service—they are simple, sturdy yet *modern.*

An installation of which much will be expected—(and what other is worth while)—*deserves* CARDWELLS.

•

CARDWELL
CONDENSERS

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81 Prospect Street, BROOKLYN, NEW YORK

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