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PROCEEDINGS

of

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SUGGESTIONS FOR CONTRIBUTORS TO THE PROCEEDINGS

Preparation of Paper

Form—Manuscripts may be submitted by member and non-member contributors from any country. To be acceptable for publication manuscripts should be in English, in final form for publication, and accompanied by a summary of from 100 to 300 words. Papers should be typed double space with consecutive numbering of pages. Footnote references should be consecutively numbered, and should appear at the foot of their respective pages. Each reference should contain author's name, title of article, name of journal, volume, page, month, and year. Generally, the sequence of presentation should be as follows: statement of problem; review of the subject in which the scope, object, and conclusions of previous investigations in the same field are covered; main body describing the apparatus, experiments, theoretical work, and results used in reaching the conclusions; conclusions and their relation to present theory and practice; bibliography. The above pertains to the usual type of paper. To whatever type a contribution may belong, a close conformity to the spirit of these suggestions is recommended.

Illustrations—Use only jet black ink on white paper or tracing cloth. Cross-section paper used for graphs should not have more than four lines per inch. If finer ruled paper is used, the major division lines should be drawn in with black ink, omitting the finer divisions. In the latter case, only blue-lined paper can be accepted. Photographs must be very distinct, and must be printed on glossy white paper. Blueprinted illustrations of any kind cannot be used. All lettering should be 3/16 in. high for an 8 x 10 in. figure. Legends for figures should be tabulated on a separate sheet, not lettered on the illustrations.

Mathematics—Fractions should be indicated by a slanting line. Use standard symbols. Decimals not preceded by whole numbers should be preceded by zero, as 0.016. Equations may be written in ink with subscript numbers, radicals, etc., in the desired proportions.

Abbreviations—Write a.c. and d.c., kc, μf, $\mu\mu$f, emf, mh, μh, henries, abscissas, antennas. Refer to figures as Fig. 1, Figs. 3 and 4, and to equations as (5). Number equations on the right, in parentheses.

Summary—The summary should contain a statement of major conclusions reached, since summaries in many cases constitute the only source of information used in compiling scientific reference indexes. Abstracts printed in other journals, especially foreign, in most cases consist of summaries from published papers. The summary should explain as adequately as possible the major conclusions to a non-specialist in the subject. The summary should contain from 100 to 300 words, depending on the length of the paper.

Publication of Paper

Disposition—All manuscripts should be addressed to the Institute of Radio Engineers, 33 West 39th Street, New York City. They will be examined by the Committee on Meetings and Papers and by the Editor. Authors are advised as promptly as possible of the action taken, usually within one month.

Proofs—Galley proof is sent to the author. Only necessary corrections in typography should be made. *No new material is to be added.* Corrected proofs should be returned *promptly* to the Institute of Radio Engineers, 33 West 39th Street, New York City.

Reprints—With the notification of acceptance of paper for publication reprint order form is sent to the author. Orders for reprints must be forwarded promptly as type is not held after publication.

PROCEEDINGS OF

The Institute of Radio Engineers

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CONTENTS

GENERAL INFORMATION

The PROCEEDINGS of the Institute are published monthly and contain the papers and the discussions thereon as presented at meetings.

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It is understood that the statements and opinions given in the PROCEEDINGS are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

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Member of the Board of Direction of the Institute, 1928

Arthur Batcheller

MEMBER OF THE BOARD OF DIRECTION OF THE INSTITUTE, 1928

Arthur Batcheller was born at Wellesley, Massachusetts, in 1888. He studied electrical engineering for three years at the Y.M.C.A. Polytechnic School at Boston, Mass., and was instructor for four years in radio and electricity at the evening sessions of the Boston School of Telegraphy. Mr. Batcheller was assistant to the electrical engineer in charge of installation and maintenance of railroad electric signal system for the Boston, Revere Beach, and Lynn Railroad for four years. From 1915 to 1916 he was employed as chief electrician for the Eastern Steamship Corporation at Boston, and from 1917 to 1919 he was U. S. Radio Inspector in charge of the New England District. In 1919 he became associate partner and founder of the Massachusetts Radio Telegraph School. Mr. Batcheller accepted an appointment as Radio Inspector in charge of the Second Radio District in 1920 with headquarters in New York. He has served as Supervisor of Radio since that date.

In 1925 he was commissioned a Lieutenant Commander in the United States Naval Service.

Mr. Batcheller is a member of the Committee on Conference to study safety of life at sea to be held in London in 1929. He was elected to Associate membership in the Institute in 1914 and was transferred to the Member grade in 1920.

Mr. Batcheller was appointed a member of the Board of Direction by the Board for a one year term in January of 1928.

CONTRIBUTORS TO THIS ISSUE

Bashenoff, Valerian I.: Born January 9, 1890 at Kostroma, U.S.S.R. E. E. degree, Polytechnical High School, 1918; in charge of radio engineering, 1918–1920. Engineer in charge at State Radio Works, Moscow, 1920–1921. Docent in radio engineering at Moscow Technical High School, 1921; associate professor of radio engineering at the Moscow Transport Engineers Institute, 1924–1928. Charter Member (1918) and Secretary (1919–) of the Russian Society of Radio Engineers. Secretary of the All-Russian Radio Association, 1921–1925. Since 1921 chief engineer of the radio department of the State Electrical Research Institute. Since 1927 technical editor of radio engineering section of the *Technical Encyclopedia.* Member of the American Association for the Advancement of Science; Member of the Institute of Radio Engineers, 1927.

Colwell, Robert C.: Born October 14, 1884 at Fredericton, N. B., Canada. A. B. degree, Harvard University; A. M. degree, University of New Brunswick; Ph. D. degree, Princeton University; professor of physics, Geneva College, 1913–1923; assistant director of radio laboratory, West Virginia University, 1918–1919; professor of physics, West Virginia University, 1924– . Member American Physical Society, Franklin Institute, American Mathematical Society. Associate member, Institute of Radio Engineers, 1921.

Dellinger, J. H.: (See PROCEEDINGS for May, 1928.)

Dickey, Edward T.: Born November 16, 1896 at Oxford, Penna. B. S. degree, College of the City of New York, 1918. Amateur experimenter, 1908–1918. Marconi Wireless Telegraph Company of America and Radio Corporation of America, 1918 to date. Chairman of the Subcommittee on Receiving Sets of the Standardization Committee, I.R.E., and member of the Meetings and Papers Committee, 1928. Fellow in the Radio Club of America; Junior member, Institute of Radio Engineers, 1915; Associate, 1917; Member, 1923.

Engel, Francis H.: Born July 19, 1899 at Washington, D. C. Educated at George Washington University, Washington, D. C. With National Electrical Supply Company, 1917–1918; U. S. Naval Radio Service, 1918–1919; radio laboratory, U. S. Bureau of Standards, 1919–1923; Radio Corporation of America, 1923 to date. Associate member, Institute of Radio Engineers, 1925; Member, 1928.

Harrison, J. R.: Born September 26, 1903 at Boston, Massachusetts. B. S. degree, Tufts College, 1925; M. A. degree, Wesleyan University, 1927. Electrician, Boston and Maine Railroad, 1921–1925. Assistant in physics, Wesleyan University, 1925–1927. Charles A. Coffin Fellow (Charles A. Coffin Foundation established by the General Electric Company) at Wesleyan University, 1927– . Member, Optical Society of America and American Physical Society; Associate member, Institute of Radio Engineers, 1926.

Schelleng, J. C.: Born November 11, 1892 at Freeport, Ill. A. B. degree, Cornell University, 1915. Instructor in physics at Cornell, 1915–1918. Since 1918 with the Western Electric Company and Bell Telephone Laboratories working on radio transmitters and transmission. For past few years in charge of studies on high power transmitters, transmitting antennas, and radio transmission. Associate member, Institute of Radio Engineers, 1923; Member, 1925; Fellow, 1928.

Terry, Earle M.: Born January 16, 1879 at Battle Creek, Michigan. A. B. degree, University of Michigan, 1902; M. A. degree, University of Wisconsin, 1904; Ph. D. degree, University of Wisconsin, 1910. Instructor, University of Wisconsin, 1904–1910; assistant professor, 1910–1917; associate professor, 1917–1928; professor, 1928, in charge of teaching engineering physics. Member of research staff, U. S. Naval Experimental Station during World War. In charge radio station WHA, University of Wisconsin. Previous research work in field of magnetism. President, local chapter Sigma Xi. Fellow, American Physical Society; Associate member of the Institute of Radio Engineers, 1919; Member, 1928.

Turner, H. M.: (See PROCEEDINGS for June, 1928.)

Van Dyck, A. F.: Born May 20, 1891 at Stuyvesant Falls, New York. Ph. B. degree, Sheffield Scientific School, Yale University, 1911. Amateur experimenter and commercial operator at sea, 1907–1910. With National Electric Signalling Company, Brant Rock, Mass., 1911–1912; Westinghouse Electric and Manufacturing Company, Research Dept., 1912–1914; instructor in electrical engineering, Carnegie Institute of Technology, 1914–1917; expert radio aide, U. S. Navy, 1917–1919; Marconi Company, General Electric Company, Radio Corporation of America, 1919 to date. Charter Associate member of the Institute of Radio Engineers; Member, 1918; Fellow, 1925.

INSTITUTE NOTES AND RELATED ACTIVITIES

October Meeting of the Board of Direction

A meeting of the Board of Direction of the Institute was held in the Institute offices at 4 P.M. on October 3rd, 1928. The following were present: Alfred N. Goldsmith, President; L. E. Whittemore, Vice-President; Melville Eastham, Treasurer; Arthur Batcheller, W. G. Cady, J. H. Dellinger, R. A. Heising, R. H. Manson, R. H. Marriott, and John M. Clayton, Secretary.

Upon recommendation of the Committee on Admissions, the following were transferred or elected to the higher grades of membership in the Institute: transferred to the grade of Fellow: Arthur E. Kennelly and C. W. Rice; elected to the grade of Fellow: Captain S. C. Hooper and Lynde P. Wheeler; transferred to the grade of Member: Kenneth N. Cumming and Alfred H. Hotopp; elected to the grade of Member: K. R. Smith and H. J. Walls.

Sixty Associate members and six Junior members were elected.

1928 Morris Liebmann Memorial Prize

Upon the recommendation of the Committee on Awards, the Board of Direction decided that the 1928 Morris Liebmann Memorial Prize is to be awarded to Professor Walter G. Cady, of Wesleyan University, for his fundamental investigations in piezo-electric phenomena and their application to radio technique.

The vote of the Committee on Awards and the Board was unanimous save for Dr. Cady's dissent in each case.

It was decided that the award is to be made at the November 7th meeting in New York City.

The Morris Liebmann Memorial Prize has been awarded in past years as follows:

Leonard F. Fuller	1919	H. H. Beverage	1923
R. A. Weagant	1920	John R. Carson	1924
R. A. Heising	1921	Frank Conrad	1925
C. S. Franklin	1922	Ralph Bown	1926
A. Hoyt Taylor	1927		

Board of Editors

To assist in the greatly increased work involved in the editing of manuscripts received for publication in the PROCEEDINGS, a Board of Editors of the PROCEEDINGS has been appointed with membership as follows: Alfred N. Goldsmith, Chairman; Stuart

Ballantine, Ralph Batcher, W. G. Cady, Carl Dreher, and G. W. Pickard.

The work of the Committee on Meetings and Papers has not been altered through the appointment of the Board of Editors. The Committee will continue to function as an Institute body which secures papers for publication and passes upon their suitability from a technical standpoint for publication in the PROCEEDINGS.

1929 YEAR BOOK

The membership list in the 1929 Year Book will be dated as of December 15th, 1928. No changes of address can be included in the 1929 Year Book unless such changes are received by the Institute not later than December 15th.

Members who have failed to return the address slips which accompanied the ballots for 1929 officers and members of the Board, mailed early in October, are urged to do so immediately.

It is expected that the 1929 Year Book will contain the adopted report of the Committee on Standardization in addition to the material published in former Year Books.

CHANGES OF ADDRESS

In future years it is planned that no "change of address" form will be sent to the entire membership each year. The addresses for the membership list of each Year Book will be kept up to date continuously.

Members who change their business connections or business title, even though there is no change in mailing address, are requested to advise the Institute office when such changes are made so that the Year Book catalog may correctly list both their mailing and business addresses.

FORTHCOMING PAPERS

The following is a list of papers on hand for probable publication in the PROCEEDINGS. It is expected that these papers will be published in early forthcoming issues:

Note on the Effect of Reflection by the Microphone in Sound Measurements, by Stuart Ballantine.

The Design of Transformers for Audio-Frequency Amplifiers with Preassigned Characteristics, by Glenn Koehler.

A Fine Adjustment Frequency Control for R. F. Oscillators, by G. F. Lampkin.

A Bridge Circuit for Measuring the Inductance of Coils While Passing Direct Current, by V. D. Landon.

Detection Characteristics of Three-Element Vacuum Tubes, by F. E. Terman.

A Note on the Directional Observations of Grinders in Japan, by E. Yokoyama and T. Nakai.

Standard Frequency Transmissions by the Bureau of Standards

The Bureau of Standards' Standard Frequency Transmissions for the months of November, 1928 to March, 1929 inclusive are given as follows:

Standard Frequency Schedule of Frequencies in Kilocycles

Eastern Stand. Time	Nov. 20	Dec. 20	Jan. 21	Feb. 20	March 20
10:00–10:08 P.M.	1500	4000	125	550	1500
10:12–10:20 P.M.	1700	4200	150	600	1700
10:24–10:32 P.M.	2250	4400	200	650	2250
10:36–10:44 P.M.	2750	4700	250	800	2750
10:48–10:56 P.M.	2850	5000	300	1000	2850
11:00–11:08 P.M.	3200	5500	375	1200	3200
11:12–11:20 P.M.	3500	5700	450	1400	3500
11:24–11:32 P.M.	4000	6000	550	1500	4000

Members are referred to page 1300 of the October, 1928 issue for more detailed information regarding these signals from the Bureau's Station WWV at Washington, D. C.

Information on how to receive and utilize the signals is given in Bureau of Standards' letter circular No. 171, which may be obtained by applying to the Bureau of Standards, Washington, D. C.

Institute Meetings

Atlanta Section

A meeting of the Atlanta Section was held in the Chamber of Commerce Building, Atlanta, on September 13th at 8 P.M. Walter Van Nostrand, chairman of the Section, presided. The meeting was addressed by Irving Wolff, of the Radio Corporation of America, on the subject of "Sound Measurements and Loud Speaker Characteristics," which included a brief description of the method used in measuring loud speaker response, comparing the Rayleigh Disk and Condenser Microphone as sound detectors. A number of loud speaker sound pressure response curves were shown and interpreted in terms of pleasantness of reproduction as determined by low and high frequency cut-off, smoothness of response and tone balance. The speaker also discussed tube overloading and the effect of loud speaker response on its apparent accentuation and diminution. The effect of room absorption characteristics, room resonances, position of loud speaker in the room, and position of listener with respect to the loud speaker were discussed. Numerous lantern slides showing diagrams and loud speaker response curves were shown.

Twenty-five members of the Section attended the meeting.

Canadian Section

The Canadian Section held a meeting on September 14th in the auditorium of T. Eaton Company. A. M. Patience presided. J. L. McCoy, of the Westinghouse Electric and Manufacturing Company of East Pittsburgh, Pa., presented a paper on "The Televox."

Messrs. Patience, Pipe, Soucy, and others participated in the discussion which followed.

One hundred and fifty members of the Section and their guests attended the meeting.

Cleveland Section

The October meeting of the Cleveland Section was held on the 10th of the month in the Case School of Applied Science. John R. Martin, chairman of the Section, presided.

The paper of the evening was presented by R. H. Ranger, of the Radio Corporation of America, the subject being "Recent Developments in Photo Radio."

The paper included a demonstration of telephoto and radio photograph transmission as well as numerous lantern slides.

Three hundred and thirty-five members of the Section and guests attended the meeting.

The next meeting of the Cleveland Section will be held on Friday, November 23rd, in the Case School of Applied Science. Dayton C. Miller will present a paper, "Analysis of Musical Sounds," and John R. Martin will present a paper on "Experimental Analysis of Loud Speaker Input and Output."

Connecticut Valley Section

On September 13th in the Hotel Garde at Hartford, Conn., the meeting of the Connecticut Valley Section was addressed by Edward T. Dickey and Francis H. Engel. K. S. Van Dyke, vice-chairman of the Section, presided. Mr. Dickey's paper was "Quantitative Measurements Used in Testing Broadcast Receiving Sets," and Mr. Engel's, "Vacuum-Tube Production Tests."

Both papers are published elsewhere in this issue of the PROCEEDINGS. Following the presentation of the papers a general discussion took place. Twenty-five members of the Section attended the meeting.

LOS ANGELES SECTION

A meeting of the Los Angeles Section was held on September 17th in the Elite Cafe, South Flower Street, Los Angeles. D. C. Wallace, chairman of the Section, presided.

L. Elden Smith read a paper on "The Problems and Methods of Television Transmission," which was followed by a paper by R. P. Parrish on "The Problems and Methods of Television Reception."

Preceding the meeting an informal dinner was held.

Forty-seven members and guests attended the meeting.

NEW ORLEANS SECTION

The first formal meeting of the newly organized New Orleans Section was held on September 15th at New Orleans.

Dr. Wolff presented a paper, "Sound Measurements and Loud Speaker Characteristics." Messrs. Andres, DuTreil, Lehde, and Gardberg took part in the discussion which followed the paper. Officers of the Section were elected as follows: Pendleton E. Lehde, chairman; L. J. N. DuTreil, vice-chairman, and Anton A. Schiele, secretary-treasurer.

On October 8th a meeting of the New Orleans Section was held in New Orleans. Chairman Pendleton E. Lehde presided.

Two papers were presented; the first by Mr. Lehde was entitled "The Underlying Principles of the Vitaphone and Movietone." The second paper was by Anton A. Schiele on "The Basic Principles of Radio Television." The following members participated in the discussion which followed: J. M. Roberts, J. M. Shaw, C. Schneider, D. S. Elliott.

NEW YORK MEETING

A meeting was held in New York City on October 3rd in the Engineering Societies Building, 33 West 39th Street. Alfred N. Goldsmith, President of the Institute, presided.

A paper was read by J. R. Harrison, of Wesleyan University, on "Piezo-Electric Oscillator Circuits with Four-Electrode Tubes." Messrs. Goldsmith, Harrison, Cady, and Hund participated in the discussion which followed.

The paper is printed elsewhere in this issue of the PROCEEDINGS.

Three hundred and twenty-five members of the Institute attended this meeting.

On December 5th a New York meeting will be held in the Engineering Societies Building, 33 West 39th Street. H. H. Beverage and H. O. Petersen will present a paper "Recent Short Wave Developments."

Philadelphia Section

The Philadelphia Section held a meeting in the Franklin Institute on October 10th. J. C. Van Horn, chairman of the Section, presided. Austin Bailey, of the American Telephone and Telegraph Company, read a paper, "The Receiving System for Long Wave Transatlantic Radio Telephony."

A general discussion on the part of the thirty members of the Section present followed the presentation of the paper.

This paper is published in this issue of the Proceedings.

Seattle Section

On August 28th a noonday luncheon for members of the Seattle Section was held. F. M. Ryan, of the Bell Telephone Laboratories, presented a paper, "Recent Developments in Radio Broadcasting." Thirty members of the Section and guests attended the luncheon and participated in the discussion of Mr. Ryan's remarks.

On September 19th a luncheon was held with W. K. Bert as the guest. Mr. Bert outlined the recent broadcasting frequency assignments. His remarks were supplemented by a general discussion on this and allied subjects.

A meeting of the Seattle Section was held in the Navy Yard at Puget Sound, Washington, on September 29th. Lieutenant Haas, radio officer of the USS *Lexington*, presented a paper on "Radio Communication Applied to Naval Aviation." The address given outlined the communication organization of the Navy and covered in detail the various types of equipment and systems used. A description of the method of operation and results obtained from the fathometer, radio compass, submarine telegraph, and range finder in addition to some of the radio telegraph systems was given.

Messrs. Austin, Deardorff, Renfro, and others discussed the paper. Preceding the presentation of the paper the fifty members of the Section present inspected the USS *Lexington* under the direction of Lieutenant Haas.

Oliver C. Smith, secretary-treasurer of the Seattle Section, has been transferred to Spokane, Washington. Abner R. Wilson, of Seattle, has been appointed secretary-treasurer to succeed Mr. Smith.

Washington Section

On October 11th in the Continental Hotel, North Capitol Street, Washington, D. C., a meeting of the Washington Section was addressed by Austin Bailey, of the American Telephone and Telegraph Company, on "The Receiving System for Long Wave Transatlantic Radio Telephony." F. P. Guthrie, chairman of the Section, presided.

Preceding the meeting forty-nine members and guests attended an informal dinner. The attendance at the meeting was seventy-two.

In the discussion which followed the paper the following took part: Messrs. A. H. Taylor, A. Hund, H. G. Dorsey, G. D. Robinson, G. Howard, F. P. Guthrie, and E. B. Dallin.

On November 8th a meeting of the Washington Section will be held in the Continental Hotel at which time Warren B. Burgess, of the Naval Research Laboratory, will present a talk on "The Radio Compass in Theory and Practice."

Committee Work

Committee on Constitution and Laws

The Committee on Constitution and Laws held a meeting in the offices of the Institute on October 2nd. R. H. Marriott, chairman; G. W. Pickard, and H. E. Hallborg were present.

The Committee is continuing the work in connection with the revision of the Institute's Constitution and By-Laws.

Committee on Standardization

A meeting of the Committee on Standardization was held in the offices of the Institute on October 2nd, 1928. The following members were present: L. E. Whittemore, Chairman; M. C. Batsel, W. G. Cady, J. H. Dellinger, E. T. Dickey, W. E. Holland, C. B. Jolliffe, R. H. Manson, E. L. Nelson, A. F. Rose, W. J. Ruble, and H. M. Turner.

The Committee began the consideration of the material transmitted to the members with the letter calling this meeting. Action was taken on all definitions contained in sections 1 to 5, inclusive, of the preliminary draft report and on the section on electron tube nomenclature.

Copies of material submitted by the Subcommittee on Bibliography and the Subcommittee on the Use of the Transmission Unit in Radio were distributed. The general plan being followed by these two subcommittees was approved.

It was agreed that the Subcommittee on the Use of the Transmission Unit in Radio should become known as the Subcommittee on Radio Transmission, and that there should be added to the matters which it has under consideration such questions as the following:

Definitions of terms appearing in the section on "Antennas."

Measurement of radiation and specification of service area of broadcasting stations.

Constancy of frequency of transmitting stations.

Specification and measurement of harmonic radiation from transmitting stations.

Specification and measurement of transmission-frequency characteristic-fidelity of transmission.

Specification and measurement of modulation.

It was agreed that further meetings of the committee should be held at approximately two-week intervals, in order to complete the consideration of material which is ready for action.

Committee on Admissions

At the meeting of the Committee on Admissions, held in the offices of the Institute on October 10th, R. A. Heising, Chairman; F. H. Kroger, and E. R. Shute were present.

The Committee acted upon ten applications for transfer or election to the higher grades of membership in the Institute.

Committee on Institute Awards

The Board of Direction of the Institute has appointed a standing Committee on Awards with membership as follows: J. V. L. Hogan, Chairman; L. W. Austin, Ralph Bown, W. G. Cady, and A. Hoyt Taylor.

This Committee is to make appropriate recommendation to the Board of Direction for awards of the Institute Medal of Honor and the Morris Liebmann Memorial Prize.

Personal Mention

R. M. Owen, of the Radio Corporation of America, has been transferred to Dallas, Texas.

Elmer L. Brown has recently become service engineer of the California-Victor Distributing Company, of San Francisco.

A. Norwood Fenton has recently become associated with the Sound Department of Metro-Goldwyn-Mayer Studio at Culver City, Cal.

John Q. Gaubert has left the Ward Leonard Electric Company to be in charge of production of the International Resistance Company, of Philadelphia.

J. Warren Horton, until recently associated with the Bell Telephone Laboratories as research engineer, is now connected with the General Radio Company, of Cambridge, Mass.

J. Warren Wright, recently associated with the Naval Research Laboratory, has been transferred to the Design Section, Radio Division, Bureau of Engineering, Navy Department, Washington.

Edwin W. Lovejoy, for a number of years in the service of the Department of Commerce at San Francisco as radio inspector, has been promoted to the position of U. S. Supervisor of Radio at Seattle, Washington.

Oliver C. Smith, of the Pacific Telephone and Telegraph Company, has been transferred to Spokane, Washington as District Transmission Engineer. Mr. Smith has served for some time as Secretary of the San Francisco Section.

Joseph H. Phillips, Jr. has gone to London, England to become technical advisor and consulting engineer to British Phototone, Ltd. Mr. Phillips was formerly associated with the Fox Case Corporation of New York City.

Volume 16, Number 11 *November, 1928*

PIEZO-ELECTRIC OSCILLATOR CIRCUITS WITH FOUR-ELECTRODE TUBES*

By

J. R. Harrison

(Charles A. Coffin Fellow, Wesleyan University, Middletown, Connecticut)

Summary—*Two new piezo-oscillator circuits using the screen-grid tube are described. One circuit uses feedback through the crystal, which has two pairs of electrodes with connections to the anode, control grid, and filament of the tube. In the other circuit the two electrodes of the crystal are connected between the anode and control grid. The new circuits are unusually stable and at low frequencies give greater power output than the three-electrode tube circuits. They are particularly useful at those low frequencies for which flexural vibrations are employed. When oscillating at flexural vibration frequencies crystals show a tendency to creep lengthwise until a position is reached which gives maximum power output. If the crystal is displaced from this position it will return to it again.*

THE first piezo-electric oscillator circuit was that described by Cady.[1] In this circuit the quartz plate has a mounting consisting of two pairs of metallic electrodes, *AC* and *BD* (Fig. 1). One pair of electrodes *BD* are connected to the input and the other pair *AC* to the output of the vacuum-tube cir-

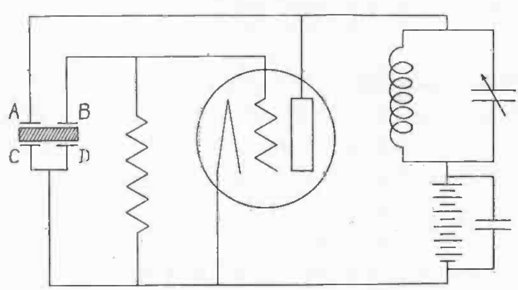

Fig. 1—Well-Known Type of Piezo-Oscillator Circuit Using Feedback through the Crystal.

cuit. The electrodes *C* and *D* are both connected to the filament of the vacuum tube, and they are sometimes replaced by a single large electrode covering the whole side of the crystal. The oscillations are sustained in this circuit by the energy feedback through the vibrating crystal. This circuit has never had wide application because it cannot be used for crystal oscillations at

* Original Manuscript Received by the Institute, August 1, 1928. Presented at New York Institute Meeting, October 3, 1928.

[1] W. G. Cady, Proc. I. R. E., 10, 111; April, 1922.

the high-frequency modes, that is, the vibrations at the frequency determined by the thickness of the plate.

The writer has found that this Cady type of crystal oscillator may be directly applied to the screen-grid type of vacuum tube.[2] This new circuit which is represented in Fig. 2 possesses several marked advantages over the Pierce type of crystal oscillator now commonly used. Here, as in the Cady circuit, the crystal mounting consists of four electrodes *A*, *B*, *C*, and *D*. The electrodes *C* and *D* are connected to the filament of the tube, and the electrodes *A* and *B* are connected to the plate and control grid respectively. The screen grid *S* is given a positive potential bias

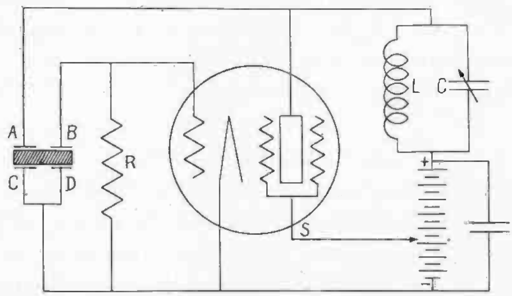

Fig. 2—Piezo-Oscillator with Screen-Grid Tube Similar in Operation to the Circuit of Fig. 1.

equal to about one-third of the plate potential. The plate-potential supply is conveniently used for this purpose. The plate elements *C*, *L* as usual are tuned approximately to the crystal frequency. The chief advantages of this circuit over the Pierce type of oscillator are more constant frequency, greater stability, and, at the lower radio frequencies, greater power output. This circuit may also be used to advantage at the high-frequency modes of the crystal, a performance which as noted previously was not possible with the original Cady oscillator circuit.

Power Tests

Power tests have been made of the piezo-electric oscillator as illustrated in Fig. 2. A 7½-watt shielded-grid tube was used

[2] For the theory and application of the screen-grid, four-electrode tube see the following:
A. W. Hull, and N. H. Williams, *Phys. Rev.*, **27**, 432; 1926.
A. W. Hull, *Phys. Rev.*, **27**, 439; 1926.
J. C. Warner, Proc. I. R. E., **16**, 424; April, 1928.

with a plate potential of 425 volts and a filament potential of 7½ volts. This tube had a rated maximum plate potential of 500 volts, but only 425 volts were used in order to allow comparison under identical conditions with the three-electrode type of 7½-watt tube, the maximum plate potential of which is of this latter value.

It has been found that at any given frequency the radio-frequency power output is a maximum at a particular shield-grid potential. Hence in each individual case the shield-grid potential should be adjusted to the optimal value. If this potential is made either too large or too small the power output will be diminished. This shield-grid potential is not very critical, but it is always preferable to make it smaller than the optimal value rather than larger, since the circuit is then more stable.

Tests were made using a quartz plate $30 \times 10 \times 1$ millimeters at the transverse effect frequency 92 kc (3300 meters). The power output was 0.55 watts. This same crystal in a Pierce circuit with a UX-210 tube gives a power output of but 0.20 watts. The power output at the lower radio frequencies is always comparatively small, but the tests indicate the relative merits of the two circuits. The optimal shield-grid potential in the above test was 200 volts.

Using the same crystal at the flexural vibration frequency[3] of 50 kc (6000 meters) with the shield-grid tube, the power output was 1.1 watts. The Pierce circuit under identical conditions but with the UX-210 tube gives 0.50 watts power output. The optimal shield-grid potential at this frequency was 225 volts.

In these tests the control grid of the shield-grid tube was given a negative bias by connecting to the negative filament lead through a three-megohm resistor R (Fig. 2). The power output could be considerably increased by substituting a choke coil and bias battery in series for the resistor R. Since this practice of using a choke coil has been found to cause undesirable fluctuations in frequency with three-electrode tube circuits[4] it was not adopted in the final tests cited here. At higher frequencies the power output of the four-electrode tube quartz-oscillator circuit is about the same as that from the Pierce oscillator at the same frequency. This would be expected since the voltage amplifi-

[3] J. R. Harrison, Proc. I. R. E., 15, 1040; December, 1927.
[4] R. C. Hitchcock, *Electric Journal*, 24, 430; 1927.

cation of the four-element tube diminishes as the frequency increases. Hull[5] has found the voltage amplification of certain tubes of this type to be 200 at 50 kc and only 7 at 10,000 kc.

Stability

It is well-known that in the case of any piezo-electric oscillator any slight damping of the crystal such as the application of pressure from the finger will cause an abrupt termination of oscillations. Furthermore oscillations will not be resumed on removing the cause of the damping until the circuit has been retuned. The screen-grid crystal-oscillator circuit of Fig. 2 is much more stable, for when the circuit has once been tuned for maximum power output, oscillations may be obtained at any time without retuning the circuit elements. For any given frequency a fixed condenser of the proper value could then be conveniently used in this circuit. Osc llations will of course terminate in this circuit when the crystal is sufficiently damped, but they will immediately be resumed when the cause of the damping is removed. The advantages of such characteristics do not need further elaboration here. In order to obtain this high degree of stability fairly good crystals must be used. In many cases crystals which would not oscillate in the three-electrode tube circuit will function in this circuit, but not with the same degree of stability.

In connection with these stability tests an interesting translational movement was noted at the flexural vibration frequency. The rotational movements of piezo-electric quartz plates in high-frequency fields have been described by Meissner[6] and certain translational movements were observed by Hirschhorn.[7] The phenomena here described were observed with a piezo-electric oscillator, whereas Hirschhorn's experiments were with a piezo-electric resonator. If a shield-grid crystal oscillator (Fig. 2) is tuned to maximum power output the tendency of the crystal to emerge from its mounting is observed. But if while oscillating the crystal is partly withdrawn from the mounting and then released it will immediately return to the original position. Some-

[5] A. W. Hull, *Phys. Rev.*, **27**, 439; 1926.

[6] A. Meissner, *Zeit. f. Tech. Physik*, **12**, 585: 1926. *Zeit. f. Hochfreq.*, **29**, 20; 1927. Proc. I. R. E., **16**, 281; April, 1927.

[7] S. J. Hirschhorn, *Zeit. f. Physik*, **44**, 223; 1927.

times when the crystal is being withdrawn from the mounting the damping is sufficient to kill oscillations, but if the plate has not been withdrawn too far it will again start oscillating and return to the former position.

If the circuit is not quite tuned to maximum power output the crystal has been found to have a tendency to slide out of the mounting. As the crystal recedes from the mounting the power output increases and the motion ceases when the power output becomes a maximum. As before the limit of emergence, until the

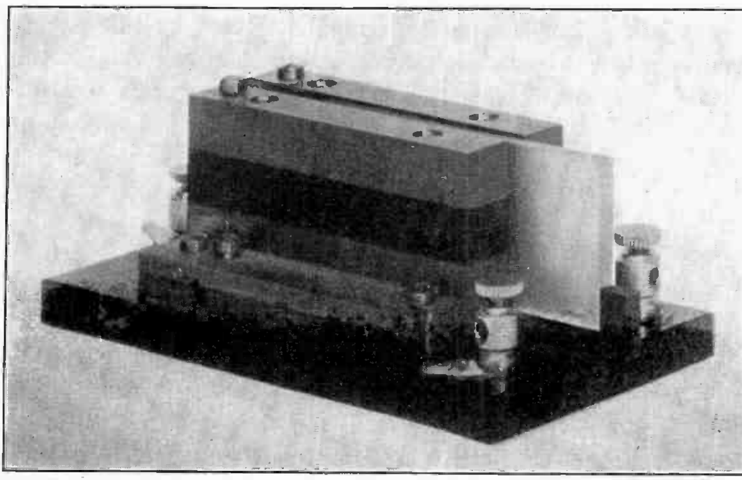

Fig. 3—Quartz Crystal in Flexural Vibration Mounting.
The crystal is at the left, projecting from the mounting to show the sled used to investigate the nature of translational movements.

circuit stops oscillating, seems to be about one-half the total surface of the plate. It is a curious fact, however, that the maximum power output is the same with one-half of the crystal emerging as it was in the previous case when the circuit was initially tuned to maximum power with the crystal wholly between the electrodes. If now the crystal is forced back between the electrodes the power output will diminish and the crystal will slide out again to the position of maximum power when the restoring force is removed. The crystal is indifferent to the direction of emergence from the mounting; slight inclinations from the horizontal of the crystal mounting seem to be the sole determinant of this direction. In any case, for a given circuit condition the distance traveled in either direction was found to be approximately the same. The oscillating crystal seems to have a tendency to tune the circuit to maximum power output by its motion as described above. The emergence of the crystal from the mounting diminishes the capacity of the system since a dielectric of air is then replacing the quartz dielectric in the crystal mounting. This means also that the circuit is operating at a different point on the characteristic curve of the crystal. A photograph of one of the crystals with flexural vibration mounting as used in these tests is shown in Fig. 3.

The same translational movements of the crystal are still observed when it is enclosed in a vacuum chamber which would indicate that the effects are probably not due to air blasts as described by Meissner.[8] If the movements are not due to air

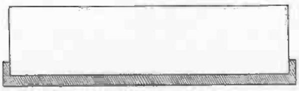

Fig. 4—Quartz Crystal Standing on Sled (cross-hatched) Which Prevented the Creeping of the Crystal When Oscillating.

blasts the only probable explanation would be that the crystal creeps on its base when vibrating, or possibly an electrostatic effect in the dielectric.

To determine the cause a very light fiber sled *AB* (Fig. 4) was constructed to fit the crystal. The ends of the sled were made projecting as shown in the same figure so the crystal could not creep off. The crystal is also shown on the sled and in the mounting by Fig. 3. If the motion was due to a creeping effect of the vibrating crystal against its mounting the sled will now arrest the motion. If the motion was due to a dielectric phenomenon it should still take place with the sled, provided the weight added was negligible and the frictional effects were still small. Care was taken to reduce the friction between the sled and the base of the crystal mounting to a minimum by careful polishing and lubrication. No tendency of the crystal to move was noted when the sled was used although crystal oscillations were obtained just as before. Evidently, then, the motion is due to the vibration of the crystal against its support with a resulting creeping tendency.

[8] A. Meissner, loc. cit.

Piezo-Electric Oscillator with Two-Electrode Mounting

Another new piezo-electric oscillator circuit is illustrated in Fig. 5. Here the crystal has a two-electrode mounting and is connected between the control grid and plate of the vacuum tube. This circuit is more stable than the crystal-oscillator circuits now commonly used, and at the lower radio frequencies gives a greater power output. As in the previous circuit a gridleak R is connected from the filament to the control grid, but for greater power output this is replaced by a choke coil and grid-bias battery. The plate circuit LC is tuned approximately to crystal frequency. The shield grid S as in the previous case is given a positive potential equal to about one-third the plate potential.

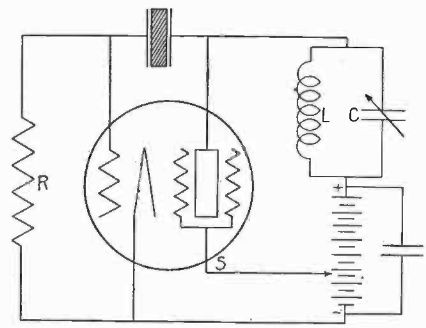

Fig. 5—Piezo-Oscillator with Screen-Grid Tube Similar in Operation to the Pierce Circuit.
The crystal is connected between the control grid and anode.

Also, as before, the shield-grid potential should be adjusted to the optimal value for maximum power output.

The four-electrode tube is here used as a shield-grid amplifier. The crystal does, however, annul the effects of shielding to a certain extent by introducing a capacity from the control grid to the plate of the vacuum tube.

This circuit (Fig. 5) is analogous to the piezo-electric oscillator using a three-electrode tube first described by Pierce.[9] This is the circuit in which the crystal is connected from grid to plate and is illustrated in Fig. 6. Oscillations are sustained in this circuit by energy feedback through the grid to filament inter-electrode capacity of the vacuum tube. It is well-known

[9] G. W. Pierce, *Proc.* Amer. Acad., 59, 81; 1923

that this circuit is analogous to the Colpitts oscillator circuit with the crystal acting the part of an inductive reactance.

From the practical point of view, the new circuit here described (Fig. 5) is more convenient than the circuit of Fig. 2, since the crystal mounting has but two electrodes like those now commonly used. The circuit possesses the disadvantage, however, that it is not as constant in frequency with variations in circuit constants as the circuit of Fig. 2.

The shielded-grid, four-electrode vacuum tube will not function as a piezo-electric oscillator with the crystal connected from

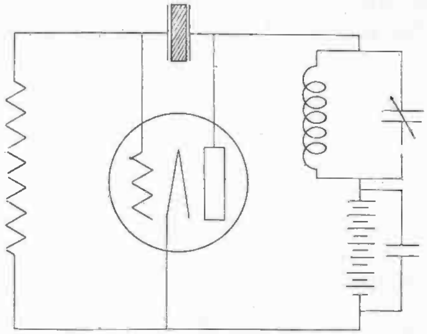

Fig. 6—Pierce Type of Piezo-Oscillator with Crystal Connected between Grid and Anode.

control grid to filament. This is not possible, since in that type of circuit oscillations are sustained by energy feedback through the control grid to plate inter-electrode capacity and in the shield-grid tube this capacity is so small that the feedback is negligible.

The circuit can be made to oscillate with the crystal connected from the control grid to filament if the shield grid and plate are connected together and used commonly as the anode of the system. There is no advantage in doing this, however, since we then have what is effectively a three-electrode tube oscillator as commonly employed.

Hull's Piezo-Electric Oscillator Circuit

A. W. Hull[10] has recently described still another piezo-electric oscillator using the four-electrode tube. Hull was the first to describe a piezo-electric oscillator circuit using the four-

[10] A. W. Hull, British Patent No. 266, 690; March, 1927.

electrode tube. This circuit, which is illustrated in Fig. 7, uses the four-electrode valve as a space-charge-grid tube. The crystal Q is connected from the filament to the grid nearest the plate (now the control grid). The inner grid G (nearest the filament) now becomes the space-charge grid and is given a positive potential from the plate supply battery B. In Hull's patent the tuned circuit LC (Fig. 7) is replaced by an inductance L having a natural frequency at least twice that of the crystal used. This circuit is then coupled to a four-electrode tube (shield-grid) amplifier with a tuned output circuit. Hull claims extreme constancy of frequency for this circuit—"With a proper choice of

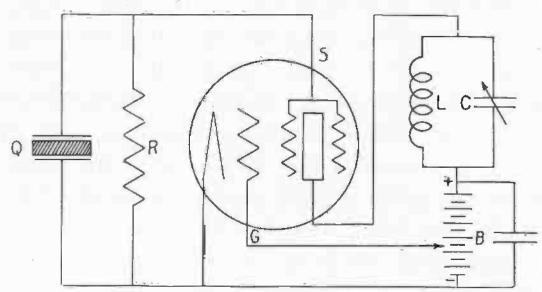

Fig. 7—Hull's Piezo-Oscillator Circuit Using the Four-Electrode Tube As A Space-Charge-Grid Device.

circuit constants and the temperature of the piezo-electric element maintained constant, the generator remains constant to less than one part in a million." The power output of this type of circuit as shown in Fig. 7 does not compare with that obtained from the new circuits here described with the four-electrode tubes now available.

Twin Oscillation Frequencies

Experiments show that crystals will oscillate at two frequencies quite close together for each mode of vibration in the four-electrode vacuum-tube circuit of Fig. 2. This only happens, however, when the two pairs of crystal electrodes AC and BD are close together. Under certain conditions, then, oscillations are obtained at two different points on the same resonance curve of the crystal. When the two pairs of crystal electrodes are not close together only one oscillation frequency is found for each mode of crystal vibration as with the familiar three-electrode tube circuits.

Normally crystal oscillations are sustained in a circuit of this type by energy feedback through the vibrating crystal itself. This was found by experiment to be the lower of the two oscillation frequencies obtained, and the one which always remained when the pairs of crystal electrodes were moved far apart.

The higher of the two oscillation frequencies obtained was found by frequency measurements to be the same that is obtained from the crystal when it is connected simply between the control grid and the plate as in Fig. 3. In other words, this is the case where the crystal acts as an inductive reactance like the inductance in a Colpitts oscillator circuit. The measurements above referred to were simply frequency measurements of the two oscillation points of the circuit of Fig. 2 and the single oscillation point of the circuit of Fig. 3. For all of the three frequency measurements the same crystal was used on the same mode of vibration. The method of measurement was to obtain an audio-frequency beat note between the piezo-electric oscillator in question and another piezo-electric oscillator of nearly the same frequency. The beat note was amplified on a two-stage, audio-frequency amplifier and measured from the readings on a sonometer driven by a telephone receiver connected to the output of the amplifier.[11] For accurate determinations of frequency from the sonometer, reference is made to Allan's corrections to the well-known formula due to Brook Taylor.[12]

If the electrical connections to one pair of metallic electrodes such as AC (Fig. 2) are reversed, oscillations will still be maintained on the fundamental mode of vibration. Cady found with the three-electrode, vacuum-tube, piezo-electric oscillator of Fig. 1 that the connections to a pair of electrodes should be reversed in this way to obtain oscillations on the first harmonic of the transverse effect.[13] He did not, however, obtain oscillations on the fundamental with the reversed connection. The circuit now under consideration (Fig. 2) has with the reversed

[11] C. B. Jolliffe and G. Hazen, Bureau of Standards Scientific Papers, 21, 179; 1926.
[12] G. E. Allan, *Phil. Mag.*, 4, 1324; 1927.
[13] W. G. Cady, Proc. I. R. E., 10, 111; April, 1922.

connection one oscillation frequency for the transverse fundamental and two oscillation frequencies close together for its first harmonic. The reversed connection then suppresses the lower oscillation frequency of the transverse fundamental. This would be expected since the proper phase relationship for sustaining oscillations by feedback through the crystal is not obtained with the reversed connection.

Tests were then made to determine whether the lower of the two oscillation frequencies obtained is due to feedback through the crystal. A long crystal of $10.3 \times 2.0 \times 0.1$ centimeters was secured which was fitted to a crystal mounting having two pairs of electrodes. The electrodes were adjustable so that the distance between the pairs of electrodes *AC* and *BD* (Fig. 2) could be varied so that they might be very close together or at the opposite ends of the crystal. When the pairs of crystal electrodes are separated by about one-half centimeter or more, oscillations are obtained only at the lower frequency corresponding to each mode of vibration. Also, when the electrodes are thus separated and the connections to one pair reversed, no oscillations are obtained at frequencies corresponding to the fundamental modes of the transverse and longitudinal effects. Oscillations are always obtained, however, with normal connections as in Fig. 2 at the lower oscillation frequency for the transverse and longitudinal fundamentals even though the pairs of electrodes are separated by 6 to 8 centimeters. This seems to indicate conclusively that the oscillations are sustained by feedback through the crystal.

Flexural Vibrations

Recently a method has been described for exciting very much lower frequencies than hitherto obtained from quartz plates with flexural vibrations in the length-breadth plane.[14] Considerable

[14] J. R. Harrison, Proc. I. R. E., **15**, 1040; December, 1927. Author's note: More recently other investigators have described similar methods for obtaining still other flexural vibrations in various planes of the quartz plate. The investigations cover both the "Curie cut" and the "30-degree cut" quartz plates. A method of exciting torsional vibrations is also given. In all these cases, however, the crystal response is so feeble that it is only detected by the luminous glow surrounding the plates when they are vibrating in a partially evacuated chamber. For details see the following references:

E. Giebe and A. Scheibe, *Zeit. f. Instrumentkunde*, **47**, 269; 1927. *Zeit. f. Hochfrequenztechn.*, **30**, 32; 1927. *Zeit. f. Physik*, **46**, 607; 1928. *Elektr. Nachr.-Techn.*, **2**, 65; 1928.

difficulty has been encountered, however, in making crystals oscillate at flexural vibration frequencies with a three-electrode tube circuit as commonly used. It was found necessary to use a pickup or sensitizing coil in series with the crystal in the grid

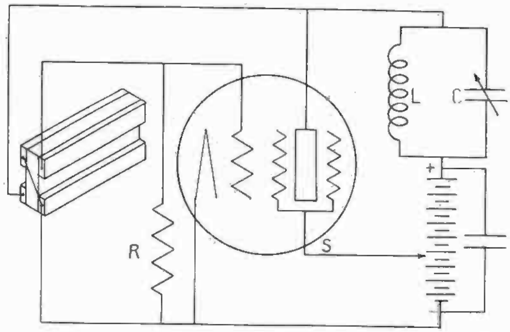

Fig. 8—Connections to the Flexural Vibration Mounting When Using the Screen-Grid Tube with Feedback through the Crystal.

circuit to obtain sufficient feedback to sustain oscillations. The only other alternative offered at that time was to connect the crystal to a three-stage, resistance-coupled amplifier using the method of feedback through the crystal. The energy feedback

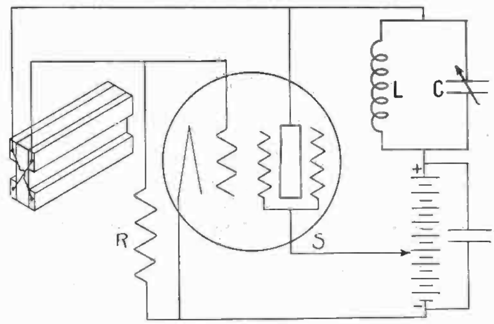

Fig. 9—Connections to Flexural Vibration Mounting When Using Screen-Grid Tube with Feedback through the Tube.

was then sufficient to sustain oscillations without the pickup coil.

The use of a pickup coil in series with the crystal is a serious disadvantage since if the coupling is made too close the large induced voltages may puncture the crystal or set up parasitic oscillations independent of it. The inconvenience of the three-stage amplifier scheme is only too apparent and the power output is comparatively small.

The four-electrode tube, crystal-oscillator circuits are used to considerable advantage at low frequencies. With the four-electrode tubes now available, crystals oscillate at the flexural mode without a pickup coil. Either of the new circuits here described can be used. The four-electrode tube circuits can be used to equal advantage at the higher modes of flexural vibration.

The screen-grid tube oscillator circuit utilizing feedback through the crystal is illustrated in Fig. 8 as applied to a crystal for flexural vibrations. The circuit is exactly the same as that shown in Fig. 2 except for the crystal mountings and the connections thereto. Fig. 9 illustrates the application of the circuit of Fig. 5 to a crystal with a flexural vibration mounting. In this type of circuit, as was explained before, oscillations are sustained by feedback through the vacuum tube.

Finally, the author wishes to thank Professor W. G. Cady for his encouragement and many helpful suggestions during the progress of this work. Thanks are also due to Professor K. S. Van Dyke for suggestions.

Discussions

August Hund†: We have just listened to a most interesting contribution to this subject. No doubt with the advent of the two-grid tube everyone working with the piezo-crystal must have recognized in such devices a means for better stabilization than that found in the ordinary tube circuits. I was glad that Mr. Harrison brought out in his paper tonight a point which I distinctly missed in the preprint of his paper. The point to which I have reference has to do with his statement, "these circuits are more stable." In tonight's presentation the speaker has told us very clearly that by "stable" he means that the oscillations start more easily, or when stopped by some means come back more easily. He, therefore, makes a distinction between stability of this type and stability with respect to frequency. Usually we think of a stabilized crystal circuit as one the frequency of which is very constant. It may therefore be advisable in the final publication of the paper to bring this point out clearly in order to avoid any misunderstanding on the part of the reader.

† Radio Division, Bureau of Standards, Washington, D. C.

I do not agree that the circuit is stable with respect to frequency when it gives more power. I doubt that very much; I think it is the opposite. Any circuit that has very much back feed is apt to run away—to swing very much from side to side, but when its amplitude of vibration is very, very small, it is more apt to stay right on the correct frequency.

Another thing which has occurred to me which was not brought out in the paper is this: Mr. Harrison realized that when we use a shield-grid tube in the real sense of a shield-grid tube (with proper shielding voltage), we cannot connect the crystal between the filament and the grid and expect oscillations because the capacity—call it effective capacity—between the control grid and the plate may be only one per cent of the physical capacity which it would have without the plate shielded; but it will oscillate. All we have to do is to use the circuit as he had it. The paper described a circuit in which the crystal is connected between the grid and the plate, using the crystal capacity as a bridge to feed back. We can also connect the crystal between the control grid and the filament and use a very small condenser between the control grid and the plate. I think this is a better circuit than the one described in which the crystal is between the control grid and the plate, because we can use a very small air condenser of good construction and produce very stable oscillations. With this circuit you can produce all three oscillations very easily. In the Sound Laboratory of the Bureau I have used this circuit for some two years with much success.

J. R. Harrison: I had supposed that the context would make clear what I meant by stability—a circuit which starts oscillating very readily without retuning.

With regard to making a screen-grid tube oscillate with the crystal connected between control grid and anode, I would say that the interlectrode capacity of the tube which is always present in parallel with the crystal is now very much smaller than if a three-electrode tube had been used. The tube is not of course then used in its complete sense as a screen-grid tube, but we are still benefited but its screening action because of the very small capacity shunted across the crystal.

I have succeeded in making a four-electrode tube oscillate with a piezo-electric crystal connected between the control and filament. This cannot be done, however, with a four-electrode tube used as a screen-grid tube. If the screen-grid tube is used in this way it is necessary to introduce a capacity between control grid and anode as Dr. Hund has done, or to make the screen-grid potential very small. Both methods then producee the same result, i.e., a reduction of the screening action of the valve.

August Hund: Then you have no screen-grid tube any more.

J. R. Harrison: But it is doing just the same thing you did only in a slightly different way.

August Hund: I do not think it is the same because it is an easy matter to connect a small fixed condenser externally, whereas the interelectrode capacity (*effective* interelectrode capacity) does not seem very constant. Changes in the filament emission, potential variations on all electrodes, etc., no doubt make the capacity rather indefinite. I regard the external capacity method as being decidedly better.

J. R. Harrison: In the Cady type of piezo oscillator which uses mechanically tuned feedback through the crystal (Fig. 2) the pairs of crystal electrodes may be 8 or 10 centimeters apart and oscillations will still be maintained. The capacity introduced across the control grid and anode of the screen-grid tube is then very small. It would seem that this is the only method of applying the crystal to the screen-grid tube which does not appreciably reduce the screening action.

August Hund: There is another question that occurs to me. The paper brings out that one should adjust the screen-grid potential to an optimum—call it an energy optimum. Does that potential which you apply still keep the screen-grid tube screened, or have you changed it so much that you have a case of a feedback, and you get more energy on account of this?

J. R. Harrison: I feel quite sure it is still being used as a screen-grid tube when using the circuit of Fig. 2. The screen-grid potential is not very critical, but there is a definite optimum value for maximum power output. Under these conditions the screen-grid current is very small, usually less than one-tenth of the anode current, thereby indicating that the tube is virtually performing as a screen-grid tube.

W. G. Cady†: Regarding the two frequencies very close together which Mr. Harrison has described, at either one of which the circuit may be made to oscillate, a word may be said. You

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will recall that they occur only with a quartz plate having two pairs of electrodes, one pair being connected between filament and grid, and the other between filament and anode. The transition from one frequency to the other comes when the two pairs of electrodes are at a certain critical distance apart. What I wish to point out is that these two frequencies are not due to two different modes of vibration of the crystal, but that they simply represent two different operating points on the resonance curve relating amplitude of vibration to frequency. The point on the curve at which any crystal operates depends on circuit conditions. We have one set of circuit conditions when the electrodes are far apart, so that feedback is due solely to the mechanical vibrations of the quartz. On gradually moving the electrodes more closely together, the effective grid-anode capacity begins to be appreciable and increases until quite abruptly feedback begins to take place electrostatically instead of mechanically. This is the change in circuit conditions, I think, that accounts for the change in frequency.

It is hardly necessary to add that this is quite a different phenomenon from the abrupt "jumps" in frequency that are sometimes so troublesome with crystal-controlled oscillators of the ordinary type. Such jumps are due to temperature changes and other causes, and represent, usually, a shift from one mode of vibration to another. They are only found, of course, when there happen to be two or more possible modes of vibration of nearly the same frequency.

Alfred N. Goldsmith†: It is indeed most fortunate that just when extremely accurate frequency control is becoming so necessary to radio, the instrumentalities for it should become available. It may be that this is putting the cart before the horse and explaining how remarkable it is that great rivers always flow past large cities. Perhaps the modern desire and need and application of constant frequency is the result of the crystal oscillator and similar high precision frequency control devices.

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Volume 16, Number 11 *November, 1928*

NOTE ON THE DETERMINATION OF THE IONIZATION IN THE UPPER ATMOSPHERE*

By

J. C. Schelleng

(Bell Telephone Laboratories, New York City)

Summary—*The paper describes a method of estimating the distribution of ionization in the upper atmosphere. It is based upon measurements on several frequencies of the effective height as determined by interference or echo experiments. The latter two types of experiment are shown to give identical results.*

A NUMBER of ingenious radio experiments have been devised and carried out by which estimates of the distribution of ionization in the upper atmosphere have been obtained. Most of these lead to an effective height which is arrived at by assuming regular reflection. Plausible assumptions are sometimes invoked to permit the calculation of corrections which take account of the fact that the density of ionization varies continuously. These calculations usually involve the method of trial and error, and while some of them may possibly lead to fairly accurate results, a more direct method is desirable.

One of the purposes of the present note is to discuss a different method which may possess certain advantages. As a preliminary we will discuss certain relationships between some of the different methods which have been used.

In one class of experiments the time required for a pulse to travel by the overhead path to the receiver is measured. While in Breit's experiment this is done directly by time measurements we must also include in this class experiments such as those of Bown, Martin, and Potter; Appleton and Barnett; and Heising, in which by means of a slow shift of frequency, the number of "fringes," i.e., maxima of field intensities, is counted, either by observing a meter or by recording with an oscillograph. That this type of measurement gives the time required for a pulse to travel between the stations (group time) is not obvious. The mistake is sometimes made of assuming that the total number of wavelengths in the path can be obtained in this way. Thus Pedersen[1] states that this type of measurement gives values of

* Original Manuscript Received by the Institute, August 27, 1928.

[1] "Propagation of Radio Waves," p. 229.

the height of the apex of the path which are too small, a statement which would be correct if the measurement gave the total number of wavelengths. As a matter of fact this type of measurement in general gives heights which are too great, as in the case of echo experiments.

This can be shown as follows. The experiment gives directly the quantity dN/df, where N is the total number of wavelengths (N_2) in the upper path minus the total number (N_1) in the direct path. In the case of reflection at a sharp surface of discontinuity we would have $N=D/\lambda=fD/c$ where D is the difference of the distances of D_1 and D_2 and c is the velocity *in vacuo*. In this case

$$\frac{dN}{df}=\frac{D}{c} \text{ and } D=c\frac{dN}{df}\cdot \tag{1}$$

The results of experiments have been interpreted in this way[2], the effective height, h, of the apex of the path being calculated by simple triangulation.

Now in general, regardless of the path followed,

$$N=N_2-N_1=f(T_{p2}-T_{p1}) \tag{2}$$

in which T_p refers to the *phase time*, or the time required for a crest of the wave to travel between stations along the path indicated by the subscript.

Therefore

$$D=c\frac{dN}{df}=c\left(\frac{d(fT_{p2})}{df}-\frac{d(fT_{p1})}{df}\right) \tag{3}$$

But $$\frac{d(fT_p)}{df} \text{ is the } \textit{group time.}$$

Hence the height is the same as would be measured at the time by an echo experiment which would measure this time lag directly. It should be noted that this conclusion does not involve any assumptions as to the mechanism of transmission. It is true in general regardless of the paths of the two waves.

One conclusion to be drawn is that we should be able to compare the results of these two methods.

Breit has shown that in the case of waves for which the effect of collisions and the effect of the earth's magnetic field may be neglected, this triangulation, in the case of pulse experiments,

[2] The authors referred to fully appreciated that the results give only apparent heights.

also gives the correct earth angle. At lower frequencies these assumptions are not strictly true. In the range of short waves they are correct to the extent that we can depend on the assumption that ionization is not a function of the horizontal coordinates.[3]

Hence the several methods for measuring the height by determining the pulse time, the earth angle, and shift of interference fringes, lead substantially to the same result for short waves. *None of them give the total number of waves in the path.*

The method to be described requires a means for obtaining the total number of waves in the path. This might be done experimentally in the following difficult manner. Starting at a very low value, the frequency would gradually be increased. At a receiver located one or two hundred kilometers away the fringes would be counted. That these fringes exist has been found by Hollingworth at 20 kc, by Bown, Martin, and Potter at 610 kc, by Appleton and Barnett at 750 kc, and by Heising at about 5000 kc. Each fringe would represent the gain of one wave in the overhead path as compared with the number, also increasing, in the direct path. This number, integrated from zero frequency to the frequency in which we are interested, would give the difference in wave numbers for the two paths. Practically, we would have to start within the radio range, so that an estimate of these quantities at the lower frequency would have to be made. This, in itself a small correction, could be calculated with sufficient accuracy to make the final error very small providing that the upper frequency limit is large compared to the lower. Thus if these limits were respectively 5000 and 20 kc the error would be a very small fraction of a per cent.

Having obtained the wave number we would use the construction suggested by Pedersen,[4] shown in Fig. 1. According to his calculations, the wave number in the path APQ is equal to AQ/λ_0 where λ_0 is the wavelength *in vacuo*. This is not strictly true, but the error is small providing that the initial earth angle is less than 60 deg. from the horizontal. This therefore furnishes a method of determining the height of the apex of the path.

However, this experimental procedure is prohibitive and unnecessary. As shown above,

[3] It also assumes the validity of the method of rays. This method should be subjected to a more critical examination than any it has yet received.

[4] "Propagation of Radio Waves," p. 176.

$$T_{g2}-T_{g1}=\frac{d}{df}(N_2-N_1)$$

Therefore

$$N_2-N_1=\int_0^{f_0}(T_{g2}-T_{g1})df=\int_0^{f_0}\frac{d}{df}(N_2-N_1)df \tag{4}$$

Hence

$$AQ-AF=\frac{\lambda_0(N_2-N_1)}{2}=\frac{c}{2f_0}\int_0^{f_0}(T_{g2}-T_{g1})df. \tag{5}$$

As pointed out above, the integrand can be obtained from different types of experiments. Having determined $AQ-AF$ the solution for FQ is obvious.

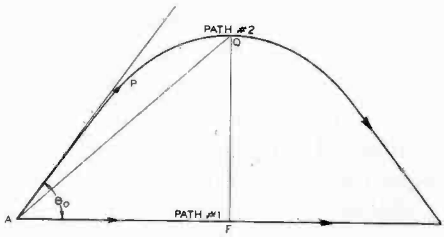

Fig. 1

We know that the group time at the lower frequencies is less than for the high. This method corrects the large apparent heights of the higher frequencies by means of the small apparent heights of the lower frequencies.

The next step is the calculation of the ionization on the basis of the earth angles calculated from the original data. Owing to complications due to the earth's magnetic field this can be done with confidence for the short waves only.

A further refinement in the estimate could be made by recalculating the number of waves in the path on the basis of the computed distribution of ionization. This would furnish a second approximation to the estimate for the height, the magnitude of the error being dependent on the earth angle and being small under the conditions already stated.

Data are not available for carrying out this calculation with confidence. It is of interest, however, to try the method with data which are based on actual experiment, but which are necessarily assumed to hold under somewhat different conditions from those which actually existed during the experiments.

In Fig. 2 the apparent night-time heights from the experiments mentioned are plotted on a kilocycle scale. The four points correspond to the results of Hollingworth, Bown, Martin and Pot-

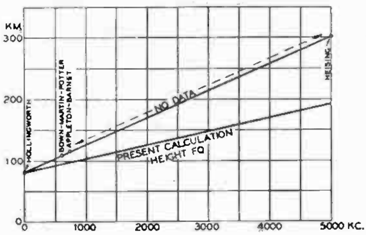

Fig. 2

ter; Appleton and Barnett; and Heising. It is rather interesting that these fall on a straight line, the equation of which is

$$H = 80 + 0.0440\, f \tag{6}$$

The exactness is accidental, however, since in the absence of knowledge regarding the time of year for some of these experiments we have averaged Hollingworth's summer and winter results. There is a very large part of the spectrum in which there are no data. The point for 5000 kc is the mean of widely different observed values.

Assuming for the sake of illustration that the base line ($2d$) had been 150 km in all these experiments, the difference in the group times along the two paths would have been

$$\frac{2}{c}\left(\sqrt{H^2+d^2}-d\right)$$

Hence by (5),

$$AQ - AF = \frac{1}{f_0}\int_0^{f_0}\left[\sqrt{H^2+d^2}-d\right]df \tag{7}$$

Substituting (6) in (7) and carrying out the indicated operations, the height FQ of the apex of the actual path can be calculated. This is shown in Fig. 2, which indicates that at the highest frequency shown the actual height for the conditions assumed would have been 192 km instead of 300. Owing to the relatively high angles implicitly assumed, the calculated figures are somewhat too low.

Fig. 3 gives the electrons per cubic centimeter calculated on the assumption that collisions and the earth's magnetic field do not greatly affect the results. These assumptions are satisfactory at frequencies higher than two or three megacycles but at lower frequencies the earth's magnetic field will produce errors.

We wish to emphasize that these calculations are given as an example of a method. While the estimate cannot have much

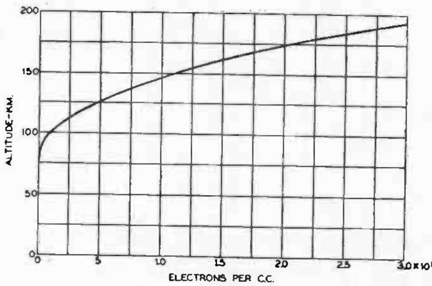

Fig. 3

weight on account of the meagerness of the data, the results nevertheless do look plausible, and are probably more accurate than the original data.

Conclusión

The similarity between interference experiments and pulse experiments is pointed out. A method for obtaining the number of waves in the trajectory of the overhead wave is described. It is then possible to calculate the height of the apex of the path. From ray theory the number of electrons per cubic centimeter can then be calculated for certain conditions. By combining the results of different experimenters and making certain assumptions regarding the numerical quantities, the distribution is calculated, primarily as an example of the method. The results indicate an approximate increase in proportion to the second power of the height above 80 km, reaching a value of 3×10^5 at about 200 km. This is for night-time transmission.

The results indicate that a fruitful line of study will be to carry out echo or fringe experiments at several frequencies from 1000 to 10,000 kilocycles, the base line being made sufficiently large to avoid initial ray angles greater than 60 deg. from the horizontal. Such experiments should enable us to calculate the number of wavelengths in the path and hence the distribution of ionization. An experiment of this kind is now in preparation.

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ANALYSIS OF BROADCASTING STATION ALLOCATION*

By

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THE new allocation of broadcasting stations announced by the Federal Radio Commission on September 11, 1928 was prepared in accordance with the allocation plan set forth in the Commission's General Order No. 40, of September 7, 1928. Both the plan and the allocation itself were drawn in compliance with the requirements of the 1928 Amendment to the Radio Act as to equalization of broadcasting facilities between the zones and states. The allocation was, furthermore, made in compliance with the Commission's decision that no existing stations should be abolished at the time of its inception. It is believed to provide the greatest aggregate of radio service to the country possible under the two conditions just mentioned. Its principal features are: (a) it provides a definite, invariant basis of station assignments for each zone and locality, (b) it can be improved wherever interference is found to exist in actual operation, through the reduction of power or the elimination or particular stations, without disturbing the station allocation as a whole, (c) it eliminates heterodyne interference on 80 per cent of the listener's dial, (d) it recognizes the essentially different requirements of local, regional, and distant service.

Proper provision for the differing requirements of the listeners in large rural areas, cities, and intermediate areas made the preparation of this allocation a difficult task. It would have been very easy to allocate all existing stations, and many more, if only local service or the effects a few miles from the station had been considered. As soon as consideration was given to service more than a few miles from a station, serious difficulty arose, since heterodyne interference extends to many times the distance from a station to which actual program service extends. Operation of two or more stations on a channel (i.e., on one freqnency or wavelength) results in an area of destructive interference very much greater than the area in which program service is provided unless the stations are of low power and widely spaced

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geographically. It is only when a station has exclusive use of its channel that program service free from interference can be furnished at great distances. But since there are only 90 channels available for broadcasting in the United States, there could not possibly be more than 90 simultaneously operating stations giving service at great distances.

The only reasonable solution of this dilemma is that which the Commission has adopted, the setting aside of a certain number of channels (40) for distant or rural service, each with only one station assignment,[1] and the use of the remaining channels for service at more moderate distances with several station assignments on each channel, all with limited power and located systematically at proper distances apart to minimize interference.

The channels used for the latter type of station assignments are subdivided into "regional service" channels, which are kept substantially free from heterodyne interference by restricting power to 1000 watts and keeping the stations on a given channel in general 1000 miles or more apart, and several other types of channels on which heterodyne interference is permitted but which give satisfactory local service.

Besides the channels designated as "local service" there are two classes of "limited service" channels on which heterodyne interference is permitted. On five of these channels, 1000-watt stations are permitted, and on four of them 5-kilowatt stations. These will not give distant service and are in that sense "limited", but will give better local service than the stations on the "local service" channels because of their higher power. In some discussions the 1000-watt limited service channels are lumped with regional service channels, because there is not a very sharp difference between them; a heavily loaded regional service channel would be indistinguishable from a 1000-watt limited service channel.

There has been no specific designation of a name for the class of channels intended to give distant or rural service. They have been called variously "rural service," "distant service," "cleared," "high-power," "heterodyne-free," and "exclusive" channels. Stations on these channels may be authorized to use power up to 25 kilowatts, and, experimentally, up to 50 kilowatts.

[1] The expression "station assignment," or "full-time assignment," indicates full-time operation 24 hours a day by a station, or a group of stations sharing time.

The allocation is in harmony with good engineering principles. In the separate provision for high-power exclusive channels and restricted-power local channels, and in the geographical spacings of stations on the same and adjacent frequencies, and in other vital respects, the allocation is in accord with "A Statement on Engineering Principles" presented to the Commission on March 30, 1927, by the Committee on Radio Broadcasting of the American Engineering Council. It is also in essential accord with the recommendations of the radio engineers in the April 6, 1928 conference, except that only 40 high-power exclusive channels are provided instead of 50.

Summary of Allocation Plan

The allocation plan is set forth in detail in General Order No. 40. Its principal features are indicated in the following table. The available numbers of station assignments have not in all cases been utilized in all the zones, in the allocation which the Commission has announced.

	High-Power, 5 kw and up	Regional, 500-1000 w	Limited Service		Local 10-100 w	Total
			5 kw	1000 w		
Number of Channels	40	35	4	5	6	90
Station Assignments per channel	1	[2] 2½	2½	5	25	—
Number Station Assignments in U. S.	40	90	10	25	150	315
Number Station Assignments in each zone	8	18	2	5	30	63

The allocation is based on night-time transmission conditions. Besides the classes of stations shown in the table, there are a number of supplementary stations added on some channels. These include a number of "daytime service" stations and "limited time" stations. The latter are allowed to operate during the day and also during certain time (after late evening in the East by western stations) temporarily not used by the stations entitled to the channel. The "day-time service" stations are allowed to operate only during non-interfering hours. They are required to shut down at sunset. This shall be taken to be sunset at the daytime service station unless it is the farthest east of the stations on the channel, in which case sunset at the next station west on the same channel. The time of sunset varies from about 4:30 in December to 7:30 in June, local sun time.

[2] Approximate Average.

The Listener's Dial

The choice of particular frequencies for the several classes of stations was influenced in considerable measure by the present frequencies of stations. Thus, one reason that the high-power channels are begun at 640 kilocycles rather than at 550 kilocycles is because the public is accustomed to hearing some of the regional service stations at this end of the spectrum. This principle has permitted reducing as much as possible the average shift of frequency which the stations must make.

The placing of several blocks of regional and local service channels in different parts of the dial has the advantage that it permits the licensing of more stations in certain places (e.g., Boston and Los Angeles) than would be possible (because of inter-channel interference) if the channels of each class of station were all bunched in a single group.

The high-power channels, however, are consolidated into a single block in the spectrum (except for Canadian exclusive and Canadian shared channels and the group of regional channels 880 to 950 kcs), so that the listeners on these heterodyne-free channels will be as free as possible from inter-channel interference from nearby stations of other classes.

The choice of channel locations is expected to have the effect of making programs as available at the high-frequency end of the listener's dial as at the low-frequency end. Thus the entire dial becomes useful, for listeners everywhere in the United States.

In the following list, the numbers in parentheses after certain frequencies indicate the zone to which that frequency is assigned.

550 560 570	Limited Service 1000
580 590 600 610 620 630	Regional Service
640 (5) 650 (3) 660 (1) 670 (4) 680 (5)	Rural Service (i.e., high power)
690	Canada
700 (2) 710 (1) 720 (4)	Rural Service (i.e., high power)
730	Canada

740 (3) 750 (2) 760 (1) 770 (4)	Rural Service (i.e., high power)
780	Regional Service (shared with Canada)
790 (5) 800 (3) 810 (4) 820 (2) 830 (5)	Rural Service (i.e., high power)
840	Canada
850 (3) 860 (1) 870 (4)	Rural Service (i.e., high power)
880 890 900	Regional Service
910	Canada
920 930 940 950	Regional Service
960	Canada
970 (5) 980 (2) 990 (1) 1000 (4)	Rural Service (i.e., high power)
1010	Regional Service (shared with Canada)
1020 (2)	Rural Service (i.e., high power)
1030	Canada
1040 (3) 1050 (5) 1060 (1) 1070 (2) 1080 (3) 1090 (4) 1100 (1) 1110 (2)	Rural Service (i.e., high power)
1120	Regional Service (shared with Canada)
1130 (5) 1140 (3) 1150 (1) 1160 (4) 1170 (2) 1180 (4) 1190 (3)	Rural Service (i.e., high power)
1200 1210	Local Service
1220 1230 1240 1250 1260 1270 1280 1290 1300	Regional Service
1310	Local Service
1320 1330 1340 1350 1360	Regional Service
1370	Local Service

1380 1390 1400 1410	Regional Service
1420	Local Service
1430	Regional Service
1440 1450	Limited Service 1000 w
1460 1470 1480 1490	Limited Service 5 kw
1500	Local Service

Equalization

The table given above under "Summary of Allocation Plan" shows how the frequencies are equalized between the zones. Each zone receives exactly one-fifth of the station assignments. In some zones there are a few vacancies in the station assignments which will be available until future stations are constructed in the localities where those station assignments can be used. The allocation of frequencies and of station assignments to the individual states is closely proportional to population, as the law requires; this correspondence, of course, cannot be exact because the inequalities of state populations lead to many fractional quotas.

The aggregate power assigned to the stations is nearly equal for the five zones and is closely proportional to the populations of the states within each zone. For the future, moreover, the potential power of stations is exactly equalized between the zones, since by General Orders 40 and 42 the same upper limit of power is prescribed for all stations of each class.

The number of licenses is equalized only approximately, as follows: Zone No. 1, 108; Zone No. 2, 106; Zone No. 3, 115; Zone No. 4, 155; Zone No. 5, 132. The total number of licenses, or stations, is 616, an average per zone of 123. The principal disparity is an excess of 32 over the average, in the Fourth Zone (the Middle West). These departures from equality are inherent in the Commission's fundamental decision that no existing stations should be abolished at the time of the inception of the new allocation.

The equalization of time "on the air" is indicated essentially by the distribution of "station assignments," which is equal as between the zones, and reasonably proportional to population as between the states. The equalization of time is somewhat altered, however, by the addition of "daytime service" stations on some of the channels.

Conclusion

The channels are carefully cleared of inter-channel interference in every part of the dial. This clearing is particularly well effected in Zones 3, 4, and 5. Zones 1 and 2 being smaller, the geographical spacings are somewhat less than in the other zones, and interference may in a few cases be perceptible on winter nights.

It is believed that heterodyne interference is substantially eliminated except on the 9 limited service channels and the 6 local service channels. If such interference should develop on any of the 75 heterodyne-free channels, the Commission may reduce it by decreasing a station's power or eliminating one or more stations.

The principal features of the allocation, such as the assignment of amounts of power and of particular frequencies to particular localities, can not in general be altered, because of the interdependence of the frequency and distance separations throughout the entire set-up. However, the selection of stations in a given locality to be put in a particular power class, the selection of stations in a locality to be assigned to the specific frequencies allotted to the locality, and the relative amounts of time divisions by groups or stations, are all features which can be changed at any time as the Commission sees fit without affecting the soundness of the set-up in any way. Thus the Commission will have a quick and definite way of determining what its action should be on all broadcast license applications.

State Quotas of Broadcasting Assignments

General Orders Nos. 40, 41, and 42, of the Federal Radio Commission, published in the Radio Service Bulletin for August 31, 1928, outline the basis for a general reallocation of the broadcasting stations of the United States.

In effect, the Commission's orders recognize three principal classes of stations and specify the broadcasting channels which shall be used by each class. The existing stations are then assigned to channels in accordance with this plan, time divisions being required where necessary, in order to minimize interference and to make the apportionment of full-time assignments as required by the law.

The full-time assignments may be classified as follows:

1. Stations to which full use of a clear channel is granted (5 kilowatts or more in power).
2. Stations which are assigned to a channel for simultaneous operation with one or two (or in some cases three or four) other stations. (On most of these channels, the power authorized for use by a given station is 500 or 1000 watts; in certain cases, power is limited to 250 watts, and on certain "limited service" channels power up to 5000 watts is permitted.)
3. Stations which are assigned to a channel jointly with about 25 other stations scattered throughout the country (up to 100 watts in power).

In addition, a number of other stations are authorized to operate during the daytime or at such other times (such as early evening or late at night) as will not cause interference with the operation of the station or stations which are assigned for the primary use of these channels.

An equal number of assignments of stations in each of the five zones, as far as possible, is required by the law. The Commission has made equal as among the zones, the number of assignments of each class. The proportionate number of full-time assignments of each class to be made to each state was determined from the ratio of the state population to the total population of the zone. The state quotas of full-time assignments of each of the three classes, based on a statement issued by the Commission, are given in the following table:

		State Quotas of Full-time "Assignments"		
	Percentage of Total National Facilities Due State	1 "Rural" Service 5-kw and above	2 "Regional" Service chiefly 500–1000-w	3 "Local" Chiefly 50-w and 100-w
FIRST ZONE				
Maine	0.6	0.24	0.7	0.9
New Hampshire	0.3	0.12	0.4	0.5
Vermont	0.3	0.12	0.3	0.4
Massachusetts	3.1	1.24	3.9	4.7
Connecticut	1.2	0.48	1.5	1.8
Rhode Island	0.5	0.20	0.7	0.8
New York	8.4	3.36	10.6	12.7
New Jersey	2.8	1.12	3.5	4.2
Delaware	0.2	0.08	0.2	0.3
Maryland	1.2	0.48	1.5	1.8
Dist. of Columbia	0.4	0.16	0.5	0.6
Porto Rico	0.9	0.36	1.2	1.4
Virgin Islands	0.02	—	—	—
	20. per cent	8.	25.	30.

		State Quotas of Full-time "Assignments"		
	Percentage of Total National Facilities Due State	1 "Rural" Service 5-kw and above	2 "Regional" Service Chiefly 500–1000-w	3 "Local" Chiefly 50-w and 100-w
SECOND ZONE				
Pennsylvania	7.0	2.80	8.8	10.5
Virginia	1.8	0.72	2.3	2.7
West Virginia	1.2	0.48	1.5	1.8
Ohio	4.9	1.96	6.1	7.3
Michigan	3.3	1.32	4.1	4.9
Kentucky	1.8	0.72	2.3	2.7
	20. per cent	8.	25.	30.
THIRD ZONE				
North Carolina	2.1	0.84	2.6	3.1
South Carolina	1.3	0.52	1.7	2.0
Georgia	2.3	0.92	2.9	3.4
Florida	1.0	0.40	1.3	1.5
Alabama	1.8	0.72	2.3	2.7
Tennessee	1.8	0.72	2.2	2.7
Mississippi	1.3	0.52	1.6	1.9
Arkansas	1.4	0.56	1.7	2.1
Louisiana	1.4	0.56	1.8	2.1
Texas	3.9	1.56	4.9	5.9
Oklahoma	1.7	0.68	2.2	2.6
	20. per cent	8.	25.	30.
FOURTH ZONE				
Indiana	2.4	0.96	3.0	3.6
Illinois	5.5	2.20	7.0	8.3
Wisconsin	2.2	0.88	2.8	3.3
North Dakota	0.5	0.20	0.6	0.7
Minnesota	2.0	0.80	2.5	3.0
South Dakota	0.5	0.20	0.7	0.8
Iowa	1.8	0.72	2.3	2.7
Nebraska	1.1	0.44	1.3	1.6
Kansas	1.4	0.56	1.7	2.0
Missouri	2.6	1.08	3.3	4.0
	20. per cent	8.	25.	30.
FIFTH ZONE				
Montana	1.0	0.40	1.2	1.5
Idaho	1.0	0.40	1.2	1.4
Wyoming	0.4	0.16	0.5	0.7
Colorado	2.0	0.80	2.4	2.9
New Mexico	0.7	0.28	0.9	1.0
Arizona	0.8	0.32	1.0	1.2
Utah	0.9	0.36	1.2	1.4
Nevada	0.1	0.04	0.2	0.2
Washington	2.8	1.14	3.5	4.2
Oregon	1.6	0.64	2.0	2.4
California	8.2	3.28	10.2	12.1
Ter. of Hawaii	0.5	—	—	—
Alaska	0.1	—	—	—
	20. per cent	8.	25.	30.

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THE DEPENDENCE OF THE FREQUENCY OF QUARTZ PIEZO-ELECTRIC OSCILLATORS UPON CIRCUIT CONSTANTS*

By

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Summary—*The mathematical theory for the quartz piezo-electric stabilized, vacuum-tube-driven oscillator is given for the following cases: tuned plate circuit, inductance-loaded and resistance-loaded triode with the crystal between grid and plate, and also between grid and filament for each case. The condition for oscillations and the exact expression for the frequencies, damping factors, coupling coefficient, tube constants, etc., is given. In the analysis of the oscillator the equivalent network for the crystal given by Van Dyke has been used. The theory has been checked by measuring the variation in frequency of a quartz stabilized oscillator for variations in impedance of the plate circuit for the tuned circuit and resistance-loaded tube respectively. To satisfy the condition for oscillation it is necessary to use values for the equivalent resistance of the crystal somewhat smaller than those given by Van Dyke's formula. A discussion of the general method by which conditions for oscillation and expressions for the driven frequency of an oscillator may be obtained from the coefficients of differential equations up to the fourth order is included.*

THE use of quartz piezo-electric oscillators, as first described by Cady,[1] for stabilizing the frequency of triode-driven circuits, has been of inestimable value in the maintenance of frequency standards and in holding radio transmitters on their assigned frequencies. Investigation has shown that the frequencies of such oscillators are, however, subject to certain variations, the chief causes of which are changes in temperature of the quartz plate, methods of mounting it, and the reactions of the electric circuit upon the mechanical properties of the quartz itself. By use of suitable thermostatic devices and by standardization of mountings, the first two sources of error have been brought under very good control, but the extent to which the frequency is influenced by the elements of the system of which the crystal forms a part has not as yet been fully investigated, and it is to supply this need in certain of the more

* Original Manuscript Received by the Institute, August 6, 1928. Presented before the International Union of Scientific Radiotelegraphy, Washington, D.C., April 19, 1928.

[1] Cady, W. G., "Piezo-electric Resonator," PROC. I.R.E., 10, 83; April, 1922.

commonly used circuits that the following work has been carried out.

Van Dyke[2] has shown that a piezo-electric quartz crystal is equivalent electrically to an inductance, a capacitance, and a resistance joined in series, as shown in Fig. 1, with a second capacitance shunted across them, and has given formulas by which these equivalent electrical quantities may be computed for any of its normal modes of oscillation from the dimensions of the crystal. Using this method of representation, Dye[3] has studied the effect of the constants of the circuit to which the crystal is connected when used as a resonator, but as far as the author is aware, no study has yet been made of the corresponding problem—namely, the effect of the constants of the circuit when the crystal is used as a stabilizer for a vacuum-tube-driven circuit.

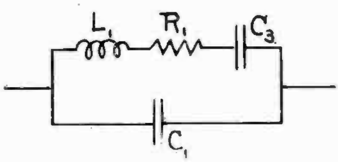

Fig. 1—Equivalent Network.

In carrying out this work, the crystal has been replaced in the circuits to be studied by its electrical equivalent as given by Van Dyke. It thus forms one of the elements of a coupled system, and the resultant frequency of the driven coupled system has been worked out in terms of that of the equivalent crystal element when uncoupled and oscillating according to one of its normal modes. In making the analysis of the various circuits considered, the method of differential equations rather than complex algebra has been used, since it permits the determination of the condition for oscillation and the calculation of frequency to be made directly from the coefficients of the differential equation. The advantages of this method, which, of course, are well-known, seem to be insufficiently appreciated, and a brief discussion of the theory may not be out of place.

Suppose we have any system, mechancial or electrical, such that its instantaneous state of motion may be described by a differential equation of the second order, e.g.,

[2] Van Dyke, K. S., "The Piezo-electric Resonator and its Equivalent Network," Proc. I.R.E., 16, 742; June, 1928.

[3] Dye, D. W., "Piezo-electric Quartz Resonator and Equivalent Electrical Circuit," *Proc.* Phys. Soc. London, 38, 399; 1926.

$$\frac{d^2x}{dt^2}+P_1\frac{dx}{dt}+P_2x=0. \tag{1}$$

In order that $x=e^{mt}$ may be a solution of (1), it is necessary that the auxiliary equation

$$m^2+P_1m+P_2=0 \tag{2}$$

be satisfied—that is

$$m=\frac{-P_1\pm\sqrt{P_1^2-4P_2}}{2} \tag{3}$$

The condition that the system may execute oscillations is that $P_1^2<4P_2$. If this condition is satisfied, then the roots of (2) may be written

$$\left.\begin{aligned} m_1&=\alpha+j\beta \quad \text{where} \quad \alpha=-\frac{P_1}{2} \text{ and } \beta=\frac{\sqrt{4P_2-P_1^2}}{2} \\ m_2&=\alpha-j\beta \qquad\qquad\qquad\qquad j=\sqrt{-1} \end{aligned}\right\} \tag{4}$$

The solution may then be written

$$x=Ae^{\alpha t}\sin\beta t. \tag{5}$$

The damping factor α is seen to be one-half the coefficient of the first order derivative in (1). In general, P_1 is positive and oscillations die out logarithmically. If, however, the system contains some source of energy or a regenerative device, P_1 may be zero, or even negative. In the former case, oscillations, once started, persist with constant amplitude, and in the latter they are built up. The condition, then, that oscillations may persist in any vacuum-tube-driven circuit whose instantaneous state may be described by a second order differential equation is that the coefficient of the first order derivative be zero. It is also to be noted by (4) that when this condition has been satisfied, the square of the radian frequency of the system is given by P_2, the coefficient of the absolute term.

Unfortunately, not many triode circuits can be described by a second order differential equation. The method may, however, be extended to cases requiring third and fourth order differential equations for their description. For example, suppose a third order equation is required, e.g.,

$$\frac{d^3x}{dt^3}+P_1\frac{d^2x}{dt^2}+P_2\frac{dx}{dt}+P_3x=0. \tag{6}$$

The auxiliary equation is then

$$m^3+P_1m^2+P_2m+P_3=0 \tag{7}$$

If the system, thus described, is to be capable of oscillations, two of the roots of (7) must be a pair of conjugate complexes, and the third, real. Let them be

$$\begin{aligned} m_1&=\kappa \\ m_2&=\alpha+j\beta \\ m_3&=\alpha-j\beta \end{aligned} \tag{8}$$

where α and β are the damping factor and radian frequency, respectively, and κ the reciprocal of the time constant for the non-oscillatory transient.

The condition that oscillations once started may persist, that is, $\alpha=0$, may be obtained from the theorem giving the relation between roots and coefficients in an algebraic equation. Thus

$$\begin{aligned} m_1+m_2+m_3&=-P_1 \\ m_1m_2+m_2m_3+m_3m_1&=+P_2 \\ m_1m_2m_3&=-P_3 \end{aligned} \tag{9}$$

Substituting (8) in (9) we have

$$\begin{aligned} \kappa+2\alpha&=-P_1 \\ 2\kappa\alpha+\alpha^2+\beta^2&=P_2 \\ \kappa(\alpha^2+\beta^2)&=-P_3 \end{aligned} \tag{10}$$

If $\alpha=0$, these become

$$\begin{aligned} \kappa&=-P_1 \\ \beta^2&=P_2 \\ \kappa\beta^2&=-P_3 \end{aligned} \tag{11}$$

Whence $\beta^2=P_2$ and $\beta^2=\dfrac{P_3}{P_1}$ (12)

The condition, then, that $\alpha=0$ is that these two values of β must be the same; that is

$$P_2 = \frac{P_3}{P_1} \tag{13}$$

Thus the condition for undamped oscillations and the expression for the frequency may be obtained from the differential equation without solving it.

For the case of the fourth order differential equation the procedure is similar, and, although the conditions are somewhat more complicated, the method is readily workable. Let the differential equation be

$$\frac{d^4x}{dt^4} + P_1\frac{d^3x}{dt^3} + P_2\frac{d^2x}{dt^2} + P_3\frac{dx}{dt} + P_4x = 0 \tag{14}$$

with its auxiliary equation

$$m^4 + P_1m^3 + P_2m^2 + P_3m + P_4 = 0. \tag{15}$$

The system which this equation describes may be either simply or doubly periodic. In the former case, (15) has two real and one pair of conjugate complex roots, and in the latter, two pairs of conjugate complex roots. For the doubly periodic case the roots may be written

$$\begin{aligned} m_1 &= \alpha_1 + j\beta_1 \qquad & m_3 &= \alpha_2 + j\beta_2 \\ m_2 &= \alpha_1 - j\beta_1 \qquad & m_4 &= \alpha_2 - j\beta_2 \end{aligned} \tag{16}$$

where α_1, α_2 and β_1, β_2 are the damping factors and radian frequencies, respectively, for the resultant oscillations. Again making use of the relation between roots and coefficients we have

$$\begin{aligned} 2(\alpha_1 + \alpha_2) &= -P_1 \\ \alpha_1{}^2 + \beta_1{}^2 + 4\alpha_1\alpha_2 + \alpha_2{}^2 + \beta_2{}^2 &= P_2 \\ 2\alpha_1(\alpha_2{}^2 + \beta_2{}^2) + 2\alpha_2(\alpha_1{}^2 + \beta_1{}^2) &= -P_3 \\ (\alpha_1{}^2 + \beta_1{}^2)(\alpha_2{}^2 + \beta_2{}^2) &= P_4 \end{aligned} \tag{17}$$

The imaginary terms drop out, since the coefficients of (15) are all real. We seek now the condition that one of the damping factors, e.g., α_1, may be zero. Putting $\alpha_1 = 0$ in (17) α_2 and β_2 may be eliminated, and there results

$$\beta_1{}^2 = \frac{P_3}{P_1} \text{ and } \beta_1{}^2 = \frac{P_2 \pm \sqrt{P_2{}^2 - 4P_4}}{2} \tag{18}$$

The condition for undamped oscillations is then either

$$\left\{\begin{aligned} &\frac{P_3}{P_1}=\frac{P_2+\sqrt{P_2{}^2-4P_4}}{2} \\ \text{or}\ &\frac{P_3}{P_1}=\frac{P_2-\sqrt{P_2{}^2-4P_4}}{2} \end{aligned}\right. \tag{19}$$

Since equations (17) are symmetrical with respect to the α's and β's, the same result would have been obtained had we sought the condition that $\alpha_2=0$. It may be shown, however, that in (19) the plus sign gives the condition for one damping factor zero, and the minus sign that for the other zero.

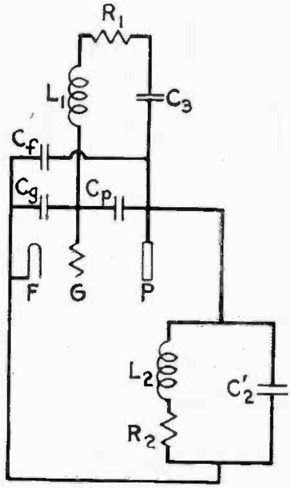

Fig. 2—Network for Crystal between Grid and Plate.

In stabilizing a vacuum-tube-driven circuit, the crystal may be connected either across the grid and filament of the tube or across the grid and plate. In the former case, the internal capacity between the plate and grid furnishes the necessary feed-back coupling, and in the latter, the grid-filament capacity serves this purpose. In this report, the solution will be given for these two cases using in each a tuned resonance circuit in series with the plate. The simplified ciruits of Pierce[4] may be discussed as special cases.

[4] Pierce, G. W., "Piezo-electric Crystal Resonators and Crystal Oscillators Applied to Precision Calibration of Wave Meters." *Proc. Am. Acad.*, 59, 81; 1923.

Crystal Between Grid and Plate

I. Tuned Plate Circuit. The circuit diagram for this case is shown in Fig. 2, in which L_1, R_1, C_3 represent the equivalent series elements of the crystals as shown in Fig. 1, while C_p is the sum of the interelectrode capacitance between plate and grid of the tube and C_1 of the crystal. The simplified diagram is shown in Fig. 3, where $C_2 = C'_2 + C_f$. In setting up the Kirchhoff equations, the d.c. grid current has been neglected and a linear static tube characteristic has been assumed. With these simplifications, we have

$$L_1\frac{di_1}{dt}+R_1i_1+\frac{1}{C_3}\int i_1dt+\frac{1}{C_p}\int(i_1-i)dt=0 \tag{20}$$

$$L_2\frac{di_2}{dt}+R_2i_2+\frac{1}{C_2}\int(i_2-i-i_p)dt=0 \tag{21}$$

$$\frac{1}{C_g}\int idt-\frac{1}{C_2}\int(i_2-i-i_p)dt-\frac{1}{C_p}\int(i_1-i)dt=0 \tag{22}$$

$$i_p=\frac{1}{R_p}(e_p+\mu e_g) \tag{23}$$

where $\quad e_p=\dfrac{1}{C_2}\displaystyle\int(i_2-i-i_p)dt;\ e_g=\dfrac{1}{C_g}\displaystyle\int idt$

Differentiating and combining, these become

$$L_1\frac{d^2i_1}{dt^2}+R_1\frac{di_1}{dt}+\left(\frac{1}{C_3}+\frac{1}{C_p}\right)i_1-\frac{1}{C_p}i=0 \tag{24}$$

$$L_2\frac{d^2i_2}{dt^2}+R_2\frac{di_2}{dt}+\frac{1}{C_2}(i_2-i-i_p)=0 \tag{25}$$

$$i=\frac{C_0}{C_p}i_1+\frac{C_0}{C_2}(i_2-i_p) \tag{26}$$

$$\frac{di_p}{dt}=\frac{1}{R_p}\left[\frac{1}{C_2}(i_2-i-i_p)+\frac{\mu}{C_g}i\right] \tag{27}$$

where $\quad \dfrac{1}{C_0}=\dfrac{1}{C_p}+\dfrac{1}{C_g}+\dfrac{1}{C_2}$

Substituting (26) in (24), (25), and (27), respectively, we have

$$i_2-i_p=L_1C_m\frac{d^2i_1}{dt^2}+R_1C_m\frac{di_1}{dt}+\frac{C_m}{C_a}i_1 \tag{28}$$

$$L_2\frac{d^2i_2}{dt^2}+R_2\frac{di_2}{dt}+\frac{1}{C_b}(i_2-i_p)-\frac{1}{C_m}i_1=0 \tag{29}$$

$$\frac{di_p}{dt}=\frac{1}{R_p}\left[\frac{1}{C_b'}(i_2-i_p)-\frac{1}{C_m'}i_1\right] \tag{30}$$

where

$$\frac{1}{C_a}=\frac{1}{C_3}+\frac{1}{C_d};\qquad \frac{1}{C_d}=\frac{1}{C_p}-\frac{C_0}{C_p^2};\qquad \frac{1}{C_b}=\frac{1}{C_2}-\frac{C_0}{C_2^2}$$

$$\frac{1}{C_b'}=\frac{1}{C_b}+\mu\frac{C_0}{C_2C_g};\qquad \frac{1}{C_m'}=\frac{1}{C_m}-\mu\frac{C_0}{C_pC_g};\qquad \frac{1}{C_m}=\frac{C_0}{C_2C_p}$$

C_a is the total capacitance of the primary circuit between the points *da*; C_d that between the points *dd*; and C_b that between the points *ee*.

$$C_d=C_p+\frac{C_2C_g}{C_2+C_g};\quad C_b=C_2+\frac{C_pC_g}{C_p+C_g}$$

Substituting (28) in (29) and (30), respectively, there results

$$L_2\frac{d^2i_2}{dt^2}+R_2\frac{di_2}{dt}+\frac{L_1C_m}{C_b}\frac{d^2i_1}{dt^2}\frac{R_1C_m}{C_b}\frac{di_1}{dt}+\left(\frac{C_m}{C_aC_b}-\frac{1}{C_m}\right)i_1=0 \tag{31}$$

$$\frac{di_p}{dt}=\frac{L_1C_m}{R_pC_b'}\frac{d^2i_1}{dt^2}+\frac{R_1C_m}{R_pC_b'}\frac{di_1}{dt}+\frac{1}{R_p}\left(\frac{C_m}{C_aC_b'}-\frac{1}{C_m'}\right)i_1 \tag{32}$$

Differentiating (28) and substituting (32), we have

$$\frac{di^2}{dt}=L_1C_m\frac{d^3i_1}{dt^3}+\left(R_1C_m+\frac{L_1C_m}{R_pC_b'}\right)\frac{d^2i_1}{dt^2}$$
$$+\left(\frac{C_m}{C_a}+\frac{R_1C_m}{R_pC_b'}\right)\frac{di_1}{dt}+\frac{1}{R_p}\left(\frac{C_m}{C_aC_b'}-\frac{1}{C_m'}\right)i_1 \tag{33}$$

Substituting (33) and its derivatives in (31) the following fourth order differential equation results:

$$\frac{d^4i_1}{dt^4}+P_1\frac{d^3i_1}{dt^3}+P_2\frac{d^2i_1}{dt^2}+P_3\frac{di_1}{dt}+P_4i_1=0 \tag{34}$$

in which

$$\left.\begin{aligned}
P_1&=\frac{R_1}{L_1}+\frac{R_2}{L_2}+\frac{1}{R_pC_b'}\\
P_2&=\frac{1}{L_1C_a}+\frac{R_1R_2}{L_1L_2}+\frac{1}{L_2C_b}+\frac{1}{R_p}\left(\frac{R_1}{L_1}+\frac{R_2}{L_2}\right)\frac{1}{C_b'}\\
P_3&=\frac{R_2}{L_1L_2C_a}+\frac{R_1}{L_1L_2C_b}+\frac{1}{R_p}\left(\frac{1}{L_1C_aC_b'}+\frac{R_1R_2}{L_1L_2C_b'}-\frac{1}{L_1C_mC_m'}\right)\\
P_4&=\frac{1}{L_1L_2C_aC_b}-\frac{1}{L_1L_2C_m^2}+\frac{R_2}{R_p}\left(\frac{1}{L_1L_2C_aC_b'}-\frac{1}{L_1L_2C_mC_m'}\right)
\end{aligned}\right\}\quad(35)$$

Introducing now the uncoupled damping factors α_a and α_b, the uncoupled, undamped frequencies β_a and β_b, and the coupling coefficient τ, defined as follows:

$$\alpha_a=\frac{R_1}{2L_1}\qquad \beta_a^2=\frac{1}{L_1C_a}\qquad \tau^2=\frac{\frac{1}{C_m^2}}{\frac{1}{C_a}\cdot\frac{1}{C_b}}=\frac{C_aC_b}{C_m^2}$$

$$\alpha_b=\frac{R_2}{2L_2}\qquad \beta_b^2=\frac{1}{L_2C_b}$$

the coefficients of (35) become

$$\left.\begin{aligned}
P_1&=2(\alpha_a+\alpha_b)+\frac{1}{R_pC_b'}\\
P_2&=\beta_a^2+4\alpha_a\alpha_b+\beta_b^2+\frac{1}{R_p}(\alpha_a+\alpha_b)\frac{2}{C_b'}\\
P_3&=2(\alpha_b\beta_a^2+\alpha_a\beta_b^2)+\frac{1}{R_p}\left[(\beta_a^2+4\alpha_a\alpha_b)\frac{1}{C_b'}-\frac{1}{L_1C_mC_m'}\right]\\
P_4&=\beta_a^2\beta_b^2\left[1-\tau^2+\frac{R_2}{R_p}\left(\frac{C_b}{C_b'}-\frac{C_m}{C_m'}\tau^2\right)\right]
\end{aligned}\right\}\quad(36)$$

Depending upon the coefficients $P_1\cdots P_4$, the solution of (34) may represent four exponentially damped transients, two such transients and a periodic function, or a doubly periodic function. In the circuits with which we are generally concerned in radio work, the last of these possibilities usually obtains. Neglecting for the moment the effect of the tube, the normal modes of oscillation of the coupled circuits (a) and (b), Fig. 3, consist of two currents in each circuit with frequencies and damping factors β_1 and α_1, β_2 and α_2, respectively. At one of these two frequencies the current in one circuit is nearly in phase with that in the other, while at the other frequency, the two currents are nearly opposite in phase. By suitably connecting the tube to the circuit, one of the normal modes of oscillation, β_1, for example, may supply voltages to grid and plate, respectively, nearly opposite in phase, and regeneration will occur for this frequency, while for the other frequency β_2, the grid and plate voltages are nearly in phase and absorption of energy by the tube rapidly damps this oscillation out. However, by an appropriate change in the connections, the situation may be reversed, and regeneration occur for the frequency β_2 and absorption for β_1. Because of these phase relations between the primary and

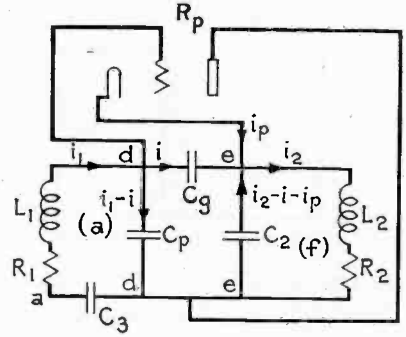

Fig. 3—Simplified Diagram for Fig. 2.

secondary currents for the two normal modes of oscillation, it is not possible to have regeneration at both frequencies at the same time with a single tube. In the case of crystal-stabilized oscillators with tuned plate circuit, the grid- and plate-voltage relations are such that the system oscillates according to one only of its normal modes when the crystal is connected between grid and plate, and to the other only, when connected between grid and filament. The latter case is discussed in Section IV.

The action of the tube in driving such a circuit may be roughly regarded as neutralizing the resistance of the circuit for one of the frequencies, that is, by making one of the damping factors effectively zero, and at the same time increasing the other damping factor. In general, resistance neutralization is incomplete in that the frequency of the resulting oscillations is determined not by the inductances, capacitances, and degree of coupling of the circuits alone, but by the resistances of the two circuits and the electrical constants of the tube as well. The expression for the resultant frequency is given by (18), where where the P's of (36) are given such values that the condition for oscillation, (19), is satisfied.

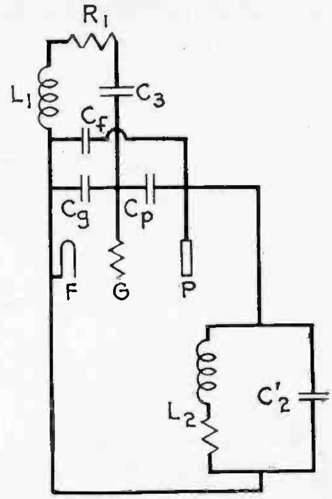

Fig. 4—Network for Crystal between Grid and Filament.

II. Inductance-Loaded Circuit. This may be regarded as a special case of the circuit just discussed in which C_2 is reduced to C_f, the capacitance between plate and filament of the tube. The circuit is still doubly periodic.

III. Resistance-Loaded Circuit. This is also a special case of the above in which, in addition to putting C_2 equal to C_f, L_2 is made zero. Thus, multiplying (34) by L_2 and then placing $L_2=0$ there results

$$\frac{d^3i_1}{dt^3}+P_1\frac{d^2i_1}{dt^2}+P_2\frac{di_1}{dt}+P_3i_1=0 \tag{37}$$

in which

$$\left.\begin{aligned} P_1&=\frac{R_1}{L_1}+\frac{1}{R_2C_b}+\frac{1}{R_pC_b'}\\ P_2&=\frac{1}{L_1C_a}+\frac{R_1}{R_2L_1C_b}+\frac{R_1}{R_pL_1C_b'}\\ P_3&=\frac{1}{R_2L_1C_aC_b}-\frac{1}{R_2L_1C_m^2}+\frac{1}{R_p}\left(\frac{1}{L_1C_aC_b'}-\frac{1}{L_1C_mC_m'}\right)\end{aligned}\right\} \tag{38}$$

Introducing the uncoupled damping factors and frequency of (36), equations (38) become

$$
\begin{aligned}
P_1 &= 2\alpha_a + \frac{1}{R_2C_b} + \frac{1}{R_pC_b'} \\
P_2 &= \beta_a^2 + \frac{2\alpha_a}{R_2C_b} + \frac{2\alpha_a}{R_pC_b'} \\
P_3 &= \frac{\beta_a^2}{R_2C_b} - \frac{1}{R_2L_1C_m^2} + \frac{1}{R_p}\left(\frac{\beta_a^2}{C_b'} - \frac{1}{L_1C_mC_m'}\right)
\end{aligned}
\tag{39}
$$

This circuit is singly periodic and its frequency is given by (12) when the condition for oscillation, (13), has been satisfied.

Crystal Between Grid and Filament

IV. Tuned Plate Circuit. The circuit for this case is shown in Fig. 4 and the simplified diagram in Fig. 5, where C_2 is again $C^1{}_2+C_f$. C_p is here the coupling capacity instead of C_g. Writing the Kirchhoff relations, we have

$$L_1\frac{di_1}{dt}+R_1i_1+\frac{1}{C_3}\int i_1dt+\frac{1}{C_g}\int(i_1-i)dt=0 \tag{40}$$

$$L_2\frac{di_2}{dt}+R_2i_2+\frac{1}{C_2}\int(i_2+i_p-i)dt=0 \tag{41}$$

$$\frac{1}{C_p}\int idt-\frac{1}{C_2}\int(i_2+i_p-i)dt-\frac{1}{C_g}\int(i_1-i)dt=0 \tag{42}$$

$$i_p=\frac{1}{R_p}(e_p+\mu e_g) \tag{43}$$

where

$$e_p=-\frac{1}{C_2}\int(i_2+i_p-i)dt$$

$$e_g=\frac{1}{C_g}\int(i_1-i)dt$$

These equations differ only in minor details from (20) to (23), and the method of elimination is strictly analogous and will not be repeated. When the process has been carried out, there again results the fourth order differential equation

$$\frac{d^4i_1}{dt^4}+P_1\frac{d^3i_1}{dt^3}+P_2\frac{d^2i_1}{dt^2}+P_3\frac{di_1}{dt}+P_4i_1=0 \tag{44}$$

in which

$$\left.\begin{aligned}
P_1&=\frac{R_1}{L_1}+\frac{R_2}{L_2}+\frac{1}{R_pC_b''}\\
P_2&=\frac{1}{L_1C_a}+\frac{R_1R_2}{L_1L_2}+\frac{1}{L_2C_b}+\frac{1}{R_p}\left(\frac{R_1}{L_1}+\frac{R_2}{L_2}\right)\frac{1}{C_b''}\\
P_3&=\frac{R_2}{L_1L_2C_a}+\frac{R_1}{L_1L_2C_b}+\frac{1}{R_p}\left(\frac{1}{L_1C_aC_b''}+\frac{R_1R_2}{L_1L_2C_b''}-\frac{1}{L_1C_mC_m''}\right)\\
P_4&=\frac{1}{L_1L_2C_aC_b}-\frac{1}{L_1L_2C_m{}^2}+\frac{R_2}{R_p}\left(\frac{1}{L_1L_2C_aC_b''}-\frac{1}{L_1L_2C_mC_m''}\right)
\end{aligned}\right\} \tag{45}$$

Substituting uncoupled frequencies, damping factors and coupling coefficients, they become

$$\begin{aligned}
P_1&=2(\alpha_a+\alpha_b)+\frac{1}{R_pC_b''}\\
P_2&=\beta_a{}^2+4\alpha_a\alpha_b+\beta_b{}^2+\frac{1}{R_p}(\alpha_a+\alpha_b)\frac{2}{C_b''}\\
P_3&=2(\alpha_b\beta_a{}^2+\alpha_a\beta_b{}^2)+\frac{1}{R_p}\left[(\beta_a{}^2+4\alpha_a\alpha_b)\ \frac{1}{C_b''}-\frac{1}{L_1C_mC_m''}\right]\\
P_4&=\beta_a{}^2\beta_b{}^2\left[1-\tau^2+\frac{R_2}{R_p}\left(\frac{C_b}{C_b''}-\frac{C_m}{C_m''}\tau^2\right)\right]
\end{aligned} \tag{46}$$

where

$$\frac{1}{C_m}=\frac{C_0}{C_2C_g};\quad \frac{1}{C_m''}=\frac{1}{C_m}+\frac{\mu}{C_d};\quad \frac{1}{C_b''}=\frac{1}{C_b}+\frac{\mu}{C_m}$$

C_d is the capacitance between the points dd of Fig. 5. The other quantities have the same meaning as in Case I.

V. Inductance-Loaded Circuit. As in Case II, the coefficients $P_1\cdots P_4$ are obtained by putting $C_2=C_f$. The circuit is doubly periodic.

VI. Resistance-Loaded Circuit. As in Case III, multiply (44) by L_2, put $L_2=0$, and there results

$$\frac{d^3i_1}{dt^3}+P_1\frac{d^2i_1}{dt^2}+P_2\frac{di_1}{dt}+P_3i_1=0 \tag{47}$$

where

$$\left.\begin{aligned} P_1 &= 2\alpha_a + \frac{1}{R_2C_b} + \frac{1}{R_2C_b''} \\ P_2 &= \beta_a^2 + \frac{2\alpha_a}{R_2C_b} + \frac{2\alpha_a}{R_pC_b''} \\ P_3 &= \frac{\beta_a^2}{R_2C_b} - \frac{1}{R_2L_1C_m^2} + \frac{1}{R_p}\left(\frac{\beta_a^2}{C_b''} - \frac{1}{L_1C_mC_m''}\right) \end{aligned}\right\} \tag{48}$$

NUMERICAL CALCULATIONS

As pointed out above in (18), (19), (12), and (13), the expression for the frequency of the vacuum-tube-driven circuit, when doubly periodic, is given by

$$\beta^2 = \frac{P_2 \pm \sqrt{P_2^2 - 4P_4}}{2} \tag{49}$$

where the coefficients of the fourth order differential equation have such values that the condition for oscillation, i.e.,

$$\frac{P_2 \pm \sqrt{P_2^2 - 4P_4}}{2} = \frac{P_3}{P_1} \tag{50}$$

is satisfied, and for the singly periodic circuit

$$\beta^2 = P_2 \tag{51}$$

where

$$P_2 = \frac{P_3}{P_1} \tag{52}$$

In satisfying the condition for oscillation for any given values of the uncoupled frequencies β_a and β_b, R_p is a variable parameter. R_p is, in reality, the reciprocal of the slope of the static characteristic of the tube as given by (23). Since, however, the actual characteristic of the tube is not linear but is curved, R_p has different values for various points on the curve. Moreover, for cyclic variations in grid potential, R_p has different values throughout the cycle and it must, therefore, when used in numerical calculations, be thought of as a sort of average value taken over the cycle. The greater the limits of grid potential variations, the greater is R_p. It is thus a purely fictitious quantity, to which it is impossible to give a definite physical meaning, but which serves a useful purpose. In general, the larger the value reached by R_p, the more vigorously is the circuit oscillating.

The direct method for computing the frequency of the system would be to substitute in (50) values of P's derived from (36) or

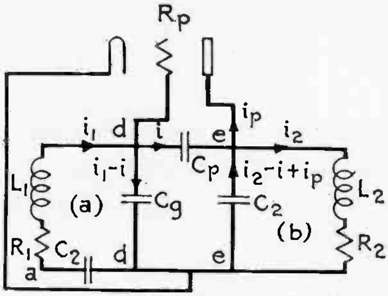

Fig. 5—Simplified Diagram for Fig. 4.

(46), using any pair of values for the uncoupled frequencies β_a and β_b, and then to solve for R_p. This value of R_p, when substituted in (49), would then give the frequency of the driven system for these values of β_a and β_b. Unfortunately, (50) is too complicated a function of R_p to make this procedure possible, and a graphical method was employed. The right- and left-hand members of (50) were plotted as a function of R_p for a series of values of β_a and β_b. The intersection of these curves then gave the value of β^2 for this combination of uncoupled frequencies.

To simplify the computations and make them of more general application, relative frequencies rather than actual frequencies of any particular crystal were used. Dividing (49) and (50) by β_a^2 we have

$$\left(\frac{\beta}{\beta_a}\right)^2 = \frac{\dfrac{P_2}{\beta_a^2} \pm \sqrt{\left(\dfrac{P_2}{\beta_a^2}\right)^2 - \dfrac{4P_4}{\beta_a^4}}}{2} \tag{53}$$

Since P_2 and P_4 from (36) are functions of β_a and β_b, (53) gives the ratio of the driven frequency of any crystal to its undriven value in terms of the ratio of the uncoupled frequency of the plate circuit to the undriven frequency of the crystal, the undriven frequency of the crystal, damping factors and other constants of the circuit. In carrying out the computations β_a was taken as unity.

The computations were carried out for a crystal having the dimensions shown in Table I. The measured value of its driven fundamental frequency for "thickness" oscillations was 451.53 kc.

TABLE I
TUNED PLATE CIRCUIT

Dimensions of crystal	Electrical Constants of crystal	Tube constants (UX–201A)
length = 3.328 cm.	L_l = 3.656 h	G-F cap. = 5.8 $\mu\mu$f
breadth = 2.750 "	R_1 = 9035.5 Ω	G-P " = 10.1 "
thickness = 0.6361 "	C_1 = 5.7551 $\mu\mu$f	P-F " = 6.1 "
	C_3 = 0.03165 "	Amp. fact. = 8.5 "

Coupling coefficients:

Crystal between grid and plate, $\tau^2 = 1.0356 \times 10^{-6}$

Crystal between grid and filament, $\tau^2 = 3.1355 \times 10^{-6}$

$\dfrac{\beta_b}{\beta_a}$	R_p	$\dfrac{\beta}{\beta_a}$ Crystal between grid and plate	$\dfrac{\beta}{\beta_a}$ Crystal between grid and filament	$\dfrac{\beta}{\beta_a}$ Natural frequencies undamped
0.94	47000	1.0000121	—	1.0000035
0.96	72500	1.0000122	—	1.0000060
0.98	144000	1.0000143	—	1.0000120
0.99	260000	1.0000262	—	1.0000251
0.995	370000	1.0000540	—	1.0000523
1.005	455000	—	0.999847	0.999846
1.01	394000	—	0.999922	0.999921
1.02	238000	—	0.999963	0.999959
1.04	126000	—	0.999986	0.999979
1.06	87000	—	0.999996	0.999986

In this table, the column marked R_p gives the effective resistance of the tube for stable oscillations, that is, the value for which one of the damping factors of the driven coupled circuit

AUTHOR'S NOTE:—In computing the equivalent electrical constants for the crystal the following unpublished formulas were used which were reported by Cady to the executive committee of the American section U. R. S. I. in 1926.

$$L_l = 130 \frac{le}{b} \qquad C_1 = 0.40 \frac{bl}{e} \qquad R_1 = 130{,}000 \frac{e}{bl}$$

$$L_e = 130 \frac{e^3}{bl} \qquad C_3 = 0.0022 \frac{bl}{e}$$

Where l, b, e represent respectively the length, breadth, and thickness of the quartz plate, measured in directions which are respectively normal to the electric and optic axes, along the optic axis and along the electric axis. L_l and L_e are the equivalent inductances for lengthwise and thickness oscillations, respectively. The computations, the results of which are given in Table I, were well under way when Van Dyke's paper, loc. cit., appeared, and since the values given by the newer formulas differ from the above by only a few per cent, it was deemed not worth while to repeat the computations, as they are extremely laborious.

is zero. It is to be noted that as resonance is approached from either side, R_p increases in magnitude corresponding to greater amplitudes of oscillation. Before resonance is reached, however, the condition for oscillation ceases to be satisfied by any value of R_p, no matter how great. The gradual increase in amplitude of oscillation as the plate circuit is brought into resonance and the sudden break are well known experimentally. Attention should be drawn to the fact that the coupling between the two

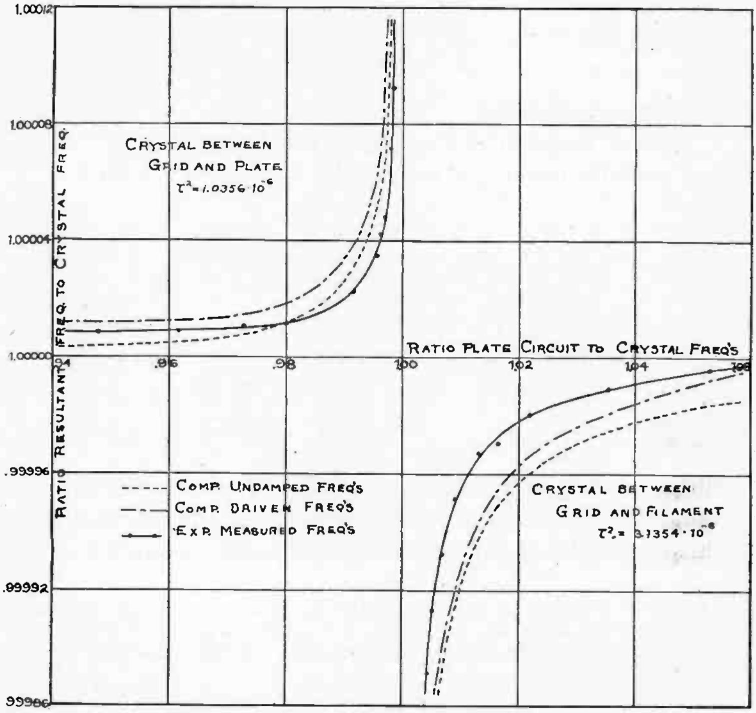

Fig. 6—Variation of Driven Frequency with Plate Circuit Frequency.

circuits is considerably closer when the crystal is connected between grid and filament than when between grid and plate, which accounts for the larger amplitude of oscillation and greater stability for this connection. The last column gives the computed undamped frequencies for the system, using in each case the appropriate coupling coefficient. The formula for computing them is obtained by putting $R_1 = R_2 = 0$, and $R_p = \infty$ in (34) or (44), which become identical under these conditions. In carrying out these computations, it is found that with the above circuit constants for ratios of β_b/β_a less than unity, the condition for oscillation can be satisfied only when the plus sign of (53) is used, and for ratios greater than unity, with the minus sign only.

These results are shown in Fig. 6, in which the dash-dot curve shows the frequency of the vacuum-tube-driven crystal-controlled oscillator as a function of the relative frequency of the plate circuit, while the dot-dot curve shows the natural frequencies of the same system if it were without resistance. It is seen that the effect of driving is to increase somewhat the frequency of the system for both connections of the crystal, and that this effect is greater the farther off resonance the circuits are. The experimentally-measured frequencies are shown in the full-line curve. It was found impossible to satisfy the condition for oscillation using the value of R_1 obtained by Van Dyke's formula, even though R_2 were as small as 0.3 ohm, the value used in the experimental work. A series of calculations was carried through, using successively smaller and smaller fractions of R_1, and in the above curves R_1 was put equal to one-tenth that given by Van Dyke's formula. It will be noted that the experimentally-measured curves show a somewhat sharper resonance effect than the computed ones, and if a still smaller value of R_1 had been used the check would have been better. Because of the uncertainty in the values of some of the other constants of the circuit, this can hardly be considered a method for measuring the effective resistance of a crystal, but it indicates that the values given by Van Dyke's formula are probably too large.

Inductance-Loaded Circuit

Calculations for this case are not given since, as pointed out above, this is a special case of the tuned plate circuit in which C_2 is simply the capacitance between plate and filament of the tube.

Resistance-Loaded Circuit

Introducing relative frequencies in (51) and (52), we have

$$\left(\frac{\beta}{\beta_a}\right)^2 = \frac{P_2}{\beta_a^2} = \frac{\dfrac{P_3}{\beta_a^2}}{P_1} \tag{53}$$

Substituting the values for $P_1 \ldots\ldots P_3$ of (38) and (48) in (53), it was found that the condition for oscillation can be satisfied only for the case of the crystal between grid and plate, and for this the following results were computed for different values of R_2 the load, or series plate resistance.

TABLE II

R_2	$\dfrac{\beta}{\beta_a}$	R_p
10000	1.00000536	6240
20000	1.00000503	6000
30000	1.00000036	5900
50000	1.00000048	5750
100000	1.00000042	5700

In this case it is to be noted that the crystal is forced from its natural frequency, at most, by only five parts in a million, and that the variation in frequency is very much less than in the case of the tuned circuit load. The values of R_p, however, are relatively small, indicating that the oscillations are weak, and the fact that they decrease as R_2 is increased indicates that the oscillations become weaker as the load is increased.

Experimental Checks

To test the theory as given above, two crystal-controlled oscillators of the various types there discussed were set up, each having its own A and B battery supply, and appropriate precautions were taken to insure a minimum of interaction between them. Each was loosely coupled to a third circuit containing a rectifier and an audio-frequency amplifier. Connected to this third circuit was an audio oscillator of continuously variable frequency calibrated in terms of a series of standard tuning forks. The crystals under test were ground in pairs so as to give audio-frequency beats of 300 to 500 cycles between them. One crystal-controlled oscillator was used to maintain a constant radio frequency while the other was experimented upon. The beat frequency between the crystals was then matched by the audio oscillator. This double heterodyne arrangement is an exceedingly sensitive method for studying problems involving frequency changes, since a variation of one cycle per second in either of the radio-frequency circuits gives an audio-frequency beat. The circuits under test were sufficiently stable to permit the audio-frequency beats to be held constant to one beat in 10 seconds.

The results for the tuned plate circuit case are shown by the full-line curve of Fig. 6, reference to which has already been made. For the resistance-loaded circuit the variations of frequency with load resistance were so small as to be barely within the limit of error of measurement, i.e., one or two parts per million. This checks the results of Table II, where maximum changes of only 5 parts per million were predicted. For standardization purposes, where extreme accuracy is the objective, the resistance-loaded circuit is thus much to be preferred. However, this circuit gives much weaker oscillations and will in general require an extra stage of amplification. Moreover, a crystal must be a very "good oscillator" to be used at all in this circuit. Out

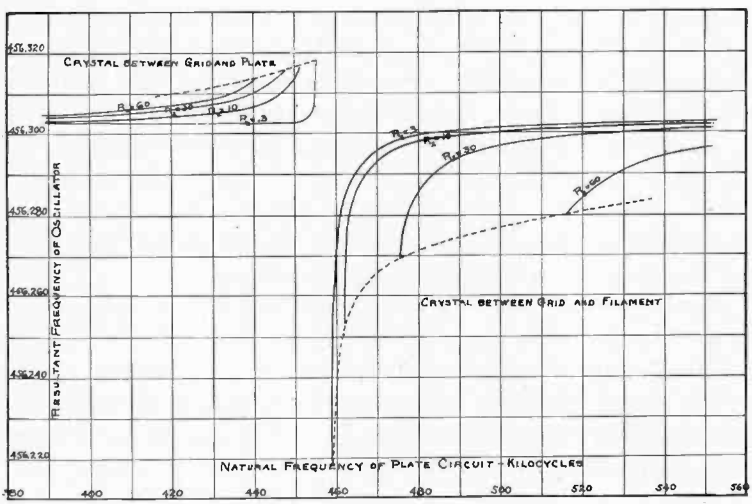

Fig. 7—Variation of Driven Frequency with Resistance of Tuned Plate Circuit.

of some twenty crystals used in connection with this work, only three would function with this arrangement.

An experimental study was made of the effect of varying the resistance R_2 for the two cases of tuned plate circuit oscillators, and the results are shown in Fig. 7, where the frequency of the driven system is shown in terms of the uncoupled frequency of the plate circuit. These results indicate that as R_2 is increased the separation between coupled frequencies is increased and that the sharpness of resonance is decreased. The range of plate circuit frequency over which oscillations occur is decreased by increasing load.

Conclusions

A quartz-crystal oscillator, when used to stabilize a vacuum-tube-driven circuit, does not oscillate at a frequency determined by its elastic and piezo-electric properties alone, but becomes part of a coupled system, and the actual resultant frequency is influenced by the degree of coupling of the two systems and the values of the constants of the entire circuit, including those of the driving device in the case of continuous oscillations. In doubly periodic vacuum-tube-driven circuits, one of the normal modes of oscillation is excited when the crystal is connected between grid and plate, and the other when connected between grid and filament. Although the oscillations are more powerful when the frequency of the plate circuit is close to that of the crystal, the departures of the resultant frequency from the natural frequency of the crystal are greater. For purposes of accurate frequency standard maintenance, the resistance-loaded circuit is much to be preferred, and when a crystal has been standardized it must always be used in exactly the same circuit and under exactly the same conditions as when the standardization was made. It is desirable from this standpoint to preserve not merely the crystal, but the entire circuit permanently assembled.

In conclusion, the author wishes to express his indebtedness to the American Association for the Advancement of Science for a grant for the purchase of equipment, to Dr. A. Hoyt Taylor of the Naval Research Laboratory for a supply of accurately-ground quartz plates, and to Mr. J. C. Cavender for carrying out the experimental measurements.

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QUANTITATIVE METHODS USED IN TESTS OF BROADCAST RECEIVING SETS*

By

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Summary—*The general classes of receiving set measurement used by the authors are outlined as special engineering tests and production tests. The apparatus and methods for both are described. A new form of radio-frequency oscillator, designed for this work, is described. Shielded test booths used for receiving-set measurement work are described. The importance of care in selecting the conditions of test used in making quantitative measurements on a receiving set is emphasized.*

MOST electrical quantities encountered in general electrical engineering are readily measurable, so that its practice has long been exact in measurements and tests of electrical products. Dynamo-electric machinery and power transformers, for example, have long been studied with the aid of relatively simple meter equipment. Radio engineering practice has not been so fortunate, except in transmitter equipment where quantities are similar to those of general electrical practice. In radio receiving set engineering, numerous obstacles to quantitative measurement work were present which required the development of new methods and new apparatus. These problems were caused in the main by the fact that the electrical quantities involved were so small that previously used meters and methods were useless with them. Many of the voltages and currents to be measured in receiving set practice are but millionth parts of those met in general electrical practice.

As a result of this lack of means of measurement, receiving set tests during the first twenty-five years or so of the radio art were conducted in a necessarily crude, practical way, chiefly by so-called "listening tests," wherein the receiving set was operated exactly as in actual service, and observations made by ear. This usually required a comparison test which rated the receiver under test in terms of some other receiver, the performance of which was familiar through previous experience. Most of the resulting data was far from having engineering

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exactitude. Signals delivered were said to be "one hundred times audibility," a "half-stage audio better" than the standard receiving set, "audible two rooms away," etc. Selectivity was "sharp as a knife," or even "razor-edge."

Using such methods of test and criteria, it was necessary to operate the receiving set in several locations having different signal conditions, and to spend considerable time at each location, in order to secure even approximate information on the performance characteristics of the receiver. Results at best were inexact and had little possibility of usefulness in predicting the performance of the receiving set under other conditions.

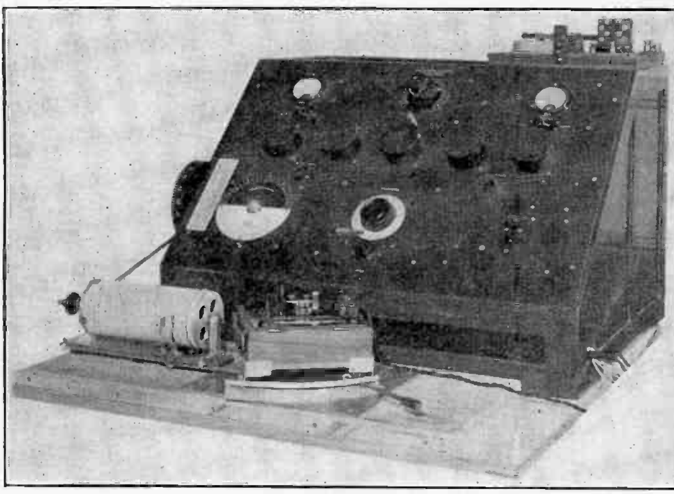

Fig. 1—Audio-Frequency Oscillator.

The ideal method of measurement would furnish such data as will make it possible to predict the performance of the receiving set under any specified service conditions. Such methods are now available for the measurement of sensitivity, selectivity, and fidelity of receiving sets, and it is the object of this paper to describe some of these methods. With these methods, a measurement laboratory is able to apply to a receiving set a measured input signal, and to measure the receiver output. In effect, the laboratory is supplied with a transmitting station which will transmit when desired, on any required carrier frequency, with any desired power, and with music or single tone modulation of fidelity equal to that of the best broadcast stations.

In the year 1922, the authors began work to develop methods and equipment for quantitative measurement of receiving set performance. At that time considerable was known about audio-amplifier measurements, and some work had been done by various laboratories and individuals in the measurement of radio-frequency amplifiers, but no effective method for measuring overall performance of receiving sets had been developed. In 1924, the work was greatly furthered by the assistance of Dr. Walter Van B. Roberts, and one system developed by him is described later in this paper.

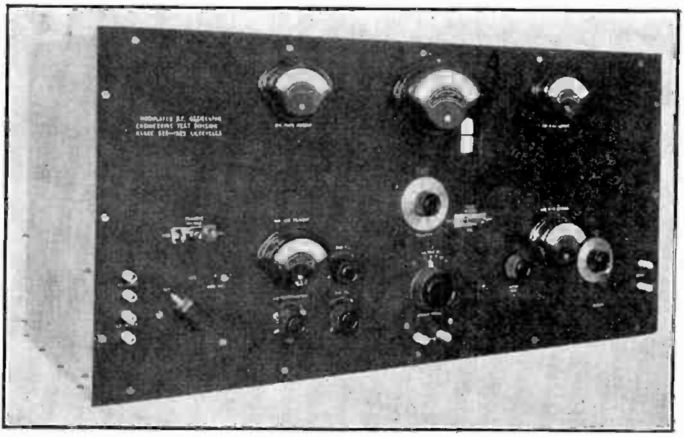

Fig. 2—Engineering Test Radio-Frequency Oscillator.

Early in this work it was found, as would be expected, that the determination of receiving set performance by measurement of individual parts of the set (for example, the radio and audio amplifiers) was impracticable. This was chiefly due to the fact that results are usually different when reactions between parts are absent, as they are under measurement of parts individually. Additional reasons arise from the facts that the electrical constants of most receiving sets are changed seriously when connections are made to internal parts, and that more time is required for measuring parts than is needed for a single over-all test. Sometimes, measurement of individual parts is desirable or even necessary, however, as when attempting to locate the cause of inferior performance of a set, or when engaged in development and design of a new set, in which cases segregation of the effects of the several parts is necessary. The methods of measurement to be described are intended chiefly for determination of the effectiveness of a complete receiving set, and are so arranged that the test results can be used to predict how the set will perform under any specified service conditions.

In order to obtain useful and dependable measurement results, several important conditions must be met, namely:

1. The equipment must be built so as to be accurate, reliable, and easy to operate.

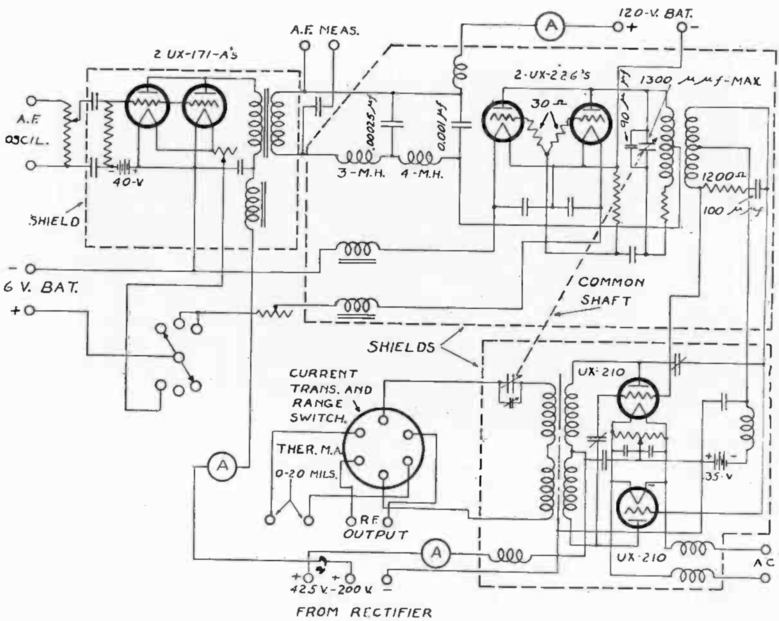

Fig. 3—Circuit of Engineering Test R. F. Oscillator.

2. Test conditions must represent service reception conditions, and no conditions can be present which cause erroneous results or conclusions.
3. The method of test should be suited to the use to which the results are to be put.

The authors have found that two types of measurement equipment are required to meet radio engineering needs. One is that used in engineering laboratories, in connection with development, design, or investigation of receiving set problems. The other is that used as a final factory production test, and applied to large numbers of sets. In the latter equipment, accuracy can be sacrificed to some extent, but in its place must be substituted greater simplicity of adjustment and operation, and increased ruggedness of construction. Reliability must be had in both classes of equipment to a maximum degree. On account of the difference between the equipments used for the two purposes, they will be discussed separately, and the test conditions which are of importance in connection with each will be discussed following the description of the apparatus in each case.

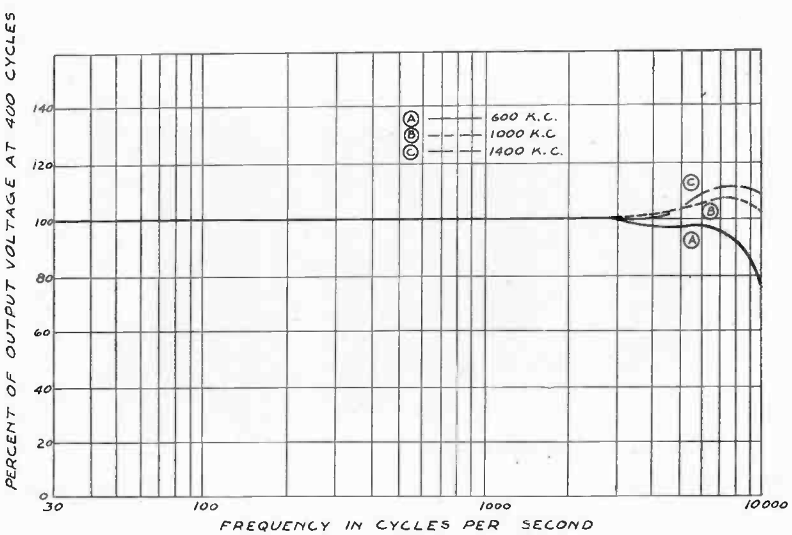

Fig. 4—Overall A. F. Characteristics of Engineering Test R. F. Oscillator.

Engineering Test Equipment

Audio-Frequency Oscillator. The source of audio-frequency voltage which we have found most satisfactory is a beat frequency vacuum-tube oscillator, employing the difference frequency between two radio-frequency oscillators. Such an oscillator is shown in Fig. 1. By combining and rectifying the radio frequencies, and then amplifying the resultant difference frequency, it is possible to obtain from the oscillator shown in this figure audio-frequency voltages of the order of 50 volts. The wave shape of the oscillations does not contain more than 1 or 2 per cent of harmonics even at the lowest frequencies, and the output potential will remain effectively constant over the frequency range of approximately 30 to 10,000 cycles per second, without readjustment.

The output voltage from this oscillator is sufficient to apply the necessary potential directly to the grids of the modulator tubes of the r.f. oscillator, without requiring any intervening amplification. In front of the oscillator in Fig. 1 will be seen the automatic curve drawing mechanism used for taking fidelity characteristics. The construction and use of this mechanism has already been described in these PROCEEDINGS.[1]

Radio-Frequency Oscillator. Two radio-frequency oscillators have been used in our engineering test work. One has already

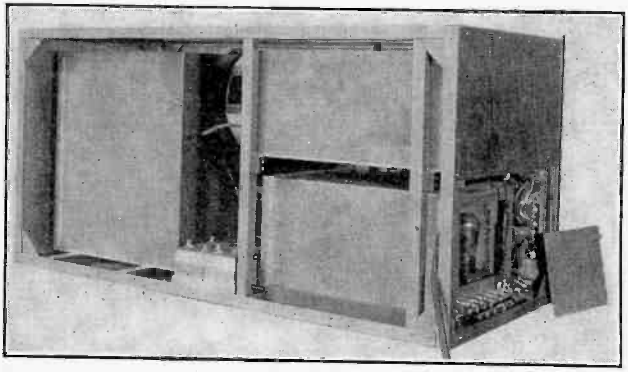

Fig. 5—Back of R. F. Oscillator Showing Separate Shielded Compartments.

been described in a paper by Messrs. Rodwin and Smith of this laboratory. This oscillator is an excellent device and is capable of wide usefulness in test work. Those desiring to obtain the details of its design are referred to the above paper,[2] which also contains information on methods of oscillator calibration.

Another r.f. oscillator has been recently completed, and is shown in Fig. 2. This oscillator embodies certain changes in construction as well as some new design features, which give improved operation. It uses two UX-171-A tubes connected in parallel as modulators, two UX-226 tubes in parallel as oscillators, and two UX-210 tubes connected in push-pull arrangement as r.f

[1] E. T. Dickey, "Notes on the Testing of Audio-Frequency Amplifiers," PROC. I.R.E., 15, 687; Aug. 1927.

[2] George Rodwin and Theodore A. Smith, "Radio-Frequency Oscillator for Receiver Investigations," PROC. I.R.E., 16, 155; Feb. 1928.

amplifiers. The modulator and oscillator tube filament currents are supplied from a storage battery. The amplifier tube filaments are supplied with alternating current at the proper voltage. The modulator and amplifier tubes receive their plate supply from a heavy duty "eliminator" operated from a.c., with its output carefully filtered. The oscillator tubes receive their plate supply from a bank of storage cells.

The r.f. range of the oscillator is 525 to 1525 kc. Slightly more than the broadcast range is provided for convenience.

It is desirable that the oscillator frequency shall not be appreciably affected by changes in the power supplied to the output circuit. By careful neutralization of the r.f. amplifier circuit,

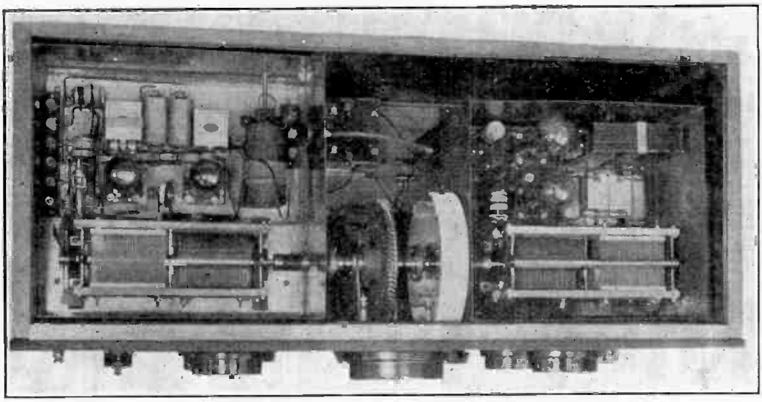

Fig. 6—Top of R. F. Oscillator Showing Oscillator and Amplifier Compartments with Shield Covers Removed.

the effect of variation (from maximum to minimum output) on the frequency of the oscillator is reduced to approximately 0.01 per cent at the high-frequency end of the range, and is lower than this at the opposite end. This amounts to no more than 150 cycles variation.

The circuit for the oscillator is shown in its essential features in Fig. 3. It will be noted that grid resistors are used in series with the grids of the oscillator tubes. These are necessary to avoid parasitic oscillations. The size of the oscillator grid condenser is quite critical if the best audio-frequency characteristic is to be obtained. In order to prevent excessive dropping of the audio-frequency characteristic at the high-frequency end of the audio

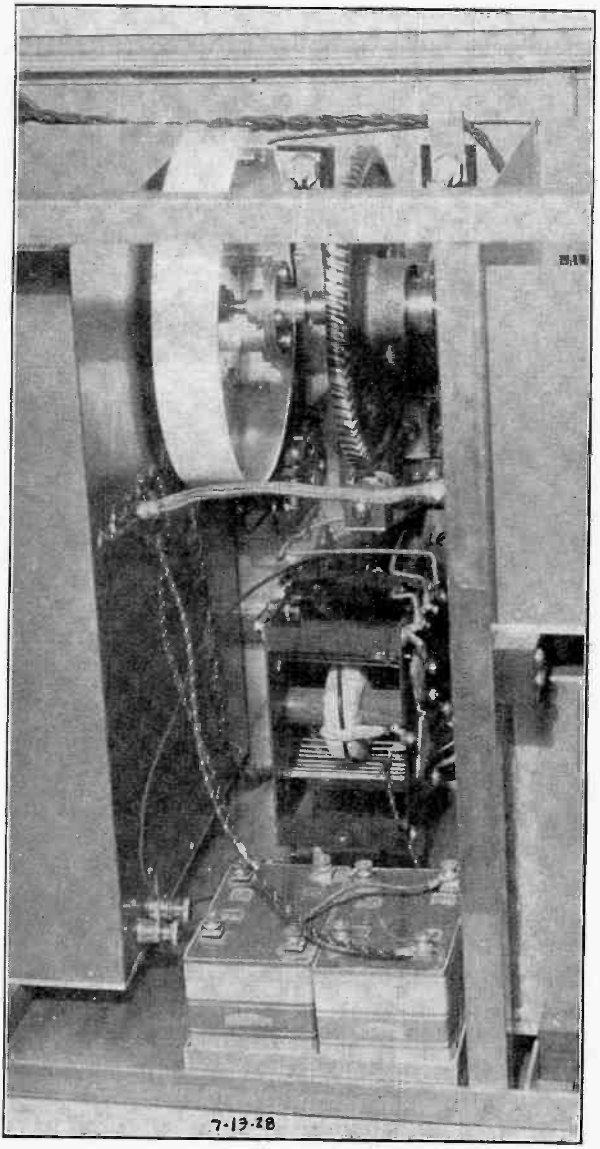

Fig. 7—View of Condenser Worm Drive and Current Transformer.

range, it is necessary to insert resistance in series with the oscillator circuit. The characteristics of the oscillator with regard to the audio-frequency modulation of the r.f. output and taken with constant input a.f. voltage, are shown in Fig. 4, for three frequencies in the broadcast range. It will be seen that a compromise has been reached at the high audio frequencies between the characteristic at 600 kc and that at 1400 kc. When the a.f. characteristics of most receiving sets are considered, it is evident that these variations in the r.f. oscillator characteristic can be neglected in practically all cases.

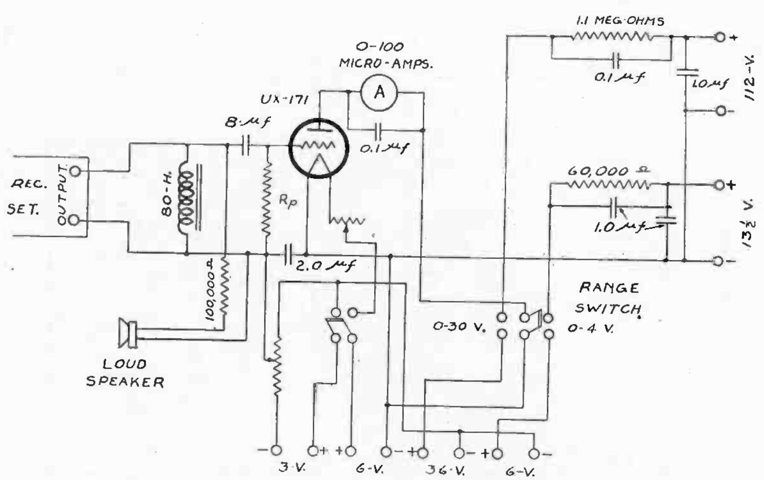

Fig. 8—Engineering Test Output Meter Circuit.

Modulation is obtained by introducing audio-frequency voltage in series with the plate-supply voltage of the oscillator tubes. This arrangement has been found to give quite satisfactory results, and it appears to have advantages over the constant current system for test oscillator use. The same a.f. voltage will produce equal percentage modulation at all radio frequencies. By properly connecting the primary and secondary of the modulation transformer, it is possible to make the plate current of the modulator tubes counteract the magnetizing effect of the oscillator tube plate current, thus avoiding any tendency toward core saturation due to direct current. This permits the use of a transformer having very low leakage reactance which is of considerable aid in obtaining a good audio-frequency characteristic for the modulation system.

Separate shielded compartments for the component parts, together with a complete shield surrounding the entire oscillator, have been provided as shown in Figs. 5 and 6. The compartment shields have been left "floating," i.e., ungrounded. This double shielding, together with the use of astatic wound coils in parts of the circuit carrying large r.f. currents, reduces the direct radiation from the oscillator to a minimum. The apparatus enclosed in each shielded compartment is shown roughly by the dotted lines in Fig. 3. It will be noted that the filter system in the secondary of the modulation transformer is inside of the oscillator compart-

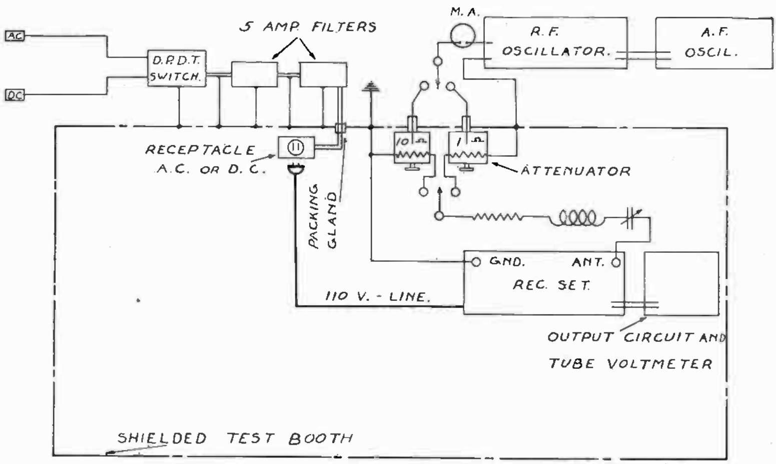

Fig. 9—Apparatus Arrangement in Test Booth.

Note: All leads between filters and switch and line boxes are carefully shielded and shielding connected to ground.

ment shield. This effectively prevents the possibility of radio-frequency current getting back into the modulator system, or out to the modulation voltage measuring meter.

The coupling between the oscillator inductor and the inductor feeding the r.f. amplifier tubes is fixed. The resistor and condenser shunted across the secondary winding have their values so chosen that the amplitude of the radio-frequency oscillations is maintained practically constant throughout the broadcast range. The values of resistance and capacitance used are, of course, dependent on the coupling between the primary and secondary windings.

The plate-circuit coils of the r.f. amplifier system are wound astatically, and variable coupling is obtained between them and the output circuit by means of a second pair of movable astatic coils. An electro-static shield is provided between the two sets of coils to permit zero coupling to be obtained. The output circuit is tuned to the oscillator frequency in order to reduce harmonics in the output current. The use of two r.f. amplifier tubes connected in push-pull also assists in this reduction. The output and meter resistance make this circuit sufficiently broad so that it does not have any material effect in cutting side bands.

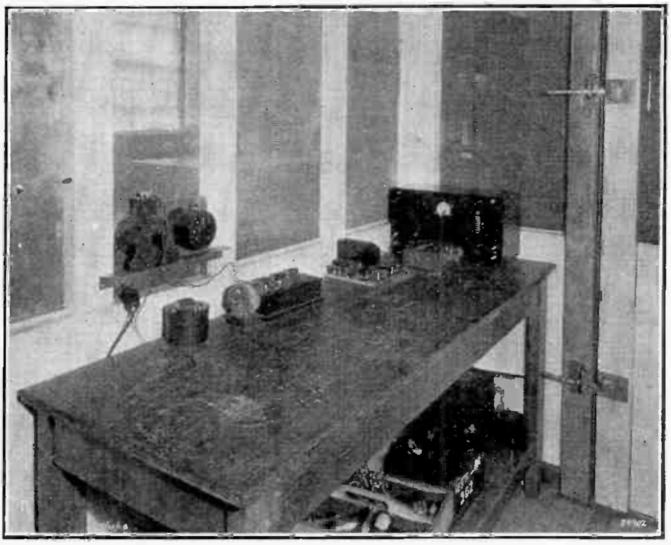

Fig. 10—Interior of Engineering Test Booth.

The oscillator variable condenser and the main variable condenser of the output circuit are directly connected to the same shaft. The large worm gear drive used for these condensers is shown in Figs. 6 and 7. This is especially designed to avoid back lash, and permits very accurate frequency calibration of the frequency adjustment dial. The main tuning variable condensers are of the straight line frequency type. This permits the vernier dial, which is attached to the worm drive, to be calibrated in divisions representing a small number of kilocycles, for use in taking selectivity characteristics. With the worm gear and this vernier dial, it is possible to detune the oscillator in steps of 2 kc either side of a test frequency, with a maximum possible error with respect to the test frequency of not more than 300 cycles, at any point up to 100 kc, from the test frequency. The worm drive permits variation of frequency as far as desired, of course, but selectivity curves are generally not taken beyond 100 kc, either side of resonance.

A high accuracy of oscillator frequency is assured by the use of relatively low inductance and high capacitance in the oscillator circuit. This tends to minimize the effect on the frequency, of variations in filament and plate voltage, as well as the changing of tube characteristics over a long period of time.

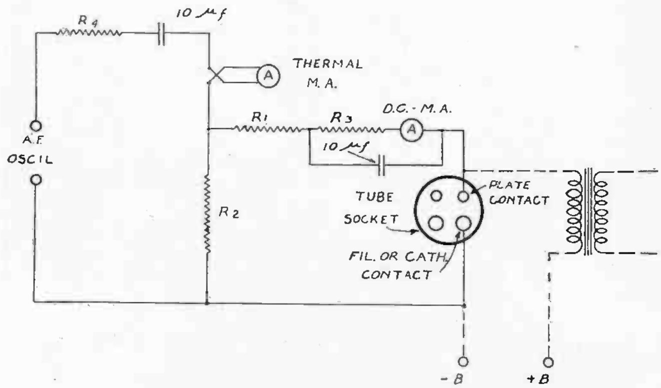

Fig. 11—Input Circuit for A. F. Amplifier Tests.

In Fig. 7 the current transformer will be seen below the condenser gear. This transformer is similar in general to that described in the previously mentioned paper by Messrs. Rodwin and Smith. The use of an electro-static shield between the primary and secondary windings, together with a "figure 8" winding for the secondary, has resulted in producing a transformer having an accuracy of not less than 97 per cent at any point of the broadcast range. This transformer is designed with an elaborate switching arrangement which provides six ranges from 50:1 to 1:50. With this transformer, a 20-milliampere thermal meter can be used to measure accurately output currents as low as 80 microamperes, and as high as the full output of the oscillator. The full output of the oscillator at 600 kc is approximately 80 milliamperes with 10-ohm output circuit, and at 1500 kc the maximum output is approximately 200 milliamperes.

Simplicity of operation has been retained to the greatest possible extent in this device to permit the taking of test data easily and quickly. Complete metering of all d.c. circuits is provided by meters on the front panel. The thermal meters for measuring the a.f. modulation voltage and the r.f. output current are connected externally, and are usually located on the table directly in front of the oscillator.

Transfer Circuit. For testing receiving sets designed for operation with antenna and ground connections, resistance type

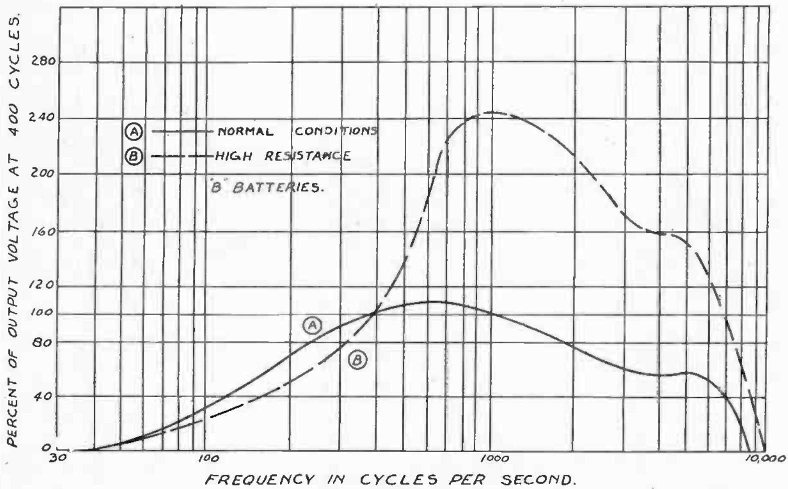

Fig. 12—Effect of High Resistance *B* Batteries on Fidelity of A. F. System.

attenuators are used between the r.f. oscillator and the artificial antenna circuit. In order to cover accurately a wide range of voltages, two attenuators are used. One attenuator has an attenuation range of from 0.01 to 0.95 in seven steps, and an output resistance of 1 ohm. The second attenuator has a range of from 0.1 to 9.0 and an output resistance of 10 ohms. Using these attenuators in connection with the above described oscillator, it is possible to impress (in series with the artificial antenna circuit) voltages of from 0.8 microvolts up to 0.7 volts. This range is sufficient for all but very exceptional test requirements.

For receiving sets arranged for loop operation, the output of the r.f. oscillator is connected to a small coil of known dimensions, and the loop of the receiving set is placed in the radio-frequency field of this coil. A single-turn coil approximately 2 inches in diameter is used for small field strengths, and a 4-turn coil approximately 8 inches in diameter for greater field strengths. The field strength at the receiving loop is then calculated from the dimensions of the transmitting coil, the current through it, and the distance between it and the receiving set loop.

Output Meter. A vacuum-tube voltmeter having two ranges (0–4 and 0–30 volts) is used to measure the voltage across the

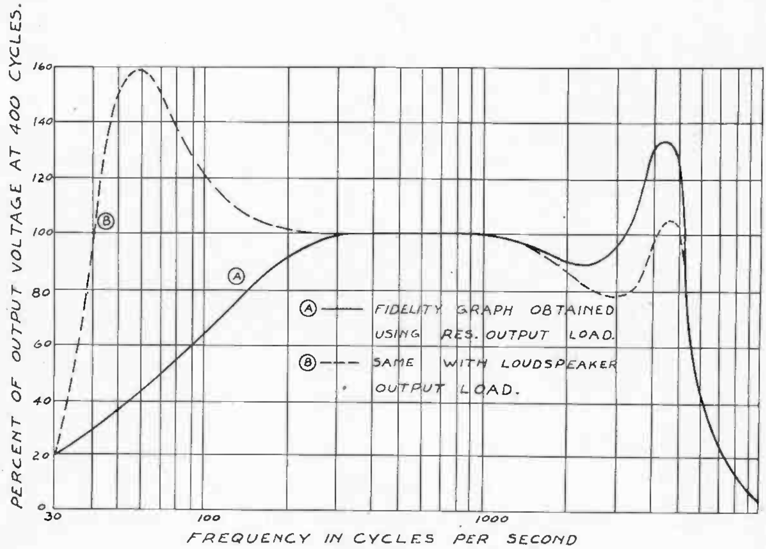

Fig. 13—Effect of Output Load on Fidelity Graph.

output resistance of the receiving set under test. Fig. 8 shows the circuit of the vacuum-tube voltmeter, together with the choke and condenser arrangement used in the receiving set output circuit when the latter has d.c. in its output circuit. The choke and condenser can, of course, be eliminated if there is no d.c. in the output circuit. The value of the resistor R_p is made equal to the plate resistance of the output tube. Across the output of the receiving set is connected a high impedance loudspeaker, in series with a 100,000-ohm resistor. This combination has no appreciable effect upon the output voltage, and serves to give a weak monitoring signal. This enables the tester to have an audible indication of proper performance during the test. It is very useful in checking undesired test conditions, such as oscillation in the receiving set, beat-note whistles between the r.f. oscillator and a powerful local broadcasting station, etc. If such a monitoring arrangement is not used, effects such as those mentioned above may be present and give erroneous test measurements, without the tester being aware of their presence.

The ranges provided by this tube voltmeter are sufficient for any of the usual measurements on receiving sets. If it is desired to measure voltages either above or below the useful range of this meter, a resistance divider or amplifier can be used at the input of the tube voltmeter to increase its range. This tube voltmeter

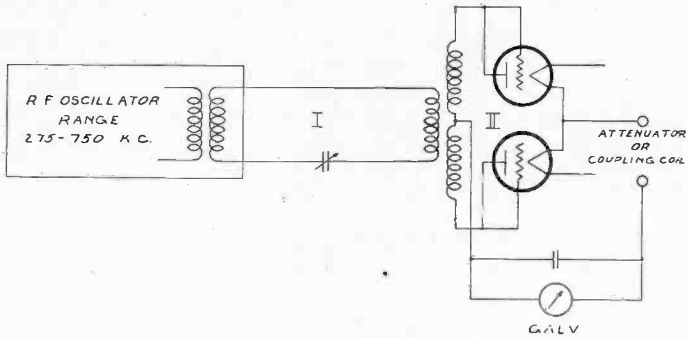

Fig. 14—Production Test R. F. Oscillator Theoretical Circuit.

has been found to be quite accurate and reliable, retaining its calibration within approximately 1 per cent over long periods of time. It is considerably more rugged than a thermo-couple instrument, since it is so designed that burnout of the plate meter is practically impossible. Compared against a thermocouple meter on a.c. voltages of bad wave shape, this tube voltmeter has an error no greater than plus or minus approximately 4 per cent, even with voltages having a total harmonic content of as much as 40 per cent. A zero reading of 10 microamperes is maintained in the plate meter by adjustment of the potentiometer. Once adjusted it will hold this zero setting for a considerable time. Those interested in obtaining further data on this tube voltmeter are referred to the previously mentioned article on a.f. amplifier testing.

ENGINEERING TEST CONDITIONS

Test Booth. It is important that the receiver under test be removed from the influence of extraneous effects such as power-line induction, atmospherics, stray pickup from local broadcasting stations, etc. The most effective way of accomplishing this is to place the receiving set on the inside of a well shielded booth. The r.f. and a.f. oscillators are situated on the outside of the booth. The general arrangement is shown diagrammatically in

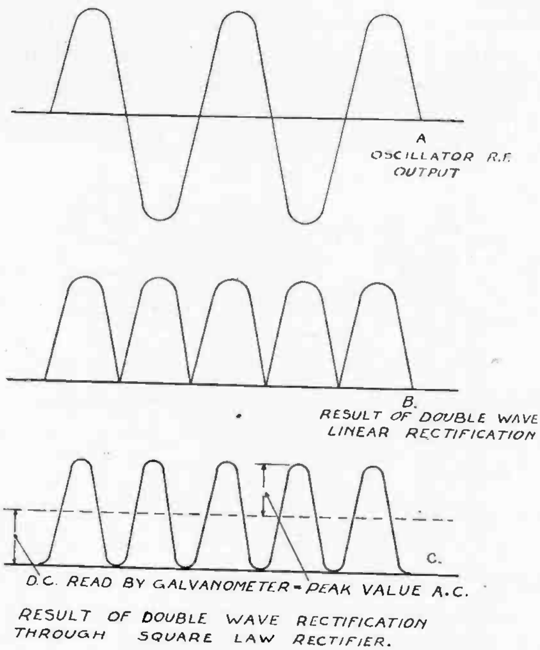

Fig. 15—Production Test R. F. Oscillator Frequency Doubling Action.

Fig. 9. The booth used for engineering tests at this laboratory has copper sheeting on the floor and parts of the sides. The top, front, and remainder of the sides are covered with copper screening. All the joints are lapped and well soldered. The copper screening was given a tinning coat before being erected to insure good electrical connection of the strands at each cross-over in the mesh. Metal weather stripping was used all around the door, and "refrigerator" type door clamps were used to secure sufficient pressure on the weather stripping to insure tight electrical contact when the door is closed.

Fig. 10 shows an interior view of one corner of the test booth. In this view at the right will be seen the door clamps, at the left the resistance attenuators and artificial antenna circuit, and at the end of the test table the output meter.

As will be seen from Fig. 9, the leads supplying alternating current to the inside of the booth are run through a system of filter circuits before entering the booth. The purpose of these is to prevent transmission of radio signals, line interference, etc.,

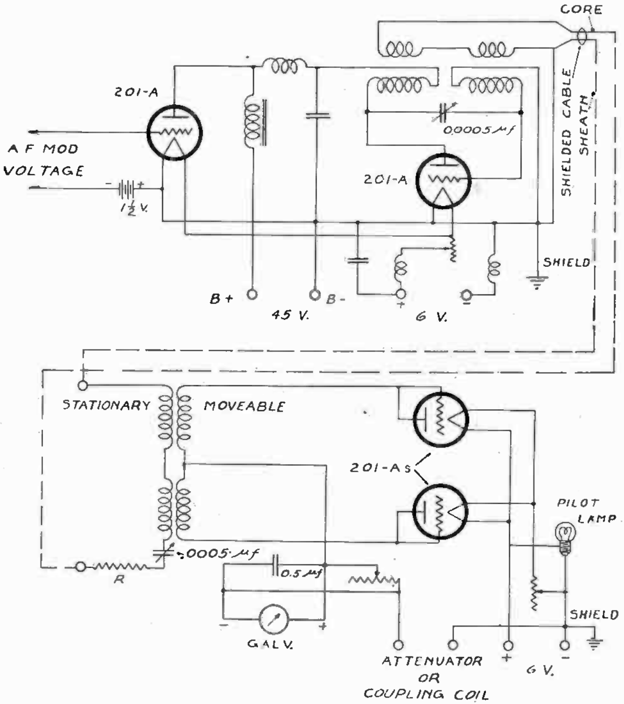

Fig. 16—Production Test R. F. Oscillator Circuit.

to the receiving set over these wires. Lighting lamps and their wires are kept outside the screen, so that induction from them may be avoided.

The position of the antenna, ground, and output circuit wires with respect to the receiving set is important. There is no general rule governing the position of these leads in actual use of the receiving set, of course, but it is best during test so to place these leads that they have a minimum effect upon the measurements. In general this involves avoidance of an arrangement which causes any of these leads to run close to the receiver for any considerable distance, and the simplest arrangement is generally to run the leads away from the receiving set in a direction perpendicular to the side from which they emerge.

Test Procedure. The test procedure used at this laboratory for taking measurements on receiving sets is the same as that outlined in the recently published Preliminary Draft of Report of the Committee on Standardization of the I.R.E. for 1928. Since this draft is available, no discussion on this subject will be given in this paper.

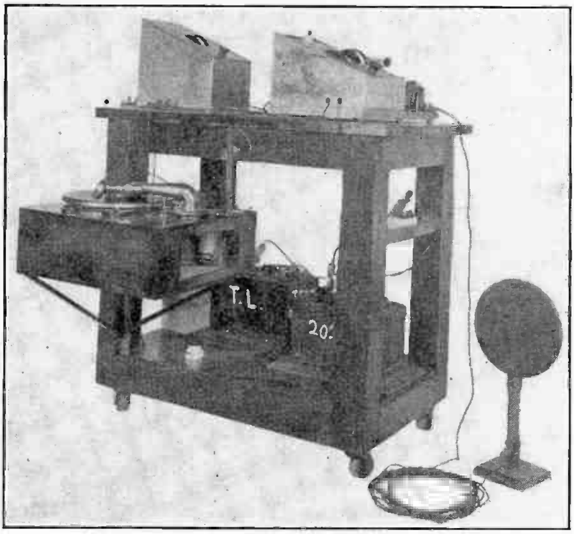

Fig. 17—Production Test R. F. Oscillator.

A. F. Amplifier Characteristics. It is generally desirable to take a fidelity characteristic of the a.f. amplifier system in a receiving set, to obtain information needed to analyze the overall fidelity characteristic in case features of this characteristic require study or correction. Segregation of the a.f. amplifier is usually sufficient. The general methods of test used at this laboratory have already been described in these PROCEEDINGS in the paper on a.f. amplifier testing mentioned previously. A circuit which has been found to be very convenient for plugging into a detector tube socket is shown in Fig. 11. This circuit is arranged to maintain the proper direct current through the primary of the a.f. transformer, using the normal B supply of the receiving set. At the same time it provides the proper resistance in series with this transformer, to simulate the plate resistance of the detector tube. Referring to Fig. 11, R_1+R_2 is made equal to the plate resistance of the detector tube. R_3 is adjusted to the proper value to give normal direct current through the transformer primary winding. R_3 and the d.c. meter are shunted with a 10-microfarad condenser so that they do not introduce appreciable impedance in the circuit for the a.f. voltage. R_2 is usually quite small with respect to R_1. R_4 is not absolutely essential, but where R_2 is small, it is desirable to have a somewhat higher resistance in the output circuit of the a.f. oscillator to prevent wave-form distortion. R_4 should be roughly equal to twice the plate resistance of the a.f. oscillator output tube.

General. In order to get complete data on a receiving set, it is necessary to test other functions which are not covered by the usual standard tests. A receiving set designed for power-supply operation must be tested to determine whether the proper voltages are being supplied to the various vacuum-tube circuits. A careful mechanical examination is also necessary, not only to locate possible faulty construction, but to determine accessibility of parts. This latter is important from the point of view of ease of servicing in the field.

There are numerous detailed points which must be investigated, but since the points needing test differ in each receiving set, it is impossible to set down any general rules. The experience of the test man must be called into use in determining the important special features for test.

Interpretation of Measurements. After measurements have been made and the graphs drawn, the interpretation of the results can be made and conclusions drawn as to the performance of the receiving set. This often requires considerable experience on the part of the engineer. The only way to acquire such experience is to make measurements on a number of receiving sets of various capabilities, and then to compare the data obtained with the degree of practical success which these receiving sets have had under broadcasting conditions in various locations. The relations between electrical measurement data and practical operating results are clearly evident after several comparisons of this sort.

It is important that the tester should realize the necessity of having all the conditions of test such that no anomalous conditions shall be introduced. A forcible example of the effect of such a condition is shown in the fidelity curves of Fig. 12. The solid curve shows the fidelity characteristic of a certain a.f. amplifier under normal conditions. The dashed curve shows the same amplifier with all conditions identical, except that high resistance *B* batteries were used. Space does not permit of further examples of this sort, but frequent cases of this kind are found during tests on receiving sets, and it is important that the tester be sufficiently skilled to recognize and avoid such unreliable test

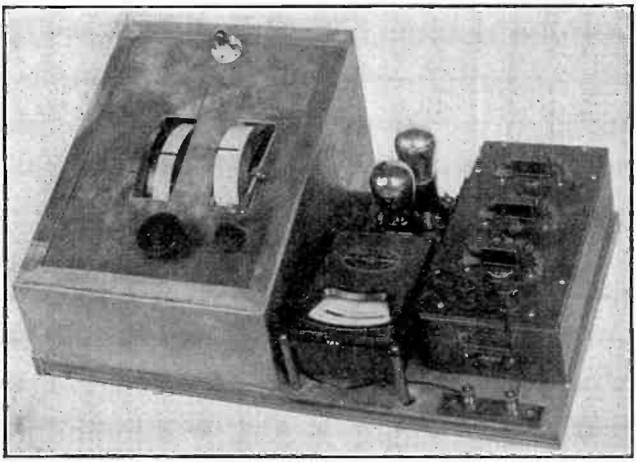

Fig. 18—Rectifier and Meter of R. F. Oscillator.

conditions or results. One of the safest methods is to check results by some other method whenever an apparently illogical result is obtained. In this connection, the necessity for standardization in test circuit constants is well illustrated in the graphs of Fig. 13. Here the difference between the two fidelity characteristics is caused merely by a change from a pure resistance output load to a loudspeaker output load.

Production Test Equipment

As stated previously, the measurement equipment used for the test of receiving sets in large quantities may be simplified in many respects from that used in special engineering tests.

Ruggedness and simplicity of operation are more important, and high accuracy of measurement is less important, than in special engineering tests.

Audio-Frequency Source. For the sensitivity test, a "hummer" signal is used to modulate the r.f. oscillator. For fidelity test, the r.f. oscillator is modulated with phonograph music, and the fidelity is judged by ear, using a standard loudspeaker of a type intended for use with the receiving set under test. The phonograph records for this test are selected with the idea of showing the low- and high-frequency response of the receiving set circuit. An electric pickup is used on the record, and the voltage from it is used to modulate the r.f. oscillator.

Radio-Frequency Oscillator. In the early part of 1926, Dr. Walter Van B. Roberts developed a radio-frequency oscillator circuit which is particularly well adapted to production test work. It has outstanding characteristics of simplicity of construction and operation, minimum necessary shielding, ruggedness of output measuring device, and reliability of operation. The theory on which the functioning of this oscillator is based is briefly described below.

The oscillator is divided into two main portions. One portion consists of oscillator and modulator circuits, and the second portion consists of coupling means for varying the output, a double-wave rectification system, and a d.c. microammeter for measuring the output. The r.f. oscillator operates at a frequency one-half that of the desired broadcast frequency. Fig. 14 shows the basic circuit arrangement. Circuit I is tuned to the fundamental of the r.f. oscillator in order to eliminate the second harmonic of the oscillator from the rectifier circuit. Circuit II consists of two rectifier tubes giving full-wave rectification. Referring to Fig. 15, the action of the rectifiers on the oscillator fundamental frequency will be seen. At A is shown the output of the r.f. oscillator, which is assumed to be sinusoidal after it has passed through tuned circuit I. If the double-wave rectifiers worked on a linear rectification principle, the resultant wave form in the rectifier circuit would be as shown at B in Fig. 15. However, if the rectifier tubes are worked sufficiently far down on their characteristic curves, they will give practically square law rectification. Therefore the rectified wave will look approximately as shown at C. Two interesting facts will be noted with regard to this rectified current. First, it is of double the frequency of the oscillator fundamental; second, it is a sine wave whose axis represents the value of the d.c. component of the rectified current which will be measured by a d.c. meter in series with the rectifiers. This direct current is equal in value to the peak value of the a.c. component of the rectified current. Thus it is possible to measure the a.c. output of this oscillator system by means of a d.c. meter. The advantages of such a system are too obvious to need comment. The only requirements affecting equality of the direct current and a.c. peak values are: (1) That the rectifiers be so adjusted that with no impressed a.c. voltage the current is zero, but that the slightest impressed voltage will cause a current to flow; (2) That the rectified currents be sufficiently

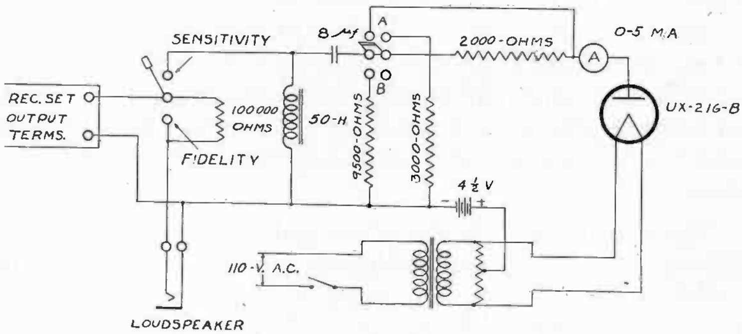

Fig. 19—Production Test Output Meter Circuit.

small so that the rectifier tubes obey a square law; and (3) That the currents due to the second harmonic of the oscillator are reduced to a negligible value in the rectifier circuit. Those desiring further information regarding the theory of this oscillator system are referred to a paper which has been published describing it.[3]

The complete circuit of this oscillator is shown in Fig.16. The Heising system of modulation is used in the oscillator. It is necessary to use separate filament supply for the oscillator and rectifier tubes. All r.f. coil systems are astatically wound.

Fig. 17 shows a photograph of the complete oscillator, together with the phonograph system for phonograph modulation.

[3] Walter Van B. Roberts, "A Method for Generating and Measuring Very Weak Radio-Frequency Currents," *Journal* of the Franklin Institute, March, 1926.

The oscillator and modulator circuit is contained in the sloping panel metal box on the left of the table, and the coupler and rectifier system is at the right. The coupling coil shown at the right of the oscillator table is used in testing loop receiving sets. Fig. 18 shows a closer view of the coupler unit, and of the rectifier and output meter system. The intermediate tuned circuit is controlled by means of a condenser in the coupler shielded compartment. The fact that a very high degree of shielding is not necessary is illustrated by the large openings provided in the sloping panel shield, for the condenser and coupling drums shown in Fig. 18.

Transfer Circuit. For tests on receiving sets using antenna and ground connections, a mutual inductance coupler attenuator is used between the oscillator output and the artificial antenna system. In testing loop receivers, a signal generating coil is connected to the output of the oscillator, as in the case of the engineering test procedure described previously.

Output Circuit. In order to make the Production Test output meter as rugged as possible, it is desirable to have it consist of a rectifier tube and a d.c. milliammeter. Since such a circuit offers a definite load to the circuit across which it is connected, it is made part of the load resistance. By proper selection of series and shunt resistors it is possible to produce a circuit which has the proper load characteristics for either a 2000-ohm or a 5000-ohm output tube. Such a circuit is shown in Fig. 19. By throwing the double-pole switch to position A, the circuit simulates a 2000-ohm load, and in position B a 5000-ohm load. In either position, normal output (50 milli-watts) is given by a reading of 1 milliampere on the d.c. meter.

As in the case of special engineering tests, a monitoring loudspeaker is provided. By throwing the single-pole switch downward, the loudspeaker is connected directly across the receiving set output for the fidelity listening test.

Production Test Conditions

Test Booth. With open antenna-type receiving sets it is not necessary to use a shielded booth when using the Roberts oscillator, unless the receiving set has very high sensitivity. For loop antenna or highly sensitive open antenna receiving sets, however, a booth is needed. The test booth used for production test work at this laboratory is shown in Fig. 20. The output meter panel can be seen in the right-hand corner of the booth, through the open door. The heavy construction of the door, together with the weather stripping around the door, can also be seen. The upper half of this booth is enclosed with wire mesh. The oscillator is located in the center of the booth. This permits measurement work to be done at one end of the booth while a receiving set is being removed from the other end, and a new set put in and connected up. This arrangement is a considerable aid in speeding up the test work, and makes it possible to use the oscillator more efficiently.

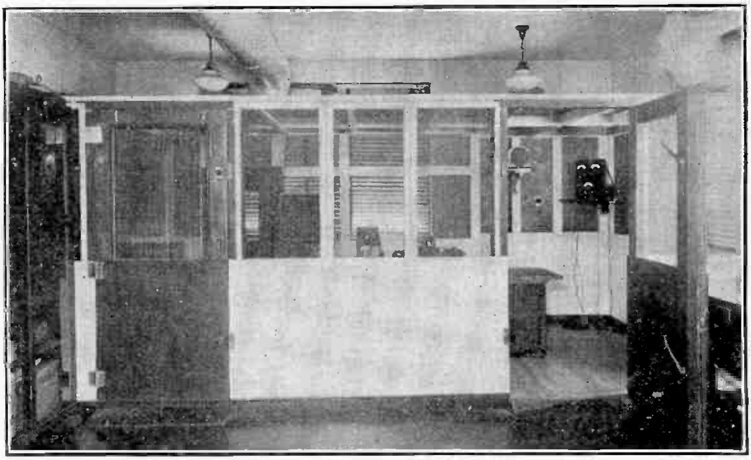

Fig. 20—Production Test Booth.

Conclusion

It is the belief of the authors that the day is not far distant when it will be possible for radio engineers to use one universally comprehensible language in speaking of receiving set measurement and performance. It is hoped that this description of test equipment and methods may be of assistance in this direction. In a recent test of the methods, measurements were made on a certain receiving set by four different laboratories, at different times, with results which checked within 25 per cent. Of this error, it has been established that about 10 per cent was due to changes in the characteristics of the receiving set itself, as it was moved from one laboratory to another. This check is the more noteworthy when it is considered that the detail parts of the test equipments in the various laboratories differed in many respects.

The authors wish to acknowledge the assistance which has been rendered by Messrs. Bonanno, Howard, and Whitehead of this laboratory in the design of the test equipment described.

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VACUUM-TUBE PRODUCTION TESTS*

BY

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Summary—*General description is given of the methods and apparatus employed by the authors in the testing of vacuum tubes in large quantities.*

EVERY manufacturer is confronted with the problem of determining and controlling the quality of his product. When the number of units produced is small and the product is simple in nature, the problem is relatively simple; when mass production methods are employed on a product of complex nature, and the number of units produced is in the millions, production testing involves difficult problems.

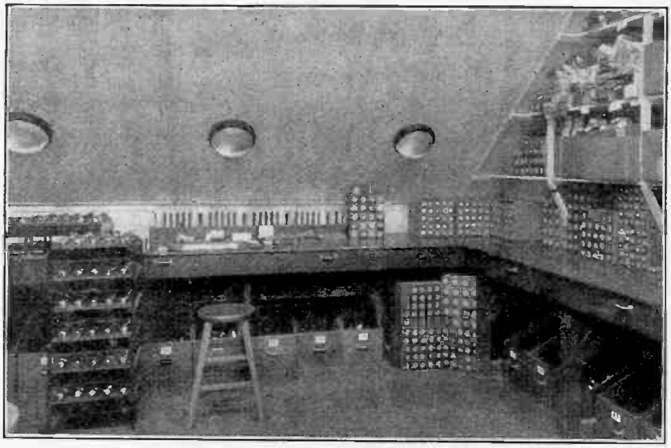

Fig. 1—Receiving Room. Unpacking and Initial Inspection.

Vacuum-tube production has increased rapidly from a total of a few thousands per year, ten years ago, to a yearly production which runs into the millions. The increased demand has made possible the introduction of automatic machinery in many of the manufacturing processes, with the result that vacuum tubes of high quality and uniform characteristics may be had today in any quantity at a fraction of their cost several years ago.

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In the early days of radio broadcasting the uniformity of the electrical characteristics of vacuum tubes available on the market was relatively unimportant because the circuit requirements were simple and provisions were made in the sets for adjustment of the tube operating conditions. An experienced, skillful operator was able to obtain maximum efficiency in the operation of his set by adjustment of the controls.

Present day multi-tube, single control receivers would be impossible without vacuum tubes having definite, uniform electrical and performance characteristics. Modern circuits with

RADIO CORPORATION of AMERICA — TECHNICAL and TEST DEPARTMENT

RADIOTRON TEST RECORD — No ______

TYPE ______ — WAREHOUSE ______

LOT No. ______ — FACTORY ______

Tube No.	I_f M.A.	I_p M.A.	Input Inped.	I_{gu}		μ	R_p ohms	G_m μ mhos	Capacitance			Emission, I, M. A.							Mech. Insp.	Carton No.
				Galv.	μ A.				G-P	G-F	P-F	0								
AVG.																				

I_f, I_p, μ, R_p, G_m, I_s measured at E_p = ____ Volts, E_g = ____ Volts, E_f = ____ Volts.
I_{gu} measured at I_p = ____ MA, E_p = ____ Volts, E_f = ____ Volts.

Fig. 2—Measurement Record Card

their high degree of selectivity, sensitivity, and fidelity, are critically designed and balanced for use with certain types of tubes of known characteristics. Departure of these characteristics of the tubes from the established values results in inferior performance, and in extreme cases, in complete failure of the set. The satisfaction given by a modern receiving set is definitely dependent upon the degree of uniformity of the characteristics of the tubes employed in the set. This being the case, the importance of maintaining the uniformity and dependability of vacuum tubes is readily appreciated.

In this paper will be given a general survey of the methods and equipment employed by the Radio Corporation of America in the testing of Radiotrons. The complexity of the equipment and the large number of highly specialized test circuits employed preclude their detailed description at this time. The circuits employed are generally known, and the special forms in which they are used in these tests are determined by practical considerations such as ease of operation, and labor and time saving qualities.

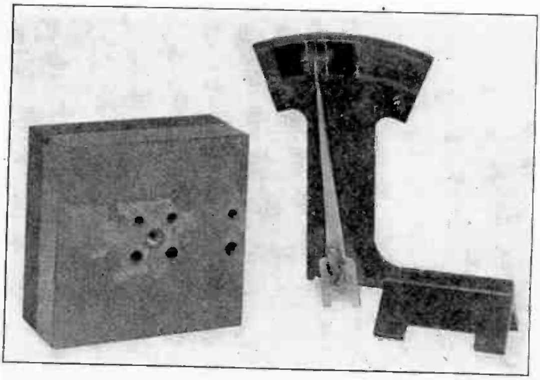

Fig. 3—Typical Gauges Used in Mechanical Inspection.

The vacuum-tube production test methods employed by the Radio Corporation of America may be divided for convenient discussion, into four operations which are listed in the order of their execution.

1. Sampling the product.
2. Initial Inspection.
3. Measurement of initial electrical characteristics.
4. Life Testing.

These operations will be discussed individually.

Sampling the Product

Great care is necessary in the selection of test samples to insure that the samples selected truly represent the quality of the entire lot of tubes from which they have been selected. The number of tubes selected should not be too small, yet an unnecessarily large number of samples should not be taken for economic reasons. In general, the larger the number of tubes under consideration the smaller the percentage of samples can be. For example, one tube is not safely representative of a group of 100 tubes if 100 is the total number under consideration, whereas one tube might safely be considered representative of 100 tubes where the total being considered runs into the thousands. The

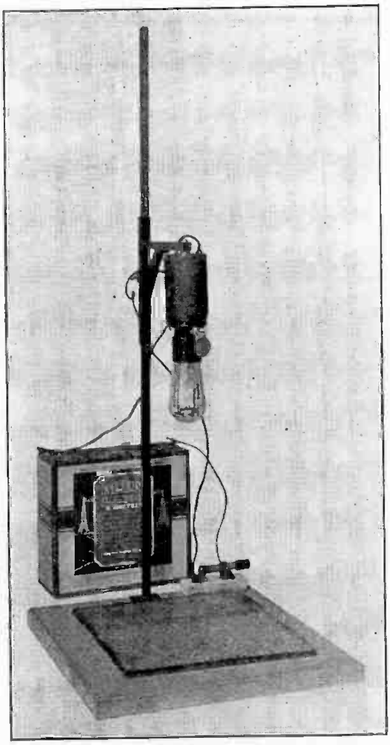

Fig. 4—Drop-Test Apparatus

percentage of tubes selected for test samples also depends upon the type of tube under consideration and its previous production history.

Sampling of the product is done at the factories, the inspector on duty selecting the finished product at the packing station according to a schedule determined by the rate of production and type of tube. These samples are carefully marked with date of manufacture and other essential information and are forwarded to the testing laboratory.

Samples for test purposes are also taken at intervals from the warehouses to check the results of tests made on samples selected at the factories.

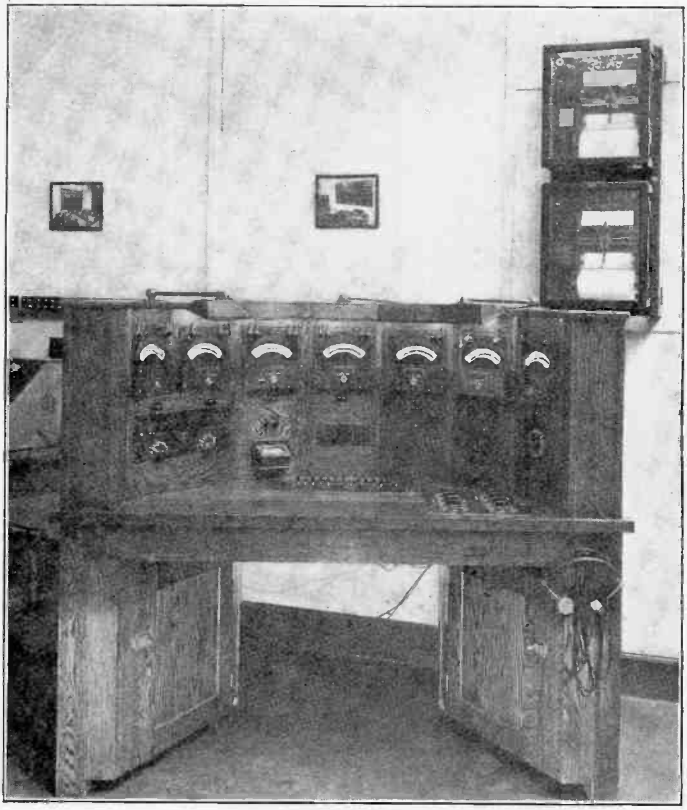

Fig. 5—Universal Test Bridge

Initial Inspection

Initial inspection of the samples is made at the time the tubes are unpacked at the testing laboratory. Each sample (including carton, wrapper and instruction sheet) is carefully inspected for appearance and mechanical condition. The tubes are labeled with serial number, factory number, and date of manufacture. Fig. 1

For certain tests in the mechanical inspection work, special gauges have been provided which make easy the detection of mechanical faults. In Fig. 3 are shown several gauges used in

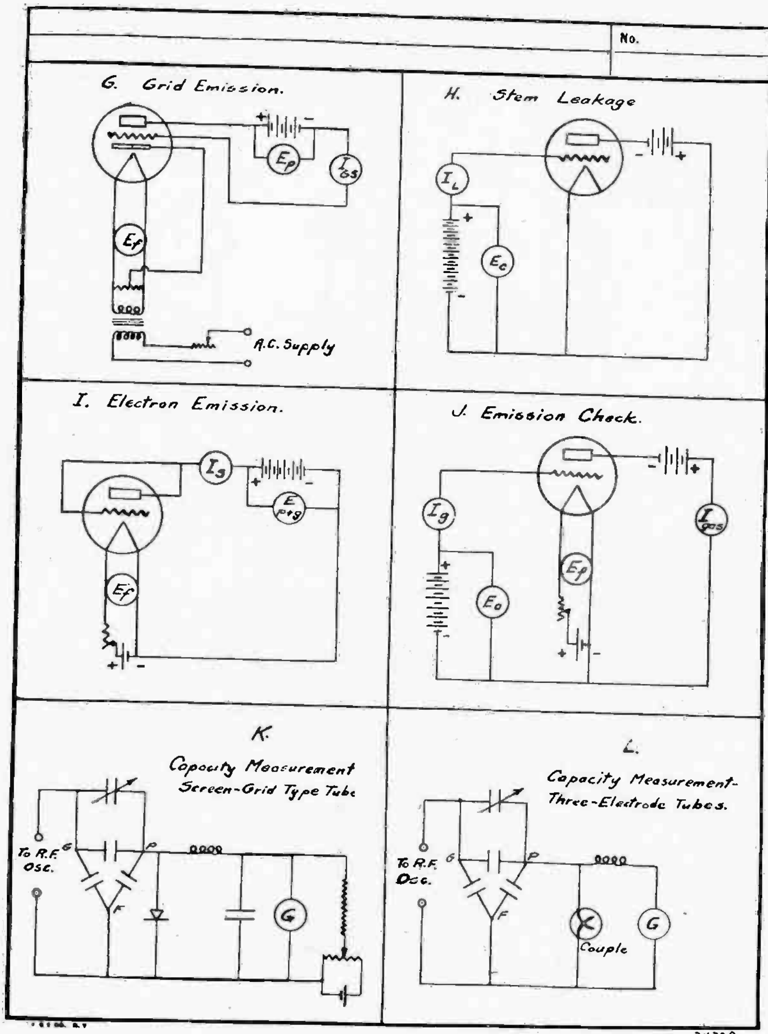

Fig. 8—Typical Test Positions.

this work. The device on the left is used for determining whether or not excessive solder is on the contact pins; the device on the right is used in measuring the degree of eccentricity of the tube bulb with respect to its base.

Mechanical strength of the product is checked by subjecting the samples to standardized "drop" and "bump" tests. In the "drop" test the tubes are dropped from various heights, and in

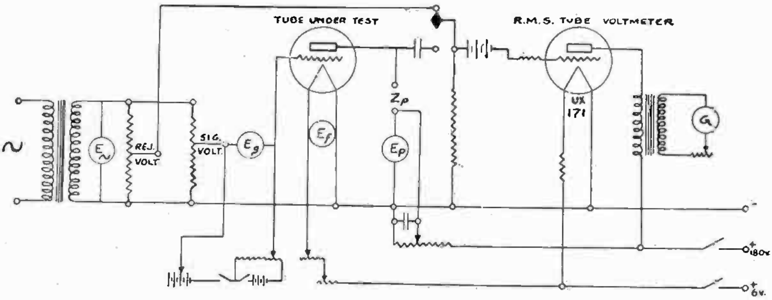

Fig. 9—Universal Test Set. Schematic Diagram.

various positions relative to the base of the test machine. In the "bump" tests the tubes are made the "bob" of a pendulum and allowed to strike a surface after having traveled through a

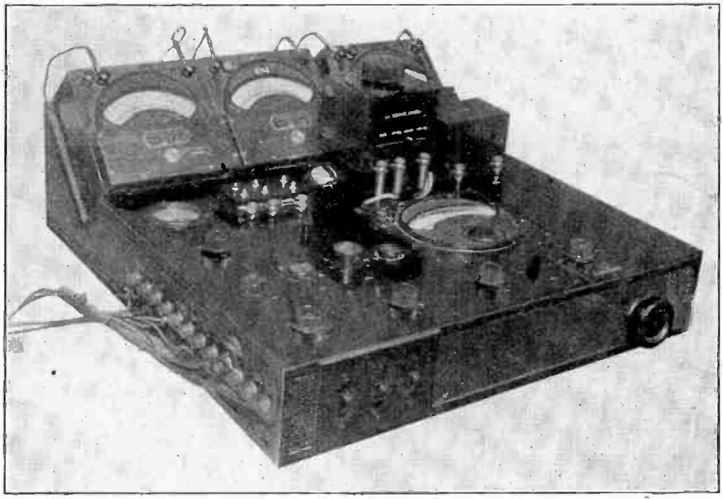

Fig. 10—Universal A.C. Test Set.

given degree of arc. These tests may be made with or without operating voltages applied to the tubes. Other tests of mechanical strength are made periodically by actual shipment of samples about the country under various conditions of packing. One type of drop testing apparatus is shown in Fig. 4.

Initial Electrical Characteristics

After being inspected for appearance and mechanical condition, each sample is tested for initial electrical characteristics.

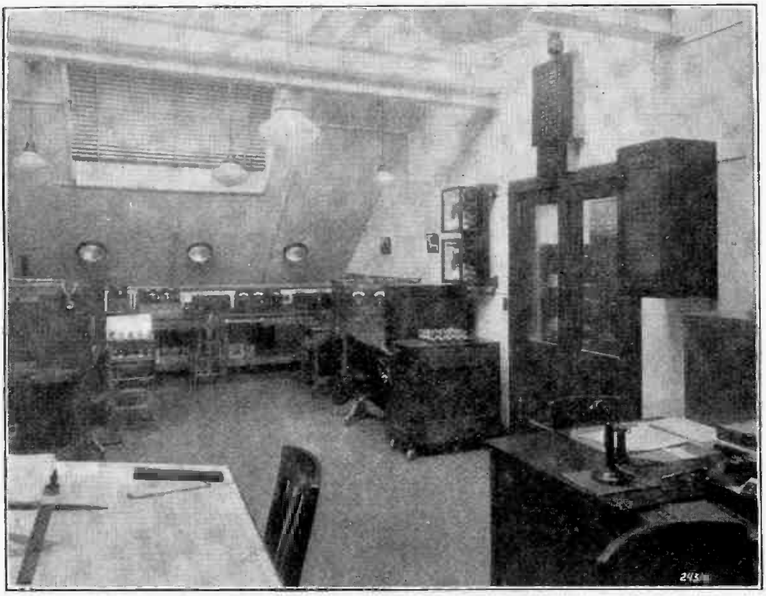

Fig. 11—Characteristic Measurement Laboratory.

The following characteristics are measured, although not every characteristic listed is tested for in every type tube.

1. Filament current at rated voltage.
2. Plate current.
3. Amplification factor.
4. Plate resistance.
5. Mutual conductance.
6. Electron emission.
7. Inter-element (stem) leakage.
8. Gas content (degree of vacuum).
9. Input impedance.
10. Grid emission.
11. Back emission.

12. A.C. test (dynamic).
13. Inter-electrode capacitance.
14. Receiving set performance.

The first ten characteristics listed above are measured with the apparatus shown in Fig. 5. This device is a universal test equipment which, by means of switches, may readily be changed from one circuit condition to another to meet the requirements of the particular test desired. A wiring diagram of this bridge is shown in Fig. 6. One model of this bridge which has been recently developed is automatically adjusted to any desired

Fig. 12—Power House—Exterior View.

test position by means of buttons controlling an automatic selector switch. Much time is saved for the operator by the bridge construction, since twenty types of tubes are tested in this bridge and each tube has its own peculiar test circuit requirements.

Figs. 7 and 8 give some of the more generally used test positions which it is possible to obtain on this bridge. The circuits shown are the ones generally used, and are conventional in design.

The a.c. test listed above is not generally known and deserves special comment. A circuit diagram of the device is shown in Fig. 9, and an external view is shown in Fig. 10.

The a.c. test is a "dynamic" test, i.e., it measures the overall amplification of a tube under conditions approximating those of service. A definite signal voltage (a.c.) is applied to the input circuit of the tube, and the resulting output signal voltage is measured in the plate or output circuit. The set is flexible and it may be readily changed to test any type of tube by simply

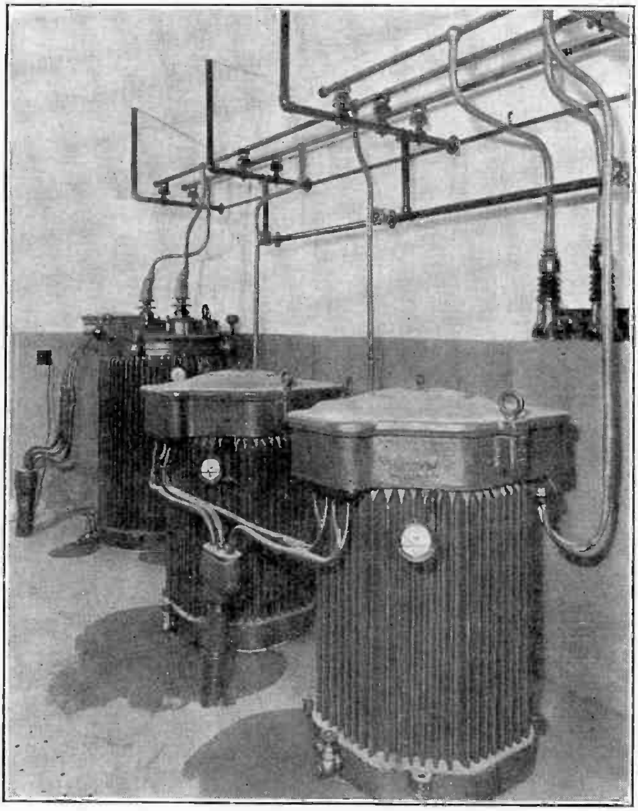

Fig. 13—Power House—High Tension Vault.

inserting the proper potential dividers and load impedances in the jacks provided for that purpose. Much work has been done on the correlation of the indications of this bridge and the actual receiving set performance of tubes, and values have been obtained for the a.c. test for many types of tubes which represent performance limits. In other words, it is possible to predict the behavior of a tube in a receiving set if its a.c. test reading is known. This test is gradually being adopted for all three-electrode tubes as a criterion for the end of useful life during life tests.

In making measurements of the electrical characteristics of tubes, great care in the selection of circuits employed is very important, as are also the construction of the apparatus, calibration of meters, and accuracy with which the readings are taken. Minor details which may seem insignificant, are quite often the cause of serious errors in measurement and inability to check results. A general view of the measurement room is shown in Fig. 11.

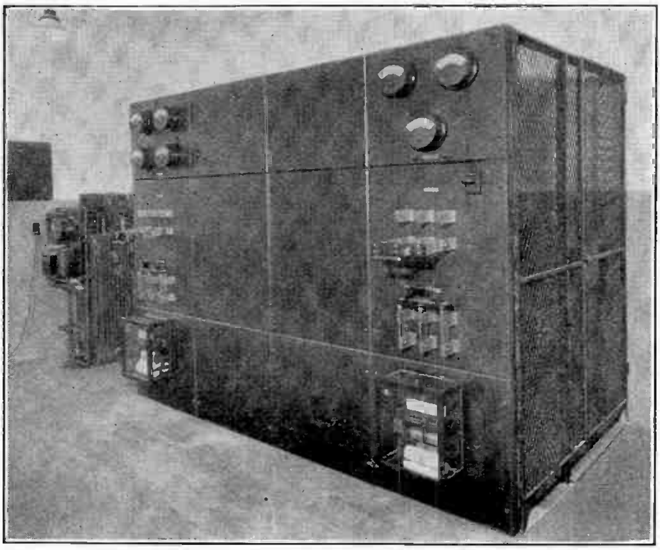

Fig. 14—Power House—Low Tension Vault.

Life Testing

The life quality of vacuum tubes is a very important characteristic and it is also, perhaps, the most difficult one to determine accurately. Absolute control of every factor affecting life performance is essential for accurate results, because apparently insignificant details of the test apparatus or method may have enormous influence on the test results.[1]

[1] W. C. White, "Life Testing of Tungsten Filament Triodes" Proc. I.R.E., **13**, 625; October, 1925.

The test equipment described represents the accumulated knowledge gained from testing thousands of tubes during the past few years. Every precaution is taken to insure the reliability of the results obtained. The tests are operated continuously

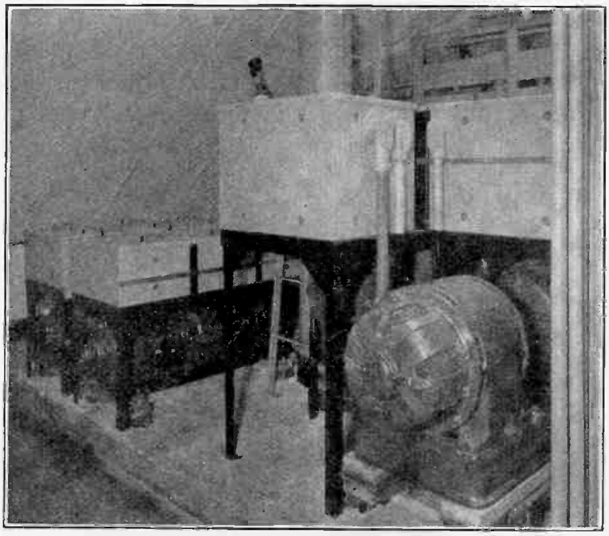

Fig. 15—Motor-Generators for D.C. Power Supply.

throughout the year so that judgments of life quality of any type of tube are not restricted to the results of a few tests but may be based on a large number of tests made on samples representative of the entire production.

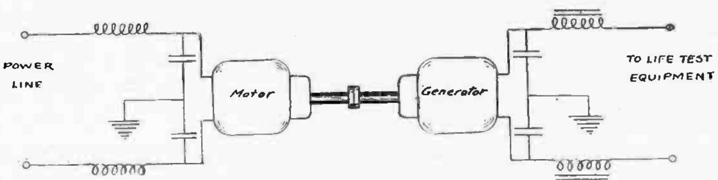

Fig. 16—Motor-Generator Filter Circuits.

Power Supply

The power used in life testing Radiotrons (New York City Laboratory) is obtained from the local power company. This power is transformed and regulated (automatic voltage regulators) in a separate substation building. Fig. 12 is an exterior view of the transformer house and Figs. 13 and 14 are views of the transformer and regulator equipment. This equipment supplies power for operating the motor-generator equipment, and is used directly (through suitable step down transformers) for supplying the filament power of the tubes on test.

Direct-current plate power is supplied by the motor-generators shown in Fig. 15. Each d.c. voltage required is supplied by an individual machine in order to minimize voltage regulation effects

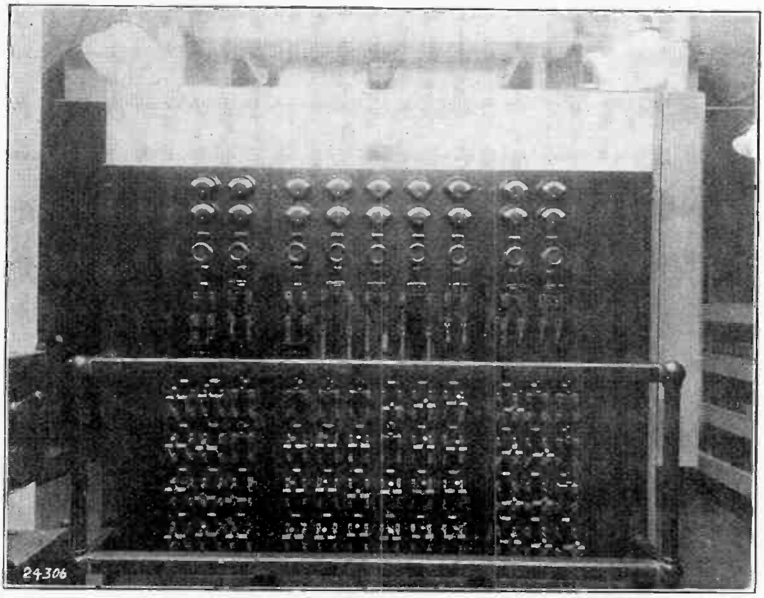

Fig. 17—Main Switchboard.

which would occur if series resistors or voltage dividers were used to obtain all voltages from one machine.

The input and output circuits of each machine are provided with electric filters which prevent radiation of electro-magnetic fields from the power lines. These filters are contained in iron boxes mounted directly over the machines. A typical circuit connection is shown in Fig. 16.

All d.c. power is controlled from the main switchboard shown in Fig. 17, by means of which any voltage generated can be supplied to any rack desired.

Grid voltage (d.c.) is supplied by batteries of dry cells, the load on this circuit being quite small and economically handled by the No. 6 type dry cell.

Direct-current power for use in making initial bridge tests and all intermediate measurements (during life) is obtained from

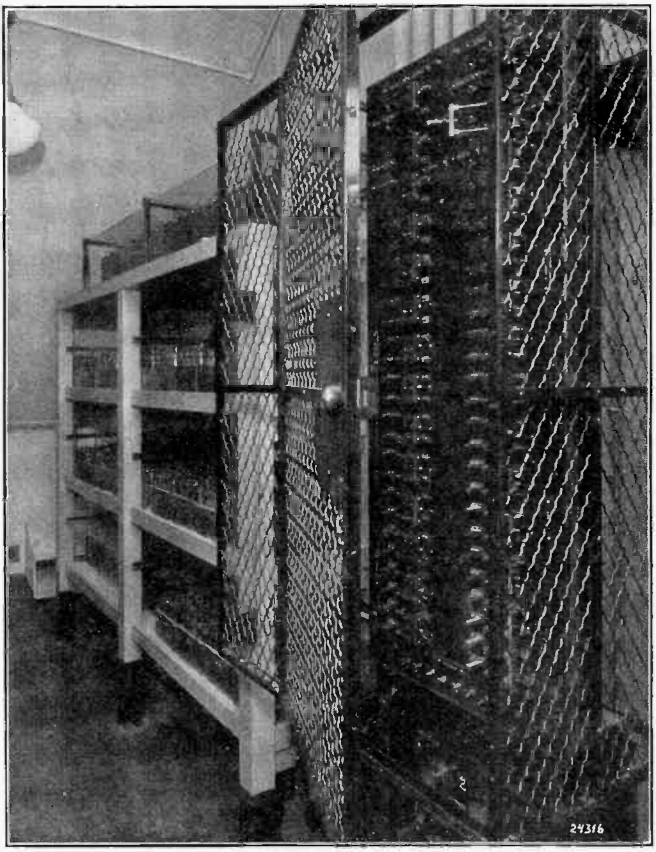

Fig. 18—High-Voltage Battery and Charging Equipment.

storage batteries. The high-voltage battery equipment and charging panel are shown in Fig. 18.

A large portion of the power used in life testing vacuum tubes is dissipated in the form of heat. Because of the large number of tubes tested in this laboratory, special precautions are necessary to control the temperature of the life test room. A cooling system

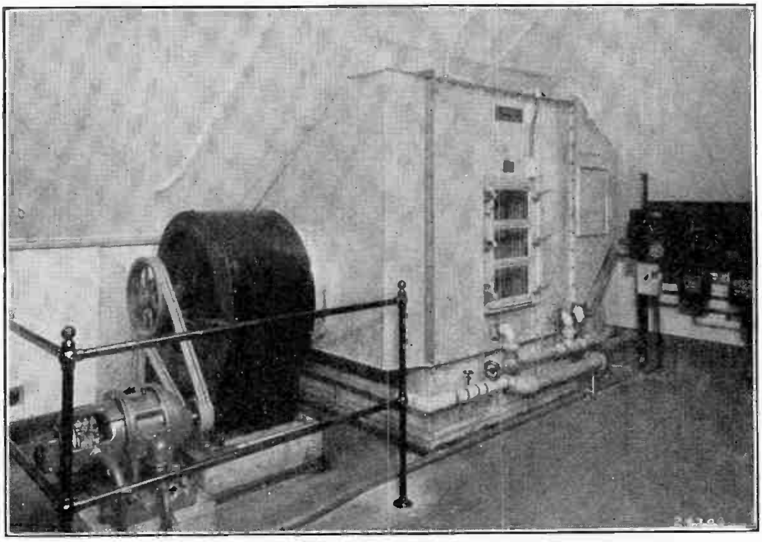

Fig. 19—One Unit of Cooling System.

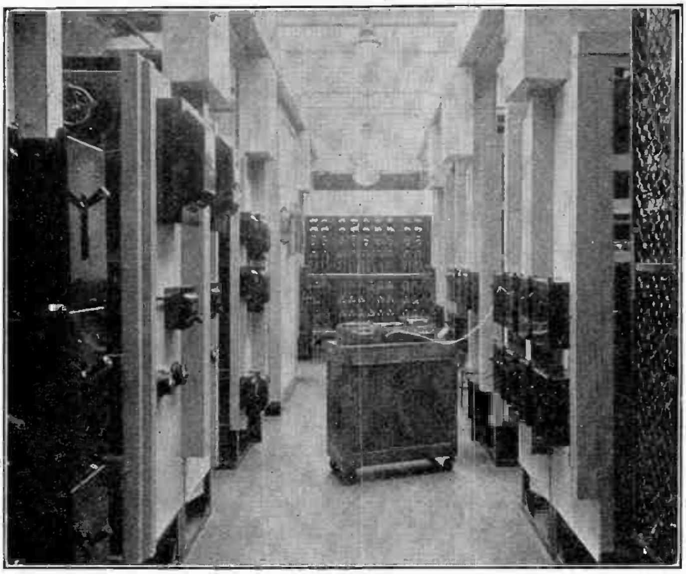

Fig. 20—Life Test Rack Room.

which supplies a continuous supply of cooled air to the room is utilized, and part of this equipment is shown in Fig. 19.

Life Test Racks

A general view of the life test rack room is shown in Fig. 20. Facilities are provided in this room for testing large quantities of every type radiotron sold for broadcast reception purposes.

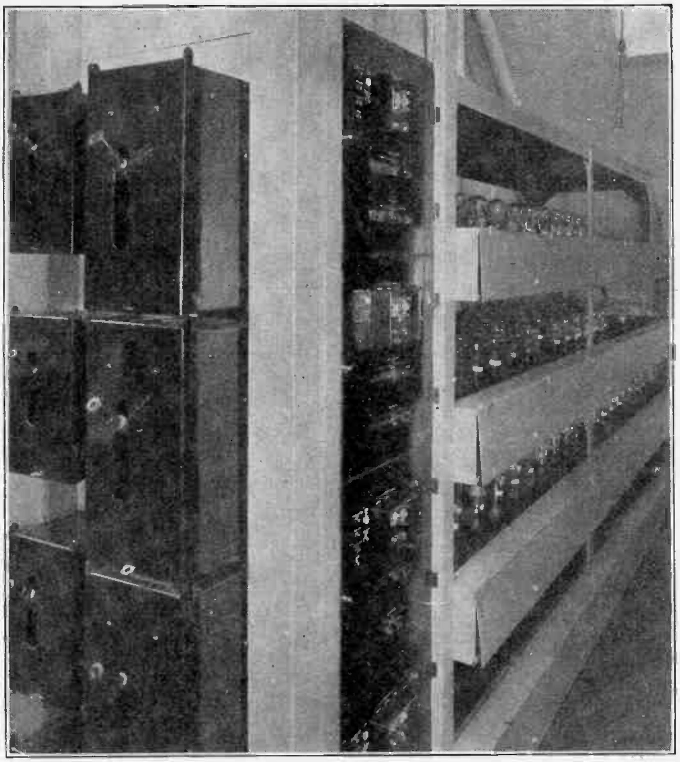

Fig. 21—View of Three-Electrode Tube Life Test Rack.

A close-up view of a typical rack employed in life testing three-electrode tubes is shown in Fig. 21. Alternating-current filament power is supplied by transformers mounted on each shelf. The voltage supplied to the tube filaments is adjusted by means of a variable resistor in the primary circuit of the transformer. Heavy copper bus bar is used for all connections to minimize drop of potential.

Series non-inductive resistors are placed in the grid circuits of all tubes to prevent oscillation of the tubes, and are of such value that they serve also to prevent removal of the grid bias potential from the rest of the tubes on the rack when one tube on test fails because of grid to filament short circuit.

Plate power is supplied to the tubes in banks of seven tubes, each bank having a "grasshopper" fuse in circuit which opens that particular circuit if abnormal conditions occur. A balanced

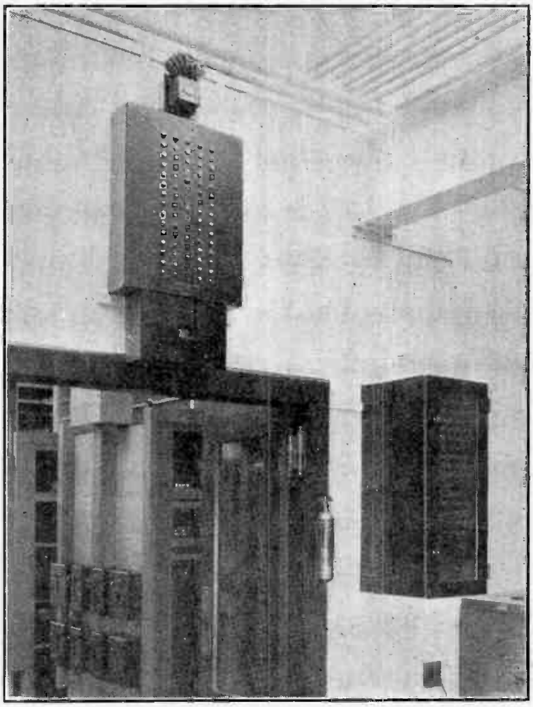

Fig. 22—Alarm Indicator and Timing Devices.

relay arrangement is also included in the main plate power supply line of each shelf of tubes which automatically shuts off the filament and plate power to that shelf if the grid, filament or plate power supply should fail, or vary more than a specified amount from normal. An alarm is also provided and the location of trouble is indicated on a signal board located in a prominent position in the test room. The relay panels may be seen in Fig. 21. The indicator panel is shown in Fig. 22.

Voltages applied to the tubes, plate current, and other operating conditions are checked frequently by means of portable measurement apparatus which may be connected to the racks. A specially designed jack is incorporated in all racks so that the instruments are inserted easily in the desired circuits. Adapters are also provided so that actual socket voltages may also be

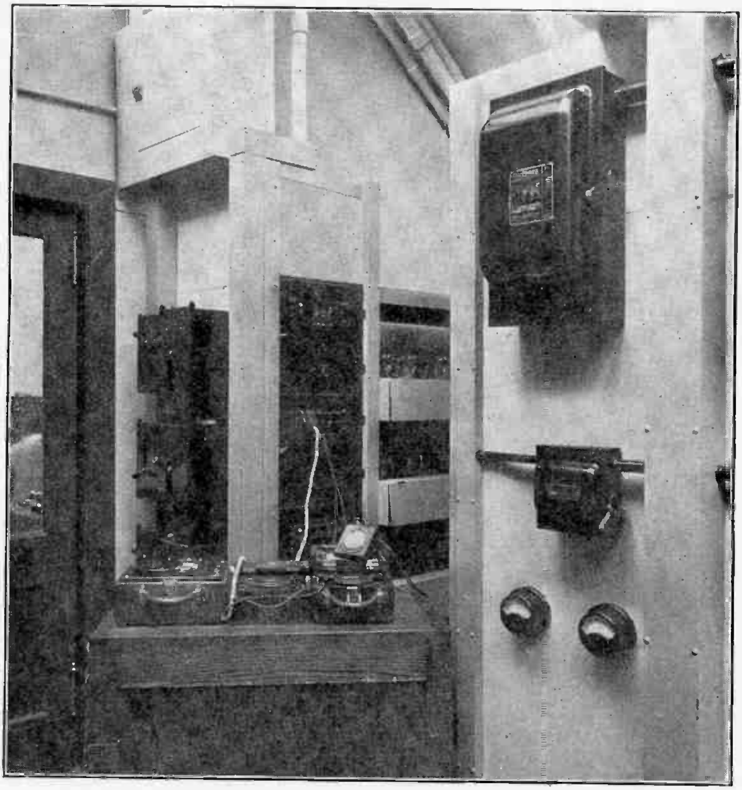

Fig. 23—Portable Measuring Apparatus.

checked at frequent intervals. A view of the portable measurement equipment is shown in Fig. 23.

A rack used for life testing hot cathode rectifier tubes is shown in Fig. 24. These tubes are tested in complete individual circuits, i.e., separate filament and plate power transformers are employed, and individual load and filter circuits are provided. Voltage, current, and other operating conditions are easily checked by means of portable measurement instruments which can be jacked into each circuit. Complete, automatic control of the power supply is provided to prevent operation of the tubes under abnormal operating conditions.

An electric clock which operates from the main power supply is used to measure the time the tubes have been on test. This

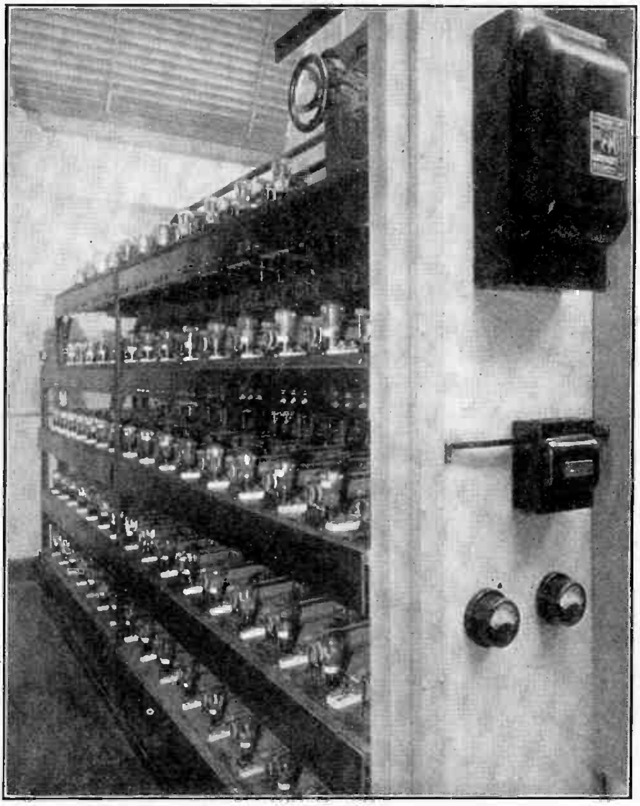

Fig. 24—Hot Cathode Rectifier Life Test Rack.

is shown in Fig. 22. Intentional shut downs, or interruptions of the test caused by failure of the power supply, are automatically eliminated from the computation of the burning time, and the keeping of test schedules and records is greatly simplified by the use of this clock. Another duty which this clock performs is to send an electrical impulse to each rack every half hour. If the racks are in normal operating condition the impulse is passed on to the relay counters (telephone message counters) shown in Fig. 22. A counter-relay is provided for each shelf of each rack. If a particular shelf is shut down, the timing impulse does not operate the counter-relay connected to that shelf, so that by observation of the totals shown on the relay dials the amount of time a particular shelf has been shut down is readily ascertained. Since all racks are automatically controlled and may shut down when an operator is not present (during the night) this timing system is necessary in order to obtain accurate timing of the tests.

Both intermittent and continuous burning life tests are conducted, the kind of test used depending upon the type of tube being tested. The continuous test is preferred because no time is lost as contrasted with intermittent testing which may utilize as little as half of the test time for actual operation of the tubes. Most types of receiving tubes give equally good results on either type test, so that most of the tests are of the continuous type.

During life test, the condition of the tubes is determined by measurement at regular intervals. For example a typical test schedule is 0–10 per cent–20 per cent–40 per cent–75 per cent–100 per cent of the total run of hours. The tubes may be tested at any intermediate time at the discretion of the operator, but the regular intervals are preferred for the sake of uniformity in the test reports.

Supplementary Note† to ABBREVIATED METHOD FOR CALCULATING THE INDUCTANCE OF IRREGULAR PLANE POLYGONS OF ROUND WIRE*

By

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(Chief of the Wireless Section of the State Research Institute, Moscow, Union of Socialist Soviet Republics)

THE author has made an analysis of the nature of the quantity a_k which occurs in the principal formulas of the foregoing paper.*

The formula (11) for the inductance of a rectangle of sides a, b, diagonal d, perimeter $l=2(a+b)$ may be transformed by means of the relation

$$L=2l\left\{\frac{2(a+b)}{l}\log\frac{ab}{l^2}\cdot\frac{2l}{r}\cdot l-\frac{2a}{l}\log(a+d)-\frac{2b}{l}\log(b+d)\right.$$

$$\left.+\frac{2(a+b)}{l}\mu\delta+\frac{4d}{l}+\frac{4r}{l}-\frac{4a}{l}-\frac{4b}{l}\right\} \qquad (44)$$

$$=2l\left\{\log\frac{2l}{r}+\log\frac{ab}{l^2}-\frac{2a}{l}\log\frac{(a+d)}{l}-\frac{2b}{l}\log\frac{(b+d)}{l}\right.$$

$$\left.+\frac{4d}{l}-2+\mu\delta+\frac{4r}{l}\right\}$$

into the form

$$L=2l\left\{\log\frac{2l}{r}-a_k+\mu\delta+\frac{4r}{l}\right\} \qquad (45)$$

where

$$a_k=-\log\frac{ab}{l^2}+\frac{2a}{l}\log\frac{a+d}{l}+\frac{2b}{l}\log\frac{b+d}{l}-\frac{4d}{l}+2 \qquad (46)$$

Calculating a_k for different values of a/b, and therefore for different values of $l/\sqrt{s}$, the following table is obtained.

* Proc. I.R.E. 15, 1013; December, 1927. The numbers of equations, tables, and figures here follow those of the previous paper.

† Original Manuscript Received by the Institute, July 4 1928. Translated from the German by F. W. Grover, Union College, Schenectady, N. Y.

TABLE V

a/b	1	2/3	0.427	1/4	1/9	1/15	1/20	1/30	1/50
$l/\sqrt{s}$	4	4.08	4.37	5	6.67	8.24	9.35	11.3	14.37
a_k	2.853	2.866	3.006	3.269	3.826	4.226	4.471	4.849	5.330
$\log l^2/s$	2.773	2.79	2.94	3.22	3.80	4.218	4.471	4.849	5.330
ϕ	0.080	0.076	0.066	0.049	0.026	0.008	0	0	0

The quantity ϕ is put for $a_k - \log l^2/s$.

It is clear that in (46) the first term $-\log ab/l^2 = \log s/l^2$ is the most important, and is increasingly so, the greater the value of $l/\sqrt{s}$ (see last row of Table V).

Replacing a_k by $\log(l^2/s)+\phi$ in (45) we obtain

$$L = 2l\left[\log\frac{2s}{rl} + \mu\delta + 4\frac{r}{l} - \phi\right] \tag{47}$$

and if we neglect here, as has been done earlier, terms of the order of magnitude of r/l and ϕ,

$$L \cong 2l\left[\log\frac{2s}{rl} + \mu\delta\right] \tag{48}$$

From this may be obtained, as was first suggested to me by Ing. Klatzkin, the known formula for a long loop[1]

$$L \cong 2l\left[\log\frac{d}{r} + \mu\delta\right] \tag{49}$$

The assumption will now be made that for other closed curves without reëntrant angles the quantity a_k is likewise nearly equal to $\log(l^2/s)$.

To prove this assumption analytically is, unfortunately, possible only in the two cases of a rectangle and a triangle, using the formulas derived by the author and Dr. Grover. Besides these, no other cases exist where, for a closed curve, formulas with two variable parameters can be given in analytical form.

By a process similar to that already described for a rectangle, formula (42) for a right triangle may be brought into the form

$$L = 2l\left[\log\frac{2s}{rl} + \mu\delta - \phi\right] \tag{51}$$

[1] More exactly, if l_1 is the length of each wire, and d their distance apart,

$$L = (4l_1 + 4d_1)\left\{\log\frac{dl_1}{r(l_1+d)} + \mu\delta\right\} \tag{50}$$

where

$$\phi=-\frac{a^2}{2lc}\log\frac{a(c-a)}{b(c+b)}-\frac{b^2}{2lc}\log\frac{b(c-b)}{a(c+a)}-\frac{c}{2l}\log\frac{c^2}{ab}$$

$$+\frac{a+c/2}{l}\log(a+c)+\frac{b^2+c/2}{l}\log(b+c)-\log l+1-\log 2 \quad (52)$$

From this follow the results of Table VI.

TABLE VI

$l/\sqrt{s}$	4.828	5.84	7.01	8.99	10.2	12
ϕ	0.182	0.223	0.252	0.271	0.276	0.282

The formula (41) for an isosceles triangle may also be written in the form (51) with

$$\phi=1-\frac{2a}{l}\log\frac{2a}{h}-\frac{c}{l}\log\frac{8h}{l} \quad (53)$$

Here h is the altitude of the triangle.

This last formula gives the results shown in Table VII.

TABLE VII

$l/\sqrt{s}$	4.559	5.67	6.94	8.01	8.95	9.8	10.59	11.3	12	12.65
ϕ	0.164	0.225	0.260	0.276	0.285	0.290	0.293	0.296	0.298	0.299

Furthermore, all the previously known formulas for polygons (32) to (37), (14) and (37a) can also be put into the form of (51). Table VIII gives the data for each.

TABLE VIII

Figure	$l/\sqrt{s}$	a_k	New Formula	$\log l^2/s$	ϕ
Circle	3.541	2.451	$L=4\pi a\left[\log\frac{a}{r}-\phi\right]$	2.5311	−0.080
Octagon	3.641	2.561	$L=2na\left[\log\frac{K_n}{r}-\phi\right]$	2.5845	−0.0235
Hexagon	3.722	2.636		2.6285	+0.0065
Pentagon	3.812	2.712		2.6763	+0.0355
Square	4.000	2.852	$L=8a\left[\log\frac{a}{2r}-\phi\right]$	2.7730	+0.0800
Figure 3a	4.395	3.091	$L=2l\left[\log\frac{2s}{rl}-\phi\right]$	2.96095	+0.130
Equilat. Triangle	4.559	3.198	$L=6a\left[\log\frac{a}{2\sqrt{3}r}-\phi\right]$	3.0340	+0.164
Right Triangle Equal legs	4.828	3.331	$L=(2+\sqrt{2})a\left[\log\frac{a}{(2+\sqrt{2})r}-\phi\right]$	3.1489	+0.182

From this it is clear that for all the regular polygons we can write a new simpler formula

$$L = 2na\left[\log\frac{R_u \cos\frac{\pi}{n}}{r} - \phi\right] = 2na\left[\log\frac{K_n}{r} - \phi\right]$$

in which n = the number of sides.

R_u = the radius of the circumscribed circle.

K_n = the apothegm of the regular polygon.

In the various cases ϕ varies between the limits of -0.08 for the circle and $+0.164$ for the equilateral triangle.

The similar relation is not difficult to derive for other figures with a known ratio of l and s. For example, for any triangle

$$L = 2l\left[\log\frac{R_e}{r} - \phi\right]$$

where R_e is the radius of the inscribed circle, and ϕ is taken from the curve, Fig. 1 (see below).

For a rhombus whose shorter diagonal is h and whose acute angle is 2α, the corresponding formula is

$$L = 2l\left[\log\frac{l \sin 2\alpha}{8r} - \phi\right] = \frac{4h}{\sin\alpha}\left[\log\frac{h\cos\alpha}{2r} - \phi\right]$$

The curves $\phi = f(l/\sqrt{s})$ for Tables V, VI, VII, and VIII are shown in Fig. 1. For figures of the form of a rectangle ϕ approaches zero with increasing $l/\sqrt{s}$: for polygons more nearly

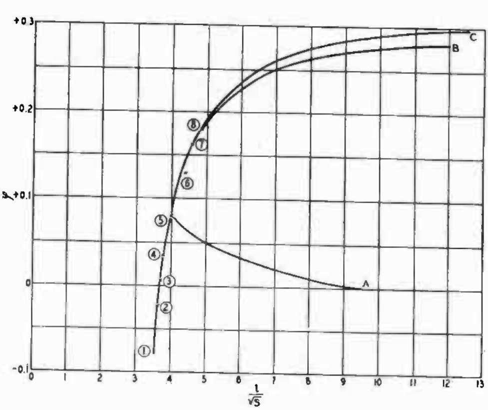

Fig. 1

of the form of a right triangle or isosceles triangle ϕ increases, but relatively quickly attains, with $l/\sqrt{s} = 10$, a nearly constant value of about 0.29. For all practical cases ϕ can be determined from the curves. If, however, the figure is strongly unlike that of a triangle (Curves B and C) or that of a rectangle (Curve A) the author proposes for practical purposes to use the formula

$$L \cong 2l\left[\log\frac{2s}{rl} - 0.15\right]$$

The maximum error for the most unfavorable cases amounts with this formula to only 1.3 per cent.

Thus the new form of our formula, in which the "noninductive effect" of the factor $l/\sqrt{s}$ is more clearly and distinctly expressed, can be used in practice for any value of $l/\sqrt{s}$ without the necessity of extrapolation as was the case previously.

In a recent paper R. G. Allen[2] has obtained the inductance of an equilateral triangle, a rectangle, and a regular hexagon by direct integration of the flux linkages in each of these cases. The resulting formulas agree with those obtained from the general abbreviated formula of the present paper.

At the beginning of March, the author made a measurement of the inductance of an ellipse in order to prove the new formula. The ellipse had semi-axes of 1.5 m and 3.47 m and consisted of wire 0.08 cm in diameter. The lead wires to the bridge were 0.5 m long and were placed 0.2 m apart. The measured value, mean of the results of three observers, was 30800, with an uncertainty of one per cent. The calculated value, assuming a_k to have the value given by Fig. 6 for $l/\sqrt{s} = 4.02$, and including the calculated value of the inductance of the lead wires, was 30775. Thus $\Delta L = (Lm - Lc)/Lc = 0.08$ per cent.

In view of the difficulty of accurately calculating the capacity of antennas,[3] the author suggests that it is better to obtain the calculated capacity of a closed aerial from its calculated inductance L_0. Supposing, for example, an aerial of a single turn, closed except at a single point, the natural wavelength $\lambda_0 = 2l$ and the electrostatic capacity C_0 is given by the relation $\lambda_0 = 4\sqrt{L_0 C_0}$, which using the author's inductance formula gives

$$C_0 = \frac{l}{8\left[\log\frac{2s}{rl} - \phi + \mu d\right]\left(1 + \frac{\Delta}{100}\right)}$$

[2] *Exper. Wireless and Wireless Eng.*, 5, No. 56, p. 259, Editorial note by G. W. O. Howe, l.c. p. 238.

[3] Proc. I.R.E., 15, 733; August, 1927.

In conclusion the author expresses his sincerest thanks to Prof. Schuleikin and to Electrical Engineers Starik and Svistoff for their interest and aid in the work, and to Prof. F. W. Grover for making the English translation of the paper.

Note added by the translator.

At the request of the author I am adding the general expressions for the quantity ϕ for two further cases.

For a triangle of sides a, b, and c, it may be shown that

$$\phi = 1 + \frac{b+c}{l} \log \frac{(c+b)^2 - a^2}{v} + \frac{a+b}{l} \log \frac{(a+b)^2 - c^2}{v}$$

$$+ \frac{a+c}{l} \log \frac{(a+c)^2 - b^2}{v} - \frac{a}{l} \log \frac{2a}{R_e} - \frac{b}{l} \log \frac{2b}{R_e} - \frac{c}{l} \log \frac{2c}{R_e}$$

in which

$$R_e = \sqrt{\frac{(P-a)(P-b)(P-c)}{P}} \quad \text{and} \quad \frac{l^2}{2s} = \frac{a+b+c}{R_e}$$

$$v = 2l\, R_e \qquad P = \frac{l}{2} = \frac{1}{2}(a+b+c).$$

For a rhombus whose acute angle is 2α,

$$\phi = 2 - \log 4 - \cos\alpha - \sin\alpha + \log\sin 2\alpha$$
$$+ \cos^2\alpha(\sinh^{-1}\cot 2\alpha + \sinh^{-1}\tan\alpha)$$
$$+ \sin^2\alpha(\sinh^{-1}\cot\alpha - \sinh^{-1}\cot 2\alpha)$$

F.W.G.

Volume 16, Number 11 *November, 1928*

THE CONSTANT IMPEDANCE METHOD FOR MEASURING INDUCTANCE OF CHOKE COILS*

BY

H. M. TURNER

(Yale University, New Haven, Connecticut)

Summary—*This paper describes a method for measuring at power frequencies the inductance of iron-cored choke coils of the type commonly used in radio as filters. It has been used to measure values of from one to more than 2000 henries. Two circuit arrangements are illustrated and several families of curves show how the inductance depends upon the magnitude of the superposed alternating and direct-current magnetomotive forces. The method may also be used at higher frequencies. It is simple, convenient to use, and requires the minimum of equipment.*

IN 1918 the writer discovered a unique property of parallel circuits which was found useful in measuring circuit constants and has been used quite successfully in our laboratory for this purpose for several years.

With an alternating emf impressed upon a parallel circuit as shown in Fig. 1 the equation for the line current is

$$I=EY=E(G+jB)=E[g_2-j(b_2-b_1)] \tag{1}$$

$$=E\sqrt{\left(\frac{R_2}{Z_2}\right)^2+\left(\frac{X_2}{Z_2}-\frac{1}{X_1}\right)^2} \tag{2}$$

$$=E\sqrt{\frac{1-2w^2LC}{R_2^2+X_2^2}+w^2c^2} \tag{3}$$

It will be observed that if the values of w, L and C are such that

$$2w^2LC=1 \tag{4}$$

the first term under the radical reduces to zero and the absolute value of the line current is equal to wCE, the current through the capacity branch; under these conditions the line current is absolutely independent of the resistance of the inductive branch. This will be referred to as the *critical condition.* Opening the inductive circuit is equivalent to introducing into this branch an infinite resistance for it reduces the inductive current to zero.

* Original Manuscript Received by the Institute, July 14, 1928.

It is this feature that is the basis of the method being described. It is unnecessary to obtain a resistance balance as in Wheatstone bridge methods of measuring inductance, nor is it necessary to determine the resistance as in other methods.

Solving (4) gives for the critical frequency

$$f=\frac{1}{\sqrt{2}\,2\pi\sqrt{LC}}=0.707\,f_r \tag{5}$$

when f_r is the resonant frequency for L and C connected in series and

$$L=1/2w^2C \tag{6}$$

When (4) is satisfied and any two of the factors are known, the third may be calculated, but it is usually the inductance that is

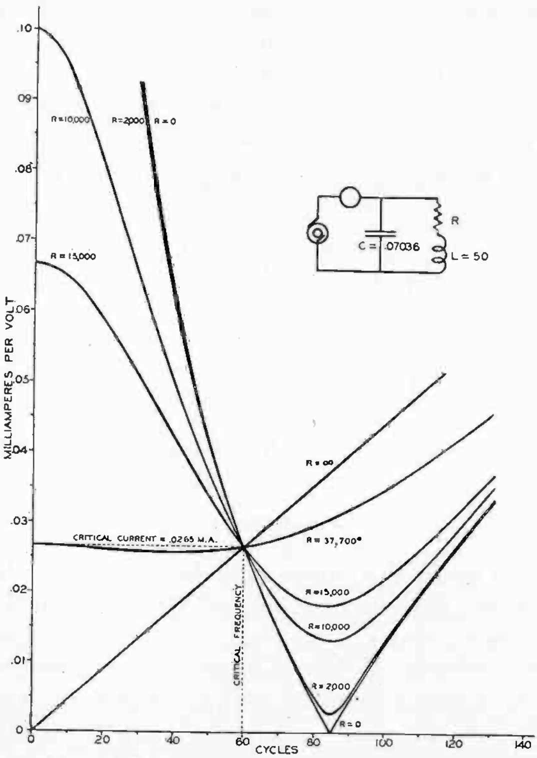

Fig. 1—Line Current Variation in Parallel Circuit Due to Frequency Variation.

desired which is expressed in terms of frequency and a standard capacity.

For constant impressed emf and critical frequency the resistance of the inductive branch may be varied from zero to infinity without affecting the magnitude of the line current as shown by the common point of intersection of the curves in Fig. 1, while the corresponding change in phase of line current is indicated in Fig. 2. The current in the inductive branch is given by

$$I=\frac{E}{Z}=\frac{E}{X}\sin\theta \tag{7}$$

the equation of a circle which is the locus of the current as R varies. The current for $R=0$, $\theta=90$ deg., is E/X the diameter of the semicircle as given by OA lagging ninety degrees behind the emf. The condenser current is wCE leading the emf by ninety degrees. Adding these two components vectorially gives the line current, the locus of which is a semicircle of radius wCE with its center at the intersection of the coordinate axes. The critical value of capacity current is $E/2X$, that is, the capacity reactance is twice that of the inductive reactance.

Procedure

In general a source of constant emf of known frequency (usually 60 cycles when measuring large choke coils where this method is particularly good), some means of measuring the current, and a standard capacity are required. It should be pointed out that while it is highly desirable to have the voltage remain constant during the entire time measurements are being made, it is only necessary that it be the same immediately after the switch is opened as it was immediately before.

It has been previously stated that when the values of w, L, and C are such as to satisfy (4) the line current has the same value regardless of whether the inductive circuit is connected or not; that is, the total impedance of the circuit is the same, and for this reason has been called the "Constant Impedance Method."

To determine whether the necessary conditions are fulfilled is extremely simple. A switch placed in the inductive branch is opened and closed while the standard capacity is varied until there is no permanent change in the reading of the line ammeter indicating that (4) is satisfied. The inductance may then be calculated by (6). With the circuit connected as shown in Fig. 2, first close the switch and observe the steady ammeter reading;

then open the switch, and if the current decreases the capacity is too small. The capacity is changed in accordance with these observations and the operation repeated until there is no permanent change in the deflection of the instrument when the switch is opened. The transient changes are ignored except insofar as they are useful in assuring the operator that the pointer moves freely as the balance is closely approached. The switching operation may be performed in the reverse order if desired;

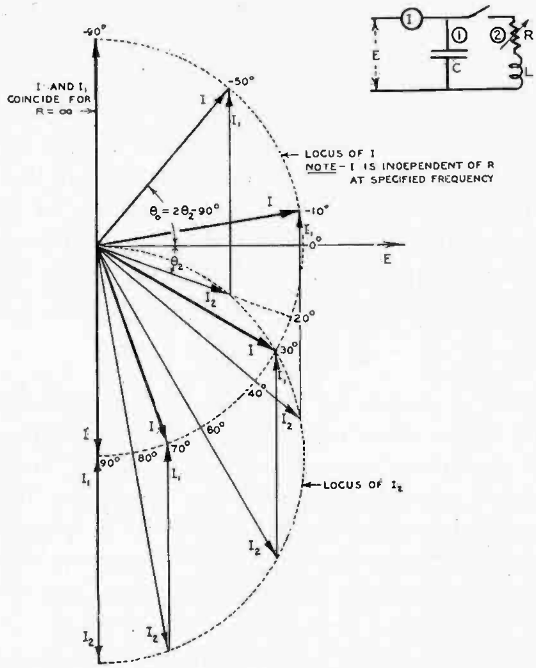

Fig. 2—Change of Phase of Line Current Due to Change in Resistance, with Critical Impressed Frequency.

that is, noting the ammeter reading with the switch open and after closing, but the method outlined is preferred.

Under certain conditions the voltage of the source may be disturbed by the change in phase of the line current when the inductive circuit is opened. For example, in Fig. 2, if $R=0$ the inductive current lags 90 deg. behind the impressed emf. For a condition of balance the line current also lags 90 deg. when the switch is closed and leads by 90 deg. when the switch is open. If R is such that the inductive current lags by 80 deg., the line current lags by approximately 70 deg. when the switch is closed and leads by 90 deg. when the switch is open. This may be avoided by connecting the inductive circuit first on the right of the ammeter and then on the left, thus keeping the magnitude and phase of the line current the same. Also, if the impedance of the line instrument is such as to cause an appreciable voltage drop, the fact that the current is displaced 70 deg. from the voltage in one case and 90 deg. in the other may cause a change in the voltage across the circuit being measured for the two conditions. This increases the voltage across the condenser when the inductive circuit is open; therefore, the capacity must be reduced to give the same line current and the calculated value of inductance is high. This error may be eliminated by increasing the frequency until the inductive components lag by 85 deg. or more. The error introduced by the ammeter impedance is usually not large. The inductance of an air-cored coil as measured with

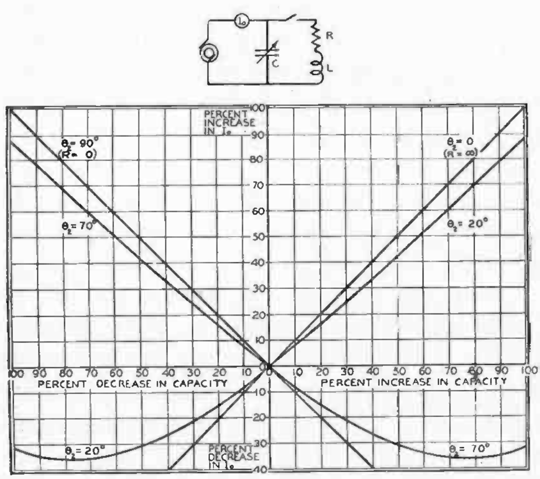

Fig. 3—Measurement of Inductance. Change in Sharpness of Tuning of Parallel Circuit Due to Change in Capacity. Impressed Frequency Critical for $C = 100$ per cent.

a five-ohm instrument was 4.32 henries and with a one-hundred-and-five-ohm instrument was 4.38.

Fig. 3 shows the per cent change of line current for a given per cent change in capacity in terms of the departure from the critical value of capacity. The point of intersection of the various curves (zero change) is the critical adjustment where the inductive circuit may be opened and closed without producing any permanent change in the line current. As a balance is approached quite closely, which is always the case in making measurements, the curves are symmetrical with respect to the zero point. It is to be observed that when the angle of lag of the inductive circuit approaches ninety degrees, which is usually the case, the line current changes at the same rate as the capacity and for the case where the angle is small the current changes somewhat less rapidly than the capacity.

It should be observed that with this method, where the apparent inductance of the coil is not affected by the distributed capacity of its winding at the frequency used, higher harmonics of considerable magnitude may be present in the electromotive-force wave without appreciably influencing the calculated inductance. For example, if there is a pronounced 29th harmonic, due to armature slots, the harmonic component of current in the inductive branch is absolutely negligible, while that through the capacity is large. With the switch closed the line current $=\sqrt{I^2+I^2_{c(29)}}$, I being the vector sum of the fundamental components in the two branches, and with the switch open the line current $=\sqrt{I_c^2+I_c^2{}_{(29)}}$ but for balance the fundamental component of the line is equal in magnitude to the fundamental component through the condenser. In other words the fundamental components combine in exactly the same manner as if the harmonic were not present, and since the harmonic component of condenser current is present in the line both with the switch open and closed there is no error introduced. If harmonics of low order but large magnitude are present, error would result because of the relatively large harmonic component through the inductance which would pass through the ammeter with the switch closed but not when open. Either use a wave of approximately sine form or use a filter to eliminate the troublesome harmonic, but usually this will not be necessary.

Iron-Cored Choke Coils

For measuring the inductance of iron-cored coils the procedure is exactly the same as already outlined. However, the inductance will vary with the impressed emf, and this method affords a simple and convenient means of determining the manner in which it depends upon the impressed voltage or current through the coil. Fig. 4 shows a curve of the inductance of a small filter choke plotted against current. Of course, under operating conditions the alternating current would not reach such large values. It was designed to carry fifteen milliamperes of direct current in normal use; however, there was no direct current flowing when these measurements were made.

When operating iron-cored coils at high values of saturation it is extremely important to have the line ammeter short-circuited

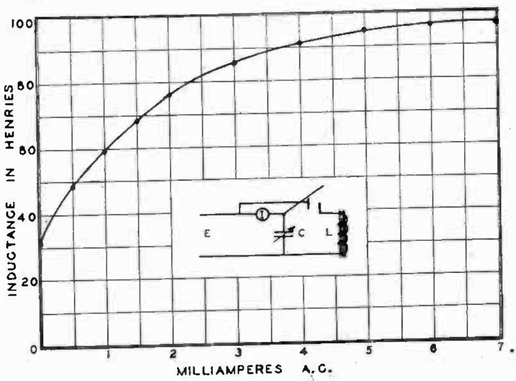

Fig. 4

at the moment the inductive circuit is connected, otherwise the instrument may be damaged by the large transient current. If an extra contact is added to a single-pole switch as shown in Fig. 4, the required protection is provided and the switch may be closed as rapidly as desired without damage to the instrument.

Iron-Cored Choke Coils with Superposed Direct Current

Since the inductance of an iron-cored coil varies with the superposed direct current flowing through its winding, provision

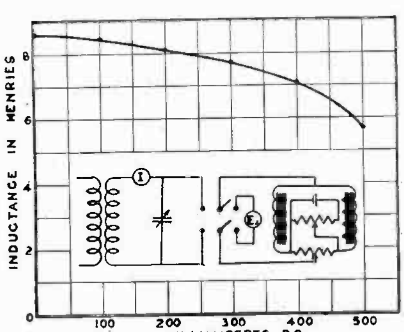

Fig. 5—Variation of Inductance with D.C. Magnetization. Filter Reactor Model UP–1627. 60 Cycles $E_{A.C.} = 110$.

should be made for supplying the desired value of direct current when the inductance is being measured. This necessitates a slight modification in the circuit arrangement. Where two similar coils are available they may be connected as in Fig. 5, providing a convenient method of introducing and controlling the direct current through the coils and preventing battery current from flowing through the thermo-couple instrument in the line. This is accomplished by varying the position of the contact B of the potential divider until there is no battery potential between A

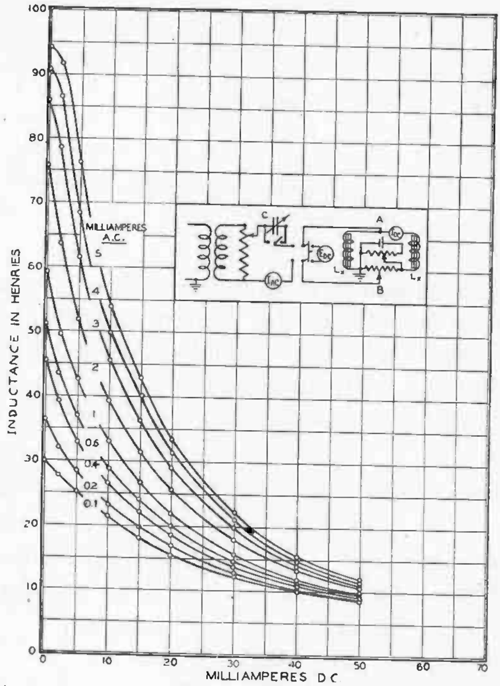

Fig. 6—Variation of Inductance with A.C. and D.C. Magnetization. 60 Cycles.

and B as indicated by a sensitive voltmeter E_{dc}. This is important for the protection of the line instrument, for a relatively small unbalanced battery voltage might burn it out. When the adjustment is once made it seldom requires changing, but the balance should be checked occasionally by throwing the switch to the right.

It is evident that the inductance of the two coils in parallel is measured, and to obtain that of a single coil this value should be doubled.

Fig. 5 shows the inductance of a filter reactor with direct current. The impressed emf was constant and of quite large value, producing an alternating current of approximately thirty milliamperes. It is to be noted that the inductance is remarkably constant for such large magnetomotive forces indicating a rather large air-gap. This reactor was designed to carry 300 milliamperes of direct current.

In a modified form of the circuit[1] the condenser is connected in series with the inductance to be measured, see Fig. 6, instead of in parallel as in the method already outlined. The measurement is made by throwing the single-pole switch first to left, noting the current through the inductance alone, and then to the right, noting the current through the capacity and inductance in series. If the line current is larger with the switch to the right the capacity is too great; if it is smaller the capacity is too small. The capacity is changed in accordance with these observations, and the switching operation repeated until there is no permanent change in the instrument reading. For a balance the capacity reactance is twice the inductive reactance and

$$L=\frac{1}{2w^2C_{farad}} \text{ henries} \tag{8}$$

which is the same as given by (6). When measuring choke coils at 60 cycles and with C expressed in microfarads

$$L=\frac{3.52}{C} \text{ henries} \tag{9}$$

Also

$$C=\frac{3.52}{L} \mu\text{f} \tag{10}$$

From which it is seen that for $L=100$ henries a capacity of 0.0352 μf is required, and for $L=500$ henries there is required a capacity of 0.00704 μf. With the switch to the left the current lags by θ degrees, and with the switch to the right the current leads by the same amount.

In the first method, where measuring the inductance of two coils in parallel, the line current is the same as the current in the

[1] Mr. H. T. Lyman, Jr., graduate student in Communication Engineering, Yale University, used this circuit in obtaining data for the curves that follow.

individual inductances (neglecting the slight effect of resistance), while in this case it is equal to twice the current through the individual inductances.

Where it is necessary to use a line instrument of high resistance for measuring the alternating current, the second method is preferred. For measuring extremely small values of alternating current, either a crystal detector in series with a direct-current

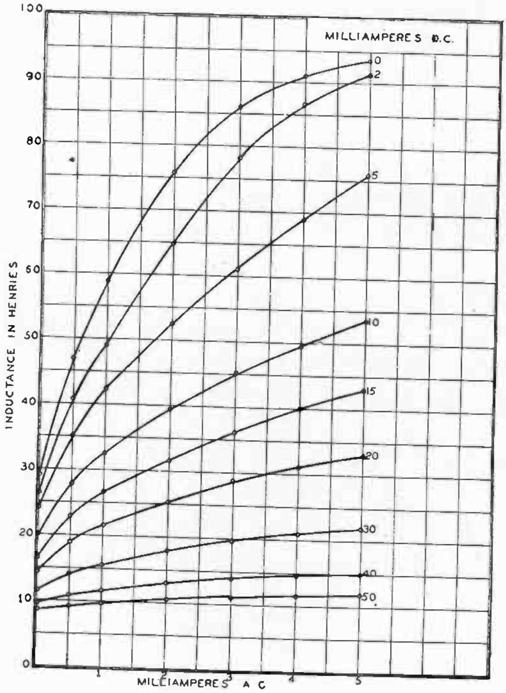

Fig. 7

microammeter or an electron-tube voltmeter may be used across a resistance in the line.

The curves that follow show the variation of inductance with both the direct- and alternating-current magnetizing components through wide limits. The family in curves Figs. 6 and 7, which were plotted from the same data, have direct current as the independent variable in one case and alternating in the other. As a matter of convenience these are illustrated for a plate-filter-choke coil designed for a maximum full-load direct current of fifteen milliamperes; under normal operating conditions the alternating current will be small.

Fig. 8 is for the primary of an audio-frequency transformer used as a choke coil at 60 cycles.

These methods have been used to measure inductances of more than 3000 henries, and there is no reason why still larger values

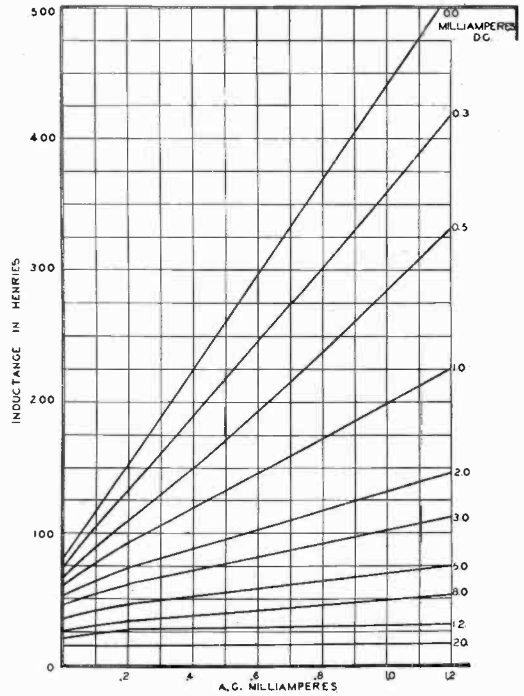

Fig. 8

could not be measured if desired. They are simple, convenient to use, and require the minimum of equipment.

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Volume 16, Number 11 *November, 1928*

FADING CURVES ALONG A MERIDIAN*

By

Robert C. Colwell

(Department of Physics, West Virginia University, Morgantown, West Virginia)

Summary—*The fluctuations in signal strength of KDKA, Pittsburgh, Pa., were observed through the sunset period of Morgantown, W. Va. Since the two cities are approximately on the same meridian, any variation at sunset should be due to changes in the Heaviside-Kennelly layer and not to refraction through the earth's shadow. Observations were made on twenty-one days; it was found that on bright clear days, the curve fluctuated considerably, while on cloudy days, the curve was fairly steady. The fluctuations can be accounted for by assuming a reflected wave on clear days.*

In May, 1925, measurements were made at Morgantown, West Virginia, upon the signal strength of Station KDKA at Pittsburgh, Pa. The results of these measurements were published by the Bureau of Standards.[1] The readings were continued during the winter of 1926–27, using a superheterodyne set connected to a semi-automatic recording galvanometer. These curves were averaged by the usual methods.

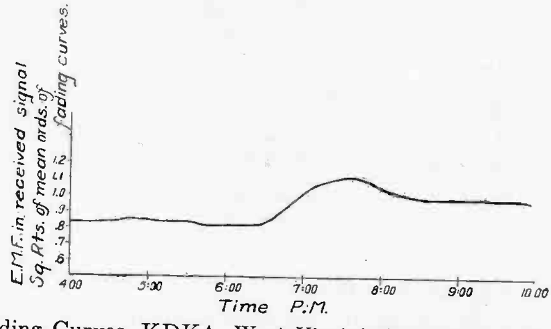

Fig. 1—Fading Curves, KDKA, West Virginia University, Morgantown, West Virginia.

All these curves were taken during the years 1926 and 1927 on the following dates:

Cloudy days 1926—January 10, 31; February 21.
1927—January 2, 9, 16, 30; February 20; March 7, 23, 24.

Clear days 1926—February 7, 23, 28; December 5.
1927—March 25, 26, 28, 29, 30, 31.

* Original Manuscript Received by the Institute, July 11, 1928.
[1] Scientific Paper of the Bureau of Standards, No. 561, p. 432.

The curve for all the readings is given in Fig. 1. The time of day is plotted along the X axis, and it is apparent that there is a slight dip between the hours of six and seven which is near the sunset period. The curves were then averaged for five-minute intervals before and after sunset; that is, the time of sunset for each separate curve was taken as zero. This average for all the curves resulted in the curve shown in Fig. 2. This figure shows

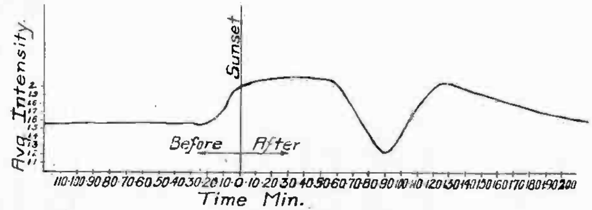

Fig. 2—Average Curve, KDKA, at Morgantown, West Virginia

that the average strength remains fairly constant during the daylight hours, takes a slight dip shortly before sunset, and then rises to a night value about thirty per cent higher than the day value. The night value, however, is not constant and sometimes falls below that of the daylight hours.

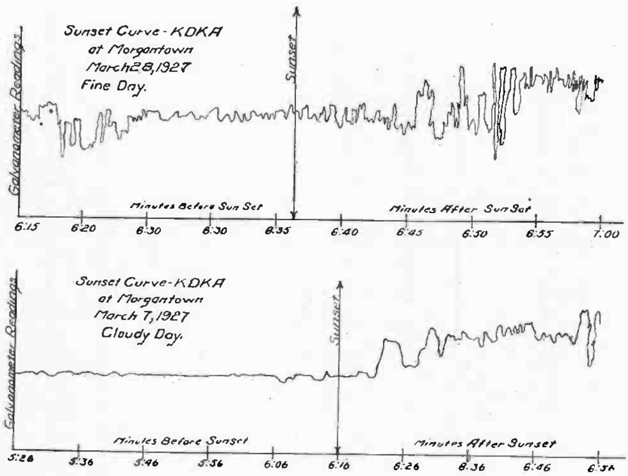

Fig. 3.

Upon examination of the curves, it was found that eleven curves had been taken on cloudy days and ten upon fine, clear days. The difference between the two types of curves is shown in

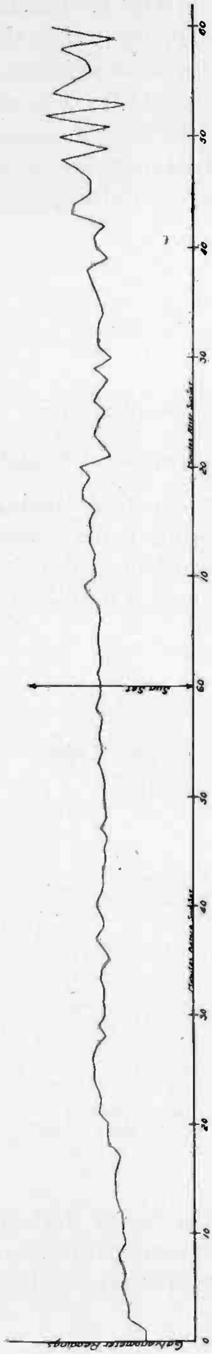

Fig. 4—Average Curve for Fine Days, KDKA, at Morgantown.

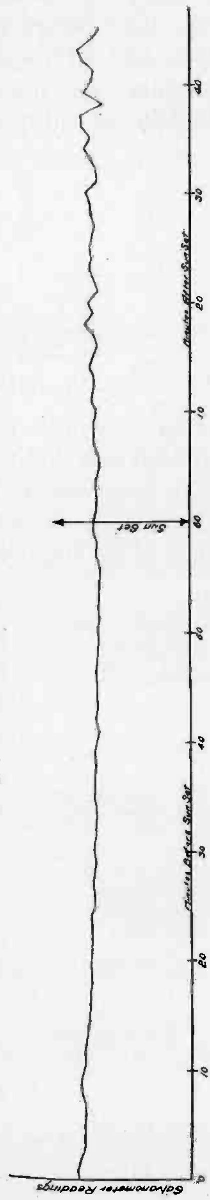

Fig. 5—Average Curve for Cloudy Days, KDKA, at Morgantown.

Fig. 3. It is apparent that the typical curve for a clear day is rather disturbed during the daylight hours, increases after sunset, and shows considerable fading. The typical curve for a cloudy day is uniform during the daylight hours, and the increase after night is fairly steady.

The ordinates for all the curves taken on fine, clear days were averaged at one-minute intervals before and after sunset. The curve of Fig. 4 shows the variable character of this average curve. A similar average was taken for the cloudy days and Fig. 5 shows the comparatively even curve typical of cloudy weather. These observations indicate a new relation between signal intensity and the state of the atmosphere. Other relations have been noted by Austin[2] and Pickard.[3]

The results of this investigation can be explained if it is assumed that the Kennelly-Heaviside layer is partially operative even during the daylight hours. On fine days there is a reflected wave (sky wave) which interferes with the ground wave causing a slight fluctuation during the afternoon. After sunset the reflected wave increases in intensity and fading becomes more pronounced. On cloudy days, the atmospheric conditions prevent the sky wave from reaching the reflecting layer, and only the steady ground wave is received.

It should be understood, however, that the typical cloudy weather curve can only be obtained in the middle of a cloudy period, and similarly for the fine weather curve. When the weather is changing from cloudy to clear and vice versa, the curves are very irregular and depart from the typical forms.

[2] Proc. I.R.E., **12**, 681; December, 1924; **14**, 781; December, 1926.
[3] Proc. I.R.E., **16**, 765; June, 1928.

BOOK REVIEW

Theory of Vibrating Systems and Sound, BY IRVING B. CRANDALL. Published by D. Van Nostrand Company, New York, 1926. 272 pages, 23 illustrations, $6\frac{1}{4}\times 9\frac{1}{4}$ cloth, \$5.00.

This book is based on studies in the Bell Telephone Laboratories and written by a well-known research worker in the field. It is intended to supplement, rather than to replace, the accepted treatises on sound by such men as Rayleigh, Lamb, and others. Its purpose is to present the theory of sound and its recent technical applications in such a way as to interest the student of physics who has given a certain amount of attention to analytical mechanics and to bring out the latest branch of applied science—"electro-acoustics."

The book also treats, in addition to problems of radiation and transmission, architectural acoustics and gives many references. The presentation is clear, as are all of Dr. Crandall's publications.

AUGUST HUND †

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RADIO STATIONS OF THE WORLD ON FREQUENCIES ABOVE 1500 KILOCYCLES*

THROUGH the courtesy of the Federal Radio Commission the following list of high-frequency allocations is published.

This list is published for the information of the Institute membership to indicate the present status of high-frequency assignments. It will not be published as a regular feature of the PROCEEDINGS.

The frequencies listed in the first column are those recently adopted by the Federal Radio Commission in its system of high-frequency channels. Each channel is approximately 0.2 per cent wide, and is indicated by the frequency at its center. Every frequency licensed or used by any station within each channel is given in the last column. This list shows only the channels upon which stations are operated. Intermediate channels, not shown, are separated by intervals similar to those shown, the separation being approximately two-tenths per cent.

The data for United States stations given correspond to the records of the Commission. For the stations of other nations, the data are not authoritative. They are compiled from various sources and have not been fully checked. In some cases, more than one frequency for a station is given because divergent values were given in the sources. In a few cases the frequencies are slightly uncertain because the source gave data in wavelengths, which may have been originally computed from frequencies by use of other conversion factors than 300,000.

For U. S. Government stations, only the frequency is given. This is because the Government departments have not released for publication the locations of their stations.

Since amateurs, and a few special cases of other stations, are licensed for bands of frequencies rather than specific channels, they are not mentioned in the table.

Channel	*Call Letters*	*Location of Transmitter*	*Owner*	*Frequency*
1500	C2BB	Valparaiso, Chile		1500
	VNAC	Port Elizabeth, U. of S. A.		1500
	CRLQ	Otchinjau, Angola		1500
	CRE	Dili, Portuguese Timor		1500
	C2AD	Valparaiso, Chile		1500
	C2BG	Vina del Mar, Chile		1500
	C3BK	Santiago, Chile		1500
	GKZ	Humber, England		1500
	——	Cuba (2 stations)		1500
1508	——	British Columbia, Canada (10 stations)		1510
1520	GMG	Guernsey, England		1520
1524	GMG	Guernsey, England		1523
	GCA	Tobermory, England		1523
	GCB	Lochboisdale, England		1523
1528	C1AC	Tocna, Chile		1530
1532	SMSM	Karlskrona, Sweden		1531

* Original Manuscript Received by the Institute, October 11, 1928.

Channel	Call Letters	Location of Transmitter	Owner	Frequency
		Campbell River, B. C.		1540
1540	CO	Thurston Bay, B. C.		1540
	DM	Vina del Mar, Chile		1540
	C2BA	Swinemunde, Germany		1579
1580	DAS	Cuxhaven, Germany		1579
	DAC	Elbe Feuerschiff Vier, Germany		1579
	KBL	Valparaiso, Chile		1579
	C2AP	Valparaiso, Chile		1579
	C2AU	Antofagasta, Chile		1579
	C1AF	Lighthouse Service, Holland		1579
	——	Washington, D. C.	Jenkins Labs.	1605
1604	3XK	Providence, R. I.	C.E. Mfg. Co.	1605
	1XAC			
1612	——	Lighthouse Service, Holland		1613
1620	——			
1664	KGIA	Drummondville, P. Q.		1620
	KGIB	(Portable) Calif.	Geophysical Research Corp.	1664
	KGIC	(Portable) Calif.	Geophysical Research Corp.	1664
	KGID	(Portable) Calif.	Geophysical Research Corp.	1664
1668	SQJ	(Portable) Calif.	Geophysical Research Corp.	1664
	SQI	Amazonas, Brazil		1667
	C1AE	Amazonas, Brazil		1667
	C2BI	Antofagasta, Chile		1667
	C3CF	Vina del Mar, Chile		1667
1708	C3AA	Santiago, Chile		1667
	C3BJ	Santiago, Chile		1710
	GMF	Santiago, Chile		1710
1716	DAL	Alderney, England		1710
	POB2	Bremerhaven, Germany		1714
1720	PA25	Haarlem, Holland		1714
1760	C3BM	Medemblik, Holland		1720
	——	Santiago, Chile		1760
1764	C3AB	Tonning, Germany		1760
	C3AL	Santiago, Chile		1765
	C3BI	Santiago, Chile		1765
1788	C3CG	Santiago, Chile		1765
1808	PA24	Santiago, Chile		1790
1876	C3CB	Medemblik, Holland		1810
	BAC	Santiago, Chile		1875
	KBL	Cuxhaven, Germany		1875
1880	DAS	Elbe Feuerschiff, Vier, Ger.		1875
1900	PA23	Swinemunde, Germany		1875
1940	C3CC	Oude Zeng, Holland		1900
1976	3XQ	Santiago, Chile		1940
2000	CPO	Mt. Lakes, N. J.	S. Ballantine	1975
	CPN	Bolivia		2000
	——	Bolivia		2000
	PB4	Glace Bay, N. S.		2000
	PA22	Amsterdam, Holland		2000
2008	9BA	Breezand, Holland		2000
2020	——	Montreal, P. Q.		2010
2028	KVT	Manitoba, Canada (2 stations)		2020
2040	KLV	Los Angeles, Calif.	Boulevard Express	2030
	KLU	(Portable)	Lowell Observatory	2040
2048	KZI	Flagstaff, Arizona	Lowell Observatory	2040
	KFZ	(Portable) Calif.	Pratt & Dutro	2050
	KGV	(Portable) Calif.	Russell Reed	2050
	KFV	(Portable) Calif.	Russell Reed	2050
	KYY	(Portable) Calif.	L. A. Co. Forestry Dept.	2050
	KYX	Los Angeles, Calif.	L. A. Co. Forestry Dept.	2050
	KVP	(Portable) Calif.	Pratt & Dutro	2050
	——	Dallas, Texas	City of Dallas	2050
2052	KJA	Quebec, Canada (2 stations)		2050
2068	KVU	Pysht, Washington	Merrill & Ring Lbr. Co.	2054
	WCK	San Diego, Calif.	Boulevard Express	2070
	C3CE	Detroit, Mich.	Detroit Police Dept.	2070
2096	——	Santiago, Chile		2070
	3XI	Lightships		2097
2100	WEQ	Baltimore, Md.	G. E. Sterling	2098
	WJH	Baltimore, Md.	Brd. of Fire Comm.	2100
	WJX	Washington, D. C.	Potomac Elec. Pow. Co.	2100
	DU	Benning, D. C.	Potomac Elec. Pow. Co.	2100
	DJ	Drummondville, P. Q.		2100
	PA21	Yamachiche, P. Q.		2100
2108	WBV	Harlingen, Holland		2100
2140	2XBW	Charleroi, Pa.	W. Penn. Power Co.	2110
	3XE	Jersey City, N. J.	W. C. Von Brandt	2140
		Baltimore, Md.	Balto. Radio Show, Inc.	2140

Channel	*Call Letters*	*Location of Transmitter*	*Owner*	*Frequency*
2140	6XT	San Francisco, Calif.	C. L. Watson & R. C. Gray	2140
	9XC	Chicago, Ill.	Univ. Wireless Comm. Co.	2140
	6XD	(Portable)	D. B. McGown	2140
	1XAC	Providence, R. I.	C.E. Mfg. Co.	2140
	2XQ	New York, N. Y.	Univ. Wireless Comm. Co.	2140
	WGF	Flint, Mich.	F. D. Fallain	2140
	WCZ	Detroit, Mich.	Detroit Yacht Club	2140
	KPG	Quanah, Texas	Quanah Light & Ice Co.	2140
2176	JMPA	Shaishu, Japan		2175
2188	WHC	Allentown, Pa.	W. Penn. Power Co.	2190
	WBI	Frackville, Pa.	W. Penn. Power Co.	2190
	WCJ	Hazelton, Pa.	W. Penn. Power Co.	2190
	WLF	Wilsonville, Pa.	W. Penn. Power Co.	2190
	WPH	Williamsport, Pa.	W. Penn. Power Co.	2190
	WOY	Springdale, Pa.	W. Penn. Power Co.	2190
2200	6XZ	Oakland, Calif.	Southern Pacific Co.	2200
	PA20	den Oever, Holland		2200
2224	JMCA	Mokpo, Japan		2222
2242	——	Manitoba, Canada (2 stations)		2240
	KND	(Portable)	Texas Co.	2245
	KNB	(Portable)	Texas Co.	2245
	KNF	(Portable)	Texas Co.	2245
	KNE	(Portable)	Texas Co.	2245
	KNC	(Portable)	Texas Co.	2245
	——	(Portable)	Texas Co.	2245
2260	WBC	Highland Park, Mich.	H. P. Hardesty	2260
2278	4XM	Airplane *Pan American*	Radio Corp. of America	2278
2302	8XA	Any Ford plane	Ford Motor Co.	2300
	——		U. S. Government	2305
2314			U. S. Government	2315
2326	KUO	San Francisco, Calif.	Examiner Printing Co.	2325
2332	——		U. S. Government	2335
2350	KYF	Seattle, Washington	City of Seattle	2350
2356	——		U. S. Government	2355
2386	——		U. S. Government	2385
2398	WSV	Miami, Florida	Electrical Equipment Co.	2400
2404	——		U. S. Government	2405
2434	——		U. S. Government	2435
2464	——		U. S. Government	2465
2482	——		U. S. Government	2485
2500	3XI	Baltimore, Md.	G. E. Sterling	2500
	KHX	Los Angeles, Calif.	G. C. Tichenor	2500
	XOF	West Beach, Chefoo, China		2500
2512	——		U. S. Government	2515
2518	WEY	Boston, Mass.	Boston Fire Dept.	2520
2542	WFU	Miami Beach, Fla.	Carl G. Fisher	2540
	——		U. S. Government	2545
2572	——		U. S. Government	2575
2584	WMD	Fordson, Mich.	Ford Motor Co.	2584
2602	——		U. S. Government	2605
	9BA	Montreal, P. Q.		2600
2608	KJU	Culver City, Cal.	Cecil B. DeMille	2610
	KNI	Wilmington, Calif.	Wilmington Transportation Co.	2610
2656	——		U. S. Government	2655
2674	——		U. S. Government	2675
2686	——		U. S. Government	2685
2704	——		U. S. Government	2705
2716	——		U. S. Government	2715
2728	6XBF	Los Angeles, Calif.	Cresco, Inc.	2727
2740	KLC	(Portable) Calif.	Shell Co. of Calif.	2740
2746	——		U. S. Government	2745
2752	1XY	(Portable) N. H.	Booth Radio Labs.	2750
	3XI	Baltimore, Md.	G. E. Sterling	2752
2800	KIU	Guadelupe, Calif.	Paramount Famous Lasky Corp.	2800
	KJI	Bristol Bay, Alaska	Nakat Packing Corp.	2800
	KZN	Waterfall, Cannery, Alaska	Nakat Packing Corp.	2800
	KLW	Port Althorp, Alaska	Deep Sea Salmon Co.	2800
2830	6XAN	Los Angeles, Calif.	Freeman Lang	2830
	2XAO	Yacht *MU-1*, New York	Atlantic Broadcasting Corp.	2830
	7XAB	Spokane, Washington	Symons Investment Co.	2830
	——	Red Deer, Canada		2830
2848	WEI	Norfolk, Va.	Norfolk-Cape Charles Radio Telegraph Co.	2850
2854	9XAB	(Portable)	R. J. Rockwell	2855
	1XY	(Portable) N. H.	Booth Radio Labs.	2855

Channel	Call Letters	Location of Transmitter	Owner	Frequency
2866	KGJ	Santa Barbara, Calif.	Merit, Chapman & Scott Cor.	2864
	KHR	Santa Barbara, Calif.	Merit, Chapman & Scott Cor.	2864
2884	——		U. S. Government	2885
2914	——		U. S. Government	2915
2938	9OB	Ottawa, Ont.		2940
2956	——		U. S. Government	2955
2962	——		U. S. Government	2960
	WSY	Darlington, Md.	Susquehanna Power Co.	2960
	——		U. S. Government	2965
2968	——		U. S. Government	2970
2974	——		U. S. Government	2975
2980	——		U. S. Government	2980
	DP	Provincial Air Base, Ont.		2980
	9AZ	Maple Mount, Ont.		2980
	9BD	Long Lake, Ont.		2980
	9BF	Timagami, Ont.		2980
	9BG	Savant Lake, Ont.		2980
	9BH	Cat Lake, Ont.		2980
	DO	Gold Pines, Ont.		2980
	DQ	Woman Lake, Ont.		2980
	DR	Red Lake, Ont.		2980
2992	——		U. S. Government	2995
2998	WEP	Cape Charles, Va.	Norfolk-Cape Charles Radio Telegraph Co.	3000
	9BH	Pine Ridge Post, Ont.		3000
	9BF	Sioux Lookout, Ont.		3000
	9BD	Red Lake, Ont.		3000
	9BG	Woman Lake, Ont.		3000
3004	——		U. S. Government	3005
3034	——		U. S. Government	3035
3052	WGI	Alpena, Mich.	Alpena Marine Radio Corp.	3050
3058	PB8	Rotterdam, Holland		3061
3064	——		U. S. Government	3065
3070	WKZ	Cumberland, Md.	Potomac Edison Co.	3070
3094	LA1M	Oslo, Norway		3093
	PB7	Groningen, Holland		3093
	——		U. S. Government	3095
3112	WJV	Philadelphia, Pa.	Philadelphia Elec. Co.	3110
3124	PB6	The Hague, Holland		3125
3154	——		U. S. Government	3155
3178	KHAH	*Greater Rockford* Monoplane	Bert Hassell	3178
3196	——		U. S. Government	3195
3202	DK	Shawinigan Falls, P. Q.		3200
	BG	Isle Naligme, P. Q.		3200
	BJ	Montreal, P. Q.		3200
	BH	Quebec, P. Q.		3200
	BI	St. Narcisse, P. Q.		3200
3208	3XK	Washington, D. C.	Jenkins Labs.	3210
	1XAC	Providence, R. I.	C.E. Mfg. Co.	3210
3226	——	Amsterdam, Holland		3226
3232	——		U. S. Government	3235
3262	——		U. S. Government	3265
3292	WFE	(Portable)	Cmdr. Richard E. Byrd	3290
	WFD	(Portable)	Cmdr. Richard E. Byrd	3290
	KFK	(Portable)	Cmdr. Richard E. Byrd	3290
	WFA	(Portable)	Cmdr. Richard E. Byrd	3290
	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	3290
	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	3290
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	3290
	——		U. S. Government	3295
3298	PB1	Rotterdam, Holland		3297
	WBV	Charleroi, Pa.	West Penn. Power Co.	3301
	WOB	Connellsville, Pa.	West Penn. Power Co.	3301
3316	CM	Noranda, P. Q.		3320
	CK	Selquirk Mines, Manitoba		3320
3332	WPM	Birmingport, Ala.	Inland Waterways Corp.	3331
	——	Soerabaya, Java		3331
	——	Warsaw, Poland		3333
	——	Lwow, Poland		3333
3340	——		U. S. Government	3340
	9CH	Geizers Hill, Nova Scotia		3340
3348	——		U. S. Government	3345
	——		U. S. Government	3350
3356	——		U. S. Government	3355
	——		U. S. Government	3360
3364	——		U. S. Government	3365
3372	——		U. S. Government	3370
	——		U. S. Government	3375

Channel	Call Letters	Location of Transmitter	Owner	Frequency
3380	——		U. S. Government	3380
3388	——		U. S. Government	3385
	——		U. S. Government	3390
3396	——		U. S. Government	3395
	——		U. S. Government	3400
3404	——		U. S. Government	3405
3412	——		U. S. Government	3410
	——		U. S. Government	3415
3428	WHF	Williamsport, Md.	Potomac Edison Co.	3430
3444	——		U. S. Government	3445
3468	KTT	Drier Bay, Alaska	Gorman Packing Corp.	3466
3476	——		U. S. Government	3475
	9BG	Savant Lake, Ont.		3480
	9BD	Long Lake, Ont.		3480
	9BH	Cat Lake, Ont.		3480
	9AZ	Maple Mount, Ont.		3480
	9BF	Timagami, Ont.		3480
3500	——		U. S. Government	3500
3532	LA1E	Bergen, Norway		3529
	C2BD	Valparaiso, Chile		3530
3588	RZV	Vonjama, Liberia		3590
3612	RZS	Sinoe, Liberia		3610
3660	RZB	Bassa, Liberia		3660
3700	RZP	Cape Palmas, Liberia		3700
3716	HBC	Berne, Switzerland		3720
3748	KFUH	SS *Kaimiloa*	M. R. Kellum	3748
	KGDQ	SS *Faith*	W. W. Shaw	3748
	HVA1	Hanoi, Indo-China		3750
	RZM	Monrovia, Liberia		3750
	HJF	Cucuta, Columbia (Proposed)		3750
	HJE	Cali, Columbia (Proposed)		3750
	VMDJ	White Island, New Zealand		3750
	2FF	Tientsin, China		3750
	XWAG	Vancouver, B. C.		3750
	——	Calgary, Alberta		3750
	——	Saskatoon, Sask.		3750
	XWAC	Winnipeg, Manitoba		3750
	——	London, Ont.		3750
	——	Toronto, Ont.		3750
	XWCB	Camp Borden, Ont.		3750
	——	Kingston, Ont.		3750
	——	Montreal, P. Q.		3750
	——	Quebec, P. Q.		3750
	——	St. John, N. B.		3750
	——	Halifax, N. S.		3750
3900	KHAS	Airplane *Maid of Detroit*	H. C. McCarroll	3904
3948	GSA			3945
	3XQ	Mt. Lakes, N. J.	S. Ballantine	3950
	JCX	Naha, Japan		3950
3956	——	Paris, France		3953
3996	YZ	Issy-les-Moulineaux, France		3998
	FL	Paris, France		3998
	JKV	Kanazawa, Japan		4000
	SQBP	Pernambuco, Brazil		4000
	SQBQ	Pernambuco, Brazil		4000
4012	WLC	Rogers, Mich.	Michigan Limestone Co.	4010
	——		U. S. Government	4015
4020	——		U. S. Government	4017
	——		U. S. Government	4020
4028	——		U. S. Government	4025
	——		U. S. Government	4030
4044	KOG	Honolulu, Hawaii	Mutual Telephone Co.	4044
	——		U. S. Government	4045
4052	——		U. S. Government	4050
	KFVM	SS *Idalia*	E. R. Parker	4052
	——		U. S. Government	4055
	JHL	Hiroshima, Japan		4050
4060	——		U. S. Government	4060
4068	——		U. S. Government	4065
	——		U. S. Government	4070
4076	——		U. S. Government	4075
	——		U. S. Government	4080
	JBD	Keijo, Japan		4080
4084	——		U. S. Government	4085
4092	——		U. S. Government	4090
4100	8XA	Any Ford plane	Ford Motor Co.	4100
	IDM	Rhodes, Italy		4100

Channel	Call Letters	Location of Transmitter	Owner	Frequency
4100	JYD	Tokyo, Japan		4100
4108	——		U. S. Government	4105
	——	Yucatan		4110
	JPP	Tokyo, Japan		4110
4132	——		U. S. Government	4135
4140	KHM	Lihue, Hawaii	Mutual Telephone Co.	4144
	KHO	Kaunakakai, Hawaii	Mutual Telephone Co.	4144
	KHL	Wailuku, Hawaii	Mutual Telephone Co.	4144
	KLN	Hilo, Hawaii	Mutual Telephone Co.	4144
4148	JKF	Kuji, Japan (Proposed)		4150
4156	——		U. S. Government	4155
4204	——		U. S. Government	4205
4220	KHAI	Airplane *C-5358*	Western Air Express	4224
	KHAG	Airplane *C-5177*	Western Air Express	4224
	KHAJ	Airplane *C-4458*	Western Air Express	4224
	KGHY	Mills Field, San Francisco, Calif.	Western Air Express	4224
4228	JEW	Osaka, Japan		4230
4236	——		U. S. Government	4235
4252	WRB	Miami, Fla.	W. G. Watts, Jr.	4250
	WRP	Pinecrest, Fla.	W. G. Watts, Jr.	4250
	——		U. S. Government	4255
4268	——		U. S. Government	4265
4276	1XAC	Providence, R. I.	CE Mfg. Co.	4280
	6XT	San Francisco, Calif.	C. L. Watson & R. C. Gray	4280
	2XQ	New York, N. Y.	Univ. Wireless Commun. Co.	4280
	9XC	Chicago, Ill.	Univ. Wireless Commun. Co.	4280
	2XDY	Jersey City, N. J.	Walter C. Von Brandt	4280
	3XE	Baltimore, Md.	Baltimore Radio Show	4280
	IDZ	Rome, Italy		4280
4284	——	Cadiz, Spain		4286
	——	Matagorda, Spain		4286
4292	SQAT	Campina Grande, Parahyba, Brazil		4290
	JBK	Kogoshima, Japan		4290
	SQAS	Rio Branco, Pernambuco, Brazil		4290
	SQAU	Parahyba, Brazil		4290
	SQAR	Recife, Pernambuco, Brazil		4290
	SQBS	Limoeiro, Pernambuco, Brazil		4290
	——		U. S. Government	4295
4300	——		U. S. Government	4300
4308	——		U. S. Government	4305
4316	——		U. S. Government	4310
4348	JMPA	Saishu, Japan		4350
4364	——		U. S. Government	4365
4372	——		U. S. Government	4370
	——		U. S. Government	4375
4380	——		U. S. Government	4380
4388	——		U. S. Government	4385
4396	KHAS	Airplane *Maid of Detroit*	H. G. McCarroll	4400
4405	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	4405
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	4405
	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	4405
	KFK	(Portable)	Cmdr. Richard E. Byrd	4405
	WFA	(Portable)	Cmdr. Richard E. Byrd	4405
	WFE	(Portable)	Cmdr. Richard E. Byrd	4405
	WFD	(Portable)	Cmdr. Richard E. Byrd	4405
4425	——		U. S. Government	4430
4435	——		U. S. Government	4435
	——		U. S. Government	4436
	——		U. S. Government	4440
4445	——		U. S. Government	4445
	JMCA	Mokpo, Japan		4450
4505	KWV	Bakers Field, Calif.	Pacific Air Transport	4510
4515	KTF	Midway Island	Mackay Radio & Teleg. Co.	4515
4525	——		U. S. Government	4525
	9AQ	Nipigon, Ont.		4530
	9AI	Toronto, Ont.		4530
4535	6XAI	Los Angeles, Calif.	Los Angeles Radio Club	4540
	8XF	Cleveland, Ohio	Radio Air Service Corp.	4540
4545	RZM	Monrovia, Liberia		4550
4565	RZP	Cape Palmas, Liberia		4570
4575	9XAD	Chicago, Ill.	J. G. Branch	4575
4595	WGT	San Juan, P. R.	Radio Corp. of America	4593
	2XBA	Newark, N. J.	WAAM Inc.	4600

Channel	Call Letters	Location of Transmitter	Owner	Frequency
4595	——	Halifax, N. S.		4600
	——	Charlottetown, P. E. I.		4600
	——	Sherbrooke, P. Q.		4600
	——	Ottawa, Ont.		4600
	XWCB	Camp Borden, Canada		4600
	——	Hamilton, Ont.		4600
	——	Chatham, Ont.		4600
	——	Port Arthur, Ont.		4600
	——	Regina, Sask.		4600
	XWBC	Edmonton, Alta.		4600
	——	Victoria, B. C.		4600
	——	Boko, Japan (Proposed)		4600
	——	Tainan, Japan (Proposed)		4600
4685	2XE	Richmond Hill, N. Y.	Atlantic Brdcstg. Corp.	4685
	SQAP	Belem, Brazil		4690
	SQAQ	Arumanduba, Brazil		4690
4695	1XAB	Portland, Me.	H. P. Rines	4700
	——	Boko, Japan (Proposed)		4700
	——	Tainan, Japan (Proposed)		4700
	DF	Winnipeg, Man.		4700
	DE	Hudson, Ont.		4700
	DP	The Pas, Man.		4700
	DA	Cold Lake, Man.		4700
	UL	Managua, Nicaragua		4700
4755	SQBI	Recife, Pernambuco, Brazil		4760
4765	SQBT	Serra Grande Alagoas, Brazil		4760
4835	G5DH	Dollis Hill, England		4835
	——	Taihoku, Japan (Proposed)		4840
4895	JEW	Osaka, Japan		4900
	UQ	Bluefields, Nicaragua		4900
4905	9XU	Council Bluffs, Iowa	Mona Motor Oil Co.	4910
4915	CF	Drummondville, P. Q.		4916
	JEW	Osaka, Japan		4920
4935	CG	Drummondville, P. Q.		4937
4975	AGC	Nauen, Germany		4975
4985	UOG	Vienna, Austria		4983
	IDX	Asmara, Italy		4990
	ISL	Afgoi, Italian Somaliland		4990
4995	CF	Drummondville, P. Q.		4997
	3XL	Bound Brook, N. J.	Radio Corp. of America	5000
	——	Warsaw, Poland		5000
	——	Lwow, Poland		5000
	JPS	Sapporo, Japan		5000
5045	JFBB	Giran, Japan		5050
5055	——	Spain		5060
5065	JBD	Keijo, Japan		5070
5095	WKA	East Pittsburgh, Pa.	Westinghouse Elec. & Mfg. Co.	5100
	UW	Cape Gracias, Nicaragua		5100
5115	JCX	Naha, Japan (Proposed)		5120
5135	——	Spain		5140
5155	KWT	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	5160
5165	JHL	Hiroshima, Japan		5170
	——	Nauen, Germany		5170
5245	JPP	Tokyo, Japan		5250
	——	Managua, Nicaragua	Emergency & Special Service	5250
5255	XMT	Mobile on Railroad, China		5260
5265	JPP	Tokyo, Japan		5270
5295	——	Chosi, Japan (Proposed)		5300
	——	Managua, Nicaragua	Emergency & Special Service	5300
5345	JKV	Kanazawa, Japan		5350
5355	GBM	Leafield, England		5355
	——	Oxford, England		5360
	JKV	Kanazawa, Japan		5360
5395	JKF	Kuji, Japan (Proposed)		5400
5405	——	Chigiqui, Panama	Tropical Radio Teleg. Co.	5410
5445	——	Riga, Latvia		5450
	IDO	Rome, Italy		5450
	JRTS	Tientsin, China		5450
5455	JEW	Osaka, Japan		5460
5485	CA	Geizers Hill, N. S.		5490
5495	JYZ	Tokyo, Japan		5500
	——	SS *Fort James*, Canada		5500
5525	WRL	Duluth, Minn.	Radio Corp. of America	5525
	WCY	Cleveland, Ohio	Radio Corp. of America	5525
	WGO	South Chicago, Ill.	Ill. Radio Corp. of America	5525
5540	KRK	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	5533
5555	7XO	Seattle, Wash.	Northwest Radio Service Co.	5550
	2XBH	Brooklyn, N. Y.	Charles G. Unger	5550

Channel	Call Letters	Location of Transmitter	Owner	Frequency
5570	WME	Duluth, Minn.	Intercity Radio Teleg. Co.	5570
	WDI	Detroit, Mich.	Intercity Radio Teleg. Co.	5570
	WAM	Buffalo, N. Y.	Intercity Radio Teleg. Co.	5570
	WTL	Cleveland, Ohio	Intercity Radio Teleg. Co.	5570
	WHD	New York, N. Y.	New York Times Co.	5570
5600	WSL	Sayville, N. Y.	Mackay Radio & Teleg. Co.	5600
	WFE	Portable	Cmdr. Richard E. Byrd	5600
	WFA	Portable	Cmdr. Richard E. Byrd	5600
	KFK	Portable	Cmdr. Richard E. Byrd	5600
	WFD	Portable	Cmdr. Richard E. Byrd	5600
	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	5600
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	5600
	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	5600
	WQBM	SS *Albacore*	State of California	5600
	AFJ	Königs Wüsterhausen, Germany		5607
5615	——	Nauen, Germany		5610
	WDI	Detroit, Mich.	Intercity Radio Teleg. Co.	5615
	WTL	Cleveland, Ohio	Intercity Radio Teleg. Co.	5615
	WAM	Buffalo, N. Y.	Intercity Radio Teleg. Co.	5615
	WME	Duluth, Minn.	Intercity Radio Teleg. Co.	5615
5645	KCZ	Riga, Latvia		5643
	ICJ	Benghazi, Italy		5650
	WFE	Portable	Cmdr. Richard E. Byrd	5650
	WFD	Portable	Cmdr. Richard E. Byrd	5650
	KFK	Portable	Cmdr. Richard E. Byrd	5650
	WFA	Portable	Cmdr. Richard E. Byrd	5650
	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	5650
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	5650
	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	5650
	6XAD	Avalon, Calif.	Laurence Mott	5650
5660	PCH	Scheveningen, Holland		5660
5675	DAN	Norddeich, Germany		5670
5690	8XAL	Harrison, Ohio	Crosley Radio Corp.	5690
5705	——		U. S. Government	5700
	——	SS *Fort James*, Canada		5700
5720	SAS	Karlsborg, Sweden		5714
	GKS	Dollis Hill, England		5715
	GKQ	Dollis Hill, England		5715
	KHO	Kaunakakai, Hawaii	Mutual Telephone Co.	5720
	KHM	Lihue, Hawaii	Mutual Telephone Co.	5720
	KHL	Wailuku, Hawaii	Mutual Telephone Co.	5720
	KLN	Hilo, Hawaii	Mutual Telephone Co.	5720
	PWH	Preston, Cuba	Tropical Radio Teleg. Co.	5720
5765	——	Spain		5760
	WKK	Ceiba, P. R.	Bureau of Insular Affairs	5766
	WGW	Viequas, P. R.	Bureau of Insular Affairs	5766
	XMH	Peking, China		5770
	UF	Barrios, Guatemala	Tropical Radio Teleg. Co.	5770
	UC	Tela, Sp. Honduras	Tropical Radio Teleg. Co.	5770
5795	KMN	San Francisco, Calif.	State of California	5800
	KNG	(Portable) Calif.	State of California	5800
	DIZ	Königs Wüsterhausen, Germany		5800
5840	KRO	Kahuku, Hawaii	Radio Corp. of America	5840
5885	KJK	King Cove, Alaska	Pacific Amer. Fisheries	5880
	KWR	Port Moller, Alaska	Pacific Amer. Fisheries	5880
	KXW	Ikatan, Alaska	Pacific Amer. Fisheries	5880
	SQCP	Belle Horizonte, Minas Geraes, Brazil		5880
	——	Spain		5880
	SQCQ	Juiz de Fora, Minas Geraes, Brazil		5880
	SQCR	Rio de Janeiro, Brazil		5880
5900	——	Kootwijk, Holland		5900
5915	——		U. S. Government	5920
	——	Kootwijk, Holland		5920
5930	——		U. S. Government	5925
	——		U. S. Government	5930
	——		U. S. Government	5935
5945	——		U. S. Government	5940
	——		U. S. Government	5945
	KOG	Honolulu, Hawaii	Mutual Telephone Co.	5945
	——		U. S. Government	5950
5960	——		U. S. Government	5955

Channel	Call Letters	Location of Transmitter	Owner	Frequency
5960	——		U. S. Government	5960
	DR	Red Lake, Ont.		5960
	DQ	Woman Lake, Ont.		5960
	DO	Gold Pines, Ont.		5960
	DP	Provincial Air Base, Ont.		5960
	9BH	Cat Lake, Ont.		5960
	9BG	Savant Lake, Ont.		5960
	9BF	Timagami, Ont.		5960
	9BD	Long Lake, Ont.		5960
	9AZ	Maple Mount, Ont.		5960
5990	HF	Moose Jaw, Canada		5990
	HG	Saskatoon, Sask.		5990
	KND	Cambridge, Mass.	The Texas Co.	5996
	WBZ	Springfield, Mass.	Westinghouse Elec. & Mfg. Co.	5996
6005	KWT	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	6000
	9OQ	Toronto, Ont.		6000
	9AQ	Nippigon, Ont.		6000
	C3BE	Santiago, Chile		6000
	OC4	Tientsin, China		6000
	ICK	Tripoli, Italy		6000
	C3CH	Santiago, Chile		6000
	OCPE	Port Etienne, Fr. West Africa		6000
6050	KRP	Salt Lake City, Utah	Western Air Express	6057
	KMV	Los Angeles, Calif.	Western Air Express	6057
6065	KNR	Las Vegas, Nev.	Western Air Express	6060
	XMP	Mobile on Railroad, China		6060
	TFA	Reykjavik, Iceland		6061
	SAD	Sweden		6060
	SASH	Motala, Sweden		6066
	——	Vienna, Austria		6072
6095	KJI	Bristol Bay, Alaska	Nakat Packing Corp.	6100
	KNR	Clearwater, Calif.	Mackay Radio & Teleg. Co.	6100
	KZN	Waterfall Cannery, Alaska	Nakat Packing Corp.	6100
	KLW	Port Althorp, Alaska	Deep Sea Salmon Co.	6100
	UL	Managua, Nicaragua		6100
6125	SQH	Amazonas, Brazil		6120
	ICF	Italy		6120
	——	Mexico		6122
6155	CFTS	Toronto, Ont.		6150
6185	ICK	Italy		6180
	KCE	Riga, Latvia		6185
6200	HBC	Berne, Switzerland		6200
6215	VAJ	Prince Rupert, B. C.		6210
	——	British Columbia, Canada		6218
6245	KWT	Palo Alto, Calif	Mackay Radio & Teleg. Co.	6240
	KSZ	McCarney, Texas	Texas Pipe Line Co.	6240
	KYI	Kings Mill, Texas	Texas Pipe Line Co.	6240
	STSM	Sweden		6250
	SQE	Amazonas, Brazil		6250
6275	WRL	Duluth, Minn.	Radio Corp. of America	6275
	WCY	Cleveland, Ohio	Radio Corp. of America	6275
	WGO	South Chicago, Ill.	Ill. Radio Corp. of America	6275
6305	——	Victoria, B. C.		6310
6320	UA	Pto. Castilla, Sp. Honduras	Tropical Radio Teleg. Co.	6320
	——	British Columbia, Canada		6316
6350	KHAH	Airplane *Greater Rockford*	Bert Hassell	6350
	——	New Zealand		6356
6365	WHD	New York, N. Y.	New York Times Co.	6365
6380	KTA	Guam, Mariana Island	Mackay Radio & Teleg. Co.	6379
	SUC	Cairo, Egypt		6379
	KGH	Hillsboro, Oregon	Mackay Radio & Teleg. Co.	6380
	GHQ	Dollis Hill, England		6380
	SUW	Abu Zabal, Egypt		6380
	CRG	El General, Costa Rica		6380
	DSNP	Denmark		6380
	ICX	Italy		6380
	SPM	Finland		6380
	RFL	Russia		6380
	KZCN	Cebu, P. I.		6380
	KPI	Cebu, P. I.		6380
	KIF	Davao, P. I.		6380
	G5DH	Dollis Hill, England		6383
	SDA	San Salvador		6383
6410	SUW	Cairo, Egypt		6410
6425	3XK	Washington, D. C.	Jenkins Laboratories	6420
	1XAC	Providence, R. I.	C. E. Mfg. Co.	6425

Channel	Call Letters	Location of Transmitter	Owner	Frequency
6455	TSB	Russia		6450
	KZCM	Pasay, P. I.		6448
6515	KGE	Medford, Oregon	Pacific Air Transport	6510
	KGT	Fresno, Calif.	Pacific Air Transport	6510
	XDA	Mexico City, Mexico		6518
	SGL	Stockholm, Sweden		6518
	UG	Tegucigalpa, Honduras	Tropical Radio Teleg. Co.	6520
	SQBK	Florianopolis, Brazil		6520
	BVJ	England		6520
	PCLL	Holland		6520
	IDZ	Italian Somaliland		6520
	RIL	Russia		6520
6530	SUW	Egypt		6525
6545	KQS	Lone Pine, Calif.	State of Calif.	6550
	KQT	Los Angeles, Calif.	State of Calif.	6550
6575	WFE	Portable	Cmdr. Richard E. Byrd	6580
	WFD	Portable	Cmdr. Richard E. Byrd	6580
	KFK	Portable	Cmdr. Richard E. Byrd	6580
	WFA	Portable	Cmdr. Richard E. Byrd	6580
	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	6580
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	6580
	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	6580
6605	KEH	Borger, Texas	Marland Pipe Line Co.	6600
	KFE	Ponca City, Okla.	Marland Pipe Line Co.	6600
6620	SGL	Sweden		6620
	AGJ	Germany		6625
6635	——	Denmark		6637
6665	KEU	Los Angeles, Calif.	Pacific Air Transport	6660
	KEG	Vancouver, Wash.	Pacific Air Transport	6660
	KYU	Wichita Falls, Tex.	Texas Pipe Line Co.	6660
	WPM	Birmingport, Ala.	Inland Waterways Corp.	6660
	WHW	Northbrook, Ill.	Wireless Teleg. & Comm. Co.	6660
	ICK	Tripoli		6660
	LAIM	Norway		6660
	OCTN	France		6660
	OCMV	France		6660
	PGO	Russia		6660
	YZ	France		6660
	XAM	Merida, Yucatan		6663
	OCTU	Tunis, Tunisia		6663
	SDA	San Salvador		6667
	CRO	Costa Rica		6667
	——	Ireland Experimental Stations		6667
	KHAT	Airplane *Roma*	Cesare Sabelli	6670
	3XI	Baltimore, Md.	Geo. E. Sterling	6670
	C3CI	Santiago, Chile		6670
	IDZ	Rome, Italy		6670
6680	DGK	Nauen, Germany		6680
	——	Manila, P. I.		6680
6695	VFL	Ottawa-Hudson Straits Stations, Can.		6690
	VBY	Ottawa-Hudson Straits Stations, Can.		6690
	VCJ	Ottawa-Hudson Straits Stations, Can.		6690
	HC	Winnipeg, Man.		6700
	——	Nauen, Germany		6700
6710	WRR	Rocky Point, N. Y.	Radio Corp. of America	6710
6725	WBO	Dearborn, Mich.	Ford Motor Co.	6720
	WQO	Rocky Point, N. Y.	Radio Corp. of America	6725
	RIL	Russia		6725
6740	KZAJ	Legaspi, P. I.		6737
	IR1	Rome, Italy		6740
	SPI	Rio de Janeiro, Brazil		6740
	UG	Honduras		6740
	WEJ	Rocky Point, N. Y.	Radio Corp. of America	6740
6755	WND	Ocean Township, N. J.	Amer. Tel. & Tel. Co.	6755
	GFV	Baghdad Iraq		6750
	GFN	Kidbrooke, England		6750
	——	Drummondville, P. Q. (Receiving)		6756
	VAJ	Digby Island, B. C.		6760
6770	WAX	Hialeah, Florida	Tropical Radio Teleg. Co.	6770
	WNN	Mobile, Alabama	Tropical Radio Teleg. Co.	6770
	DFG	Nauen, Germany		6770
6785	SGC	SS *San Francisco*, Sweden		6783
	WBF	Boston, Mass.	Tropical Radio Teleg. Co.	6785
	WNU	New Orleans, La.	Tropical Radio Teleg. Co.	6785

Channel	*Call Letters*	*Location of Transmitter*	*Owner*	*Frequency*
6785	——	Spain		6790
6800	XDF	Mexico		6800
6815	KZA	Inglewood, Calif.	Jay Peters	6810
	KXB	Inglewood, Calif.	Jay Peters	6810
	KOQ	Houston, Texas	Humble Pipe Line Co.	6810
	KZCP	Manila, P. I.		6814
	KPM	Iloilo, P. I.		6814
	UR	Costa Rica		6814
	GFA	England		6814
	SAA	Sweden		6814
	AEX	Germany		6814
	GFH	England		6814
	KTA	Guam, Mariana Island	Mackay Radio & Teleg. Co.	6814
	KHD	Quadra, Alaska	Alaska Consol. Canneries	6814
	KNW	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	6815
	CF	Montreal, P. Q.		6815
	DIZ	Königs Wüsterhausen, Germany		6820
	——	Warsaw, Poland		6820
6830	——	Pernambuco, Brazil		6830
	CF	Drummondville, P. Q.		6830
	CG	Drummondville, P. Q.		6830
	CJ	Drummondville, P. Q.		6830
6845	KEN	Bolinas, Calif.	Radio Corp. of America	6845
	——	Spain		6840
	EWHB	Budapest, Hungary		6850
	VAK	Gonzales Hill, B. C.		6850
6860	KEL	Bolinas, Calif.	Radio Corp. of America	6860
6875	6XU	Bolinas, Calif.	Radio Corp. of America	6875
	KTA	Guam, Mariana Island	Mackay Radio & Teleg. Co.	6877
6890	WGX	San Juan, P. R.	Radio Corp. of America	6890
	KOS	Pampa, Texas	Humble Pipe Line Co.	6890
	KPI	Cebu, P. I.		6897
6905	WLI	Cleveland, Ohio	J. P. Burton Coal Co.	6900
	WLG	Bypro, Ky.	The By-Products Co.	6900
	DIZ	Königs Wüsterhausen, Germany		6900
	VAI	Point Grey, B. C.		6900
6920	WEE	Rocky Point, N. Y.	Radio Corp. of America	6920
6935	WEB	Rocky Point, N. Y.	Radio Corp. of America	6935
	2XAS	Rocky Point, N. Y.	Radio Corp. of America	6935
	KTF	Midway Island	Mackay Radio & Teleg. Co.	6940
	SAD	Sweden		6942
6950	WKP	Rocky Point, N. Y.	Radio Corp. of America	6950
	GFJ	Kidbrooke, England		6950
6965	DIZ	Königs Wüsterhausen, Germany		6960
	WIZ	New Brunswick, N. J.	Radio Corp. of America	6965
6980	KZAM	Surigao, P. I.		6973
	OCAG	Agades, Niger, Fr. West Africa		6976
	OCZI	Sinder, Niger, Fr. West Africa		6976
	LAIM	Oslo, Norway		6977
	SAS	Karlsborg, Sweden		6977
	LA1E	Bergen, Norway		6977
	C2AY	Vina del Mar, Chile		6980
	SQBG	Sao Paulo, Brazil		6980
6995	WCT	L'Anse, Mich.	Ford Motor Co.	6990
	——	Quebec, P. Q.		7000
	KZBT	Butuan, P. I.		6990
7010	KZTL	Tolong, P. I.		7005
7040	SQCL	Brazil		7040
7055	HJG	Bogota, Colombia		7055
	JBK	Kagoshima, Japan		7050
	——	Rio de Janeiro, Brazil		7050
	TFA	Reykjavik, Iceland		7059
	FUA	Tunis, Tunisia		7059
	C2BE	Vina del Mar, Chile		7060
7070	——	Rio de Janeiro, Brazil		7067
	JRK	Kagoshima, Japan		7070
7130	ISZ	Alula, Italy		7130
7145	SGT	SS *Suecia*, Sweden		7139
	C2AC	Vina del Mar, Chile		7140
	VIT	Australia		7140
	VIM	Melbourne, Australia		7140
	VIP	Australia		7140
	VIS	Sydney, Australia		7140
	CRQ	Puntarenas, Costa Rica		7140

Channel	Call Letters	Location of Transmitter	Owner	Frequency
7145	——	Cuba		7140
	——	Yucatan		7140
	OCTO	Tahoua, Fr. West Africa		7142
	VJZ	British East Indies		7143
	RTRL	Russia		7143
7160	RRP			7156
7205	JAN	Tokyo, Japan		7200
	——	Nauen, Germany		7200
7250	AGJ	Germany		7250
7265	FW	France		7260
7280	SBM	SS *Fylgia*, Sweden		7277
7295	OCKI	Kidal, Fr. Sudan		7300
	JES	Osaka, Japan		7300
	XVX	Papiete, Tahiti, Fr. Oceania		7300
7310	IQB	Fiume, Italy		7310
	KZMM	Manila, P. I.		7313
	LA1V	Tromsoe, Norway		7317
7325	C2AS	Vina del Mar, Chile		7320
	——	Warsaw, Poland		7320
	JES	Osaka, Japan		7320
	SQW	Altamira, Para, Brazil		7320
	UR	Cartago, Costa Rica	Tropical Radio Teleg. Co.	7320
	IQB	Italy		7320
	FFQ	France		7320
	SMHA	Sweden		7320
7340	——	Garden City, New York	American Publ. Committee	7340
	DFH	Nauen, Germany		7340
7355	9OB	Ottawa, Ont.		7350
	——	Kootwijk, Holland		7350
	——	Boston, Mass.	American Publishers Comm.	7355
	——	Philadelphia, Pa.	American Publishers Comm.	7355
7370	——	New York, N. Y.	American Publishers Comm.	7370
7385	OCRU	Rufisque, Fr. Equatorial Africa		7385
	UOK	Deutsch-Altenburg, Austria		7389
7400	WEM	Rocky Point, N. Y.	Radio Corp. of America	7400
	KHAS	Airplane *Maid of Detroit*	H. G. McCarroll	7400
	——	Taihoku, Japan (Proposed)		7400
	OCBA	Bamako, Fr. Sudan		7407
7415	KKH	Kahuku, Hawaii	Radio Corp. of America	7415
7430	KGR	Seattle, Wash.	Robert Dollar Co.	7430
	KGS	Honolulu, Hawaii	Robert Dollar Co.	7430
	KGX	Los Angeles, Calif.	Robert Dollar Co.	7430
	WGA	New York, N. Y.	Robert Dollar Co.	7430
	KGQ	San Francisco, Calif.	Robert Dollar Co.	7430
7445	KGR	Seattle, Wash.	Robert Dollar Co.	7445
	KGS	Honolulu, Hawaii	Robert Dollar Co.	7445
	KGX	Los Angeles, Calif.	Robert Dollar Co.	7445
	WGA	New York, N. Y.	Robert Dollar Co.	7445
	KGQ	San Francisco, Calif.	Robert Dollar Co.	7445
	JAN	Tokyo, Japan		7450
	——	Horomushiro, Japan (Proposed)		7450
7460	YR-	France		7465
	AGC	Germany		7465
	ANC	Java		7465
7475	PKI	Java		7480
7490	FW	St. Assise, France		7496
	KGCT	SS *Petaluma*, USA	P. & Santa Rosa Ry. Co.	7496
	KGDQ	SS *Faith* USA	Walden W. Shaw	7496
	KFUH	SS *Kaimiloa*, USA	M. R. Kellum	7496
7505	CF	Drummondville, P. Q.		7500
	CG	Drummondville, P. Q.		7500
	CQ	Drummondville, P. Q.		7500
	XWBD	Fort Smith, N. W. T.		7500
	XWBF	Aklavik, N. W. T.		7500
	——	Halifax, N. S.		7500
	——	Charlottetown, P. E. I.		7500
	——	St. John, N. B.		7500
	——	Ottawa, Ont.		7500
	XWCB	Camp Borden, Ont.		7500
	——	Toronto, Ont.		7500
	——	Hamilton, Ont.		7500
	——	Port Arthur, Ont.		7500
	XWAC	Winnipeg, Man.		7500
	——	Regina, Sask.		7500
	——	Moose Jaw, Sask.		7500
	——	Calgary, Alta.		7500
	XWBC	Edmonton, Alta.		7500
	JOC	Ochushi, Japan		7500

Channel	Call Letters	Location of Transmitter	Owner	Frequency
7505	LVF	Flores, Guatemala		7500
	FSQ	Sainte Assise, France		7500
	B82	Belgium		7500
	ISV	Italian Somaliland		7500
	OCDB	Abyssinia		7500
	SQCL	Brazil		7500
	PB9	Holland		7500
	7MN	Cuba		7500
	——	Mexico		7500
	JFBB	Japan		7500
	BAM	Tahiti		7500
7520	WEG	Rocky Point, N. Y.	Radio Corp. of America	7520
7535	DIY	Königs Wüsterhausen, Germany		7537
7565	——	Chiriqui, Panama	Tropical Radio Teleg. Co.	7560
	AFU	Königs Wüsterhausen, Germany		7560
	RZA	Monrovia, Liberia		7570
7595	YR	La Dona, France		7595
	JFBB	Giran, Japan		7600
	UL	Managua, Nicaragua		7600
	OCLY	France		7600
7610	——	Nauen, Germany		7610
7625	——	Milwaukee, Wis.	American Publishers Comm.	7625
	——	Los Angeles, Calif.	American Publishers Comm.	7625
7640	——	Washington, D. C.	American Publishers Comm.	7640
	——	New York, N. Y.	American Publishers Comm.	7640
	OCDB	Jibuti, Fr. Somaliland		7633
7670	——	Sayville, N. Y.	Mackay Radio & Teleg. Co.	7670
7685	4JE	San Juan, P. R.		7688
	——	Nauen, Germany		7690
	JPP	Tokyo, Japan		7690
	SQCL	Sao Paulo, Brazil		7690
	OCDB	Abyssinia		7690
	IDX	Italy		7690
	——	Mexico		7690
	XOM	China		7690
	PWA	Cuba		7690
	——	Denmark		7690
	OCMV	France		7690
	OCRU	Africa		7690
	HZU	Port Gentil		7692
7700	JPP	Tokyo, Japan		7700
	JYB	Tokyo, Japan		7700
	UQ	Bluefields, Nicaragua		7700
7715	KEE	Bolinas, Calif.	Radio Corp. of America	7715
	BYA	Whitehall, England		7720
7730	——	Sayville, N. Y.	Mackay Radio & Teleg. Co.	7730
	——	Kootwijk, Holland		7732
7745	KNW	Palo Alto, Calif.	Mackay Radio & Te eg. Co.	7745
7760	KNN	Honolulu, Hawaii	Mackay Radio & Teleg. Co.	7760
	——	Kootwijk, Holland		7765
7775	WMU	Elizabeth, N. J.	Standard Oil Co. of N. J.	7775
	WTF	Akron, Ohio	Firestone Plantations Co.	7775
7790	B82	Brussels, Belgium		7790
	XDA	Mexico		7790
	AND	Java		7790
	FUE	France		7790
	OXZ	Denmark		7790
	——	Buenos Aires, Argentine		7790
7805	JRV	Saipan, Japan		7800
	——	Nauen, Germany		7800
	UW	Cape Gracias, Nicaragua		7800
	FW	France		7800
7820	——	Chicago, Ill.	American Publishers Comm.	7820
	DFT	Nauen, Germany		7820
7835	——	New York, N. Y.	American Publishers Comm.	7835
	——	Kootwijk, Holland		7835
7850	——	Floral Park, N. Y.	American Publishers Comm.	7850
7865	SUX	Abu Zabal, Egypt (Proposed)		7860
7880	——	Drummondville, P. Q.		7880
7895	KFUH	SS *Kaimiloa*	M. R. Kellum	7890
	C3AN	Santiago, Chile		7890
	JPS	Sapporo, Japan		7890
	ISL	Afgoi, Italian Somaliland		7890
	C2BK	Valparaiso, Chile		7890
	SQK	Maraba, Para, Brazil		7890
	SQY	Conceigao de Araguaya, Brazil		7890
	SQZ	Soure, Brazil		7890
	CF	Drummondville, P. Q.		7890

Channel	Call Letters	Location of Transmitter	Owner	Frequency
7895	CG	Drummondville, P. Q.		7890
	CJ	Drummondville, P. Q.		7890
	——	Mexicali		7890
	VQF	Sarawac		7890
	PKH	Java		7890
7895	IST	Afgoi, Italian Somaliland		7895
	ISQ	Afgoi, Italian Somaliland		7895
	3XQ	Mt. Lakes, N. J.	Stuart Ballantine	7900
	HBC	Berne, Switzerland		7900
	——	Nauen, Germany		7900
	JPS	Sapporo, Japan		7900
	——	Emergency & Spec. Service Nic.		7900
7910	DFP	Nauen, Germany		7910
7925	——	New York, N. Y.	American Publishers Comm.	7925
7940	GLM	Dorchester, England		7940
7955	——	Chicago, Ill.	American Publishers Comm.	7955
	DGL	Nauen, Germany		7960
7985	——	Nauen, Germany		7980
	FL	France		7980
8000	KFZQ	SS *Robador*, USA	Robert Law, Jr.	7995
	AND	Java		7995
	6XAS	Calif. (Portable)	Culver City Ra. Elec. Co.	8000
	C1AH	Chuquicamata, Chile		8000
	C3AD	Santiago, Chile		8000
	C2BJ	Valparaiso, Chile		8000
	C2BM	Quilpue, Chile		8000
	JKV	Kanazawa, Japan		8000
	JBR	Siberia, Maru, Japan		8000
	XKY	Kwaiyang, China		8000
	XRO	Chungking, China		8000
	C3CK	Rancagua, Chile		8000
	HBC	Berne, Switzerland		8000
	SDA	San Salvador		8000
	——	Mexico		8000
	ANF	Java		8000
	XOM	China		8000
	GLK	Dorchester, England		8005
8015	WLC	Rogers, Mich.	Mich. Limestone Co.	8010
8030	——		U. S. Government	8030
	——		U. S. Government	8034
8045	——		U. S. Government	8040
	——		U. S. Government	8050
	WCFL	Chicago, Ill.	Chicago Fed. of Labor	8050
	HJG	Bogota, Colombia		8050
8060	——		U. S. Government	8060
8075	KNN	Honolulu, Hawaii	Mackay Radio & Teleg. Co.	8075
8090	——		U. S. Government	8090
8105	6XF	Los Angeles, Calif.	Calvin J. Smith	8100
	WJD	New York, N. Y.	International News Service	8100
	KUY	Bear Creek, Alaska	New York-Alaska Gold Dredging Co.	8100
	——		U. S. Government	8100
	KGBT	SS *Enchantress*	S. F. Wainwright	8103
	KFVM	SS *Idalia*	E. R. Parker	8103
	KFHW	SS *Poinsettia*	Walter W. Horne	8103
	KGBB	SS *Sachen*	R. B. Metcalf	8103
	——		U. S. Government	8110
	GKT	Bunham, England		8110
	C2BL	Valparaiso, Chile		8110
	C1AI	Chuquicamata, Chile		8110
	KAV	Norddeich, Germany		8110
8120	——		U. S. Government	8120
	——	Manila, P. I.		8120
8135	——		U. S. Government	8135
	——		U. S. Government	8140
8150	——		U. S. Government	8150
	UR	Cartago, Costa Rica	Tropical Radio Teleg. Co.	8150
	OIC	Ship, Austria		8150
8165	——		U. S. Government	8160
	——		U. S. Government	8170
	DGV	Nauen, Germany		8170
8180	——	Kootwijk, Holland		8174
	DIX	Königs Wüsterhausen, Germany		8179
	——		U. S. Government	8180
8195	VDB	Esquimalt, Canada		8190
8210	KGH	Hillsboro, Oregon	Mackay Radio & Teleg. Co.	8210
	——		U. S. Government	8210

Channel	Call Letters	Location of Transmitter	Owner	Frequency
8210	GKT	Burnham, England		8210
	ME5	Matagalpa, Nic. (Proposed)		8210
	ME7	Ocotal, Nic. (Proposed)		8210
	BLF	Bluefields, Nicaragua		8210
	CAB	Puerto Cabezas, Nicaragua		8210
	F8M	(Aviation) Nicaragua		8210
	GLKY	SS. *Carinthia*, England		8214
	C3BG	Santiago, Chile		8220
	——	Mexico		8220
	ANF	Java		8220
	FUT	France		8220
	SAV	Sweden		8220
8230	GKS	Dollis Hill, England		8230
	HIK	Barahona, San Domingo		8237
	WJD	New York, N. Y.	New York Times Co.	8230
8250	SAB	Goteborg, Sweden		8242
8270	——		U. S. Government	8270
	IR1	Italy		8275
	SPC	Brazil		8280
8290	——	Königs Wüsterhausen, Germany		8300
	HBC	Berne, Switzerland		8300
	UL	Managua, Nicaragua		8300
8310	——		U. S. Government	8310
	IDX	Asmara, Italy		8320
8330	KTA	Guam, Mariana Island	Mackay Radio & Teleg. Co.	8328
	DAN	Norddeich, Germany		8330
	KCR	Riga, Latvia		8330
	FQ	Leopoldville, Congo, Belgium		8330
	C2BO	Vina del Mar, Chile		8330
	OCRB	Morocco		8330
	PCMM	Holland		8330
	XVX	Papeete, Tahiti, French Oceania		8333
8370	WME	Duluth, Minn.	Intercity Radio Teleg. Co.	8370
	WDI	Detroit, Mich.	Intercity Radio Teleg. Co.	8370
	WAM	Buffalo, N. Y.	Intercity Radio Teleg. Co.	8370
	WTL	Cleveland, Ohio	Intercity Radio Teleg. Co.	8370
8390	WRL	Duluth, Minn.	Radio Corp. of America	8385
	WGO	South Chicago, Ill.	Ill. Corporation of America	8385
	WCY	Cleveland, Ohio	Radio Corp. of America	8385
	——	Königs Wüsterhausen, Germany		8400
	UQ	Bluefields, Nicaragua		8400
8410	——		U. S. Government	8410
8430	FUT	Toulon, France		8422
	WSL	Sayville, N. Y.	Mackay Radio & Teleg. Co.	8425
	SNNI	Rio de Janeiro		8437
8450	PCRR	Sgravenhage, Holland		8446
	UR	Costa Rica		8450
	BZC	England		8450
	RKU	Russia		8450
	ICF	Italy		8450
8470	——		U. S. Government	8470
	——	Nauen, Germany		8480
8490	G5DH	England		8495
	PCH	Scheveningen, Holland		8499
	UW	Cape Gracias, Nicaragua		8500
	GCA	England		8500
8510	——		U. S. Government	8510
	RXY	SS *City of San Francisco*		8518
8530	——		U. S. Government	8530
8550	SQI	Brazil		8540
	OCKO	Cotonou, Dahoney, Fr. W. Africa		8550
8570	KFUH	SS *Kaimiloa*, USA	M. R. Kellum	8566
	BZE	Matura Ceylon	British Naval Station	8566
	BYZ	Rinella, Malta	British Naval Station	8566
	CH	Santiago, Chile		8566
	OCRB	Morocco		8566
	ASD	SS *Bergsdalen*, Norway		8566
	BZF	Aden Somaliland	British Naval Station	8566
	BXW	Seletar, Singapore	British Naval Station	8566
	CKN	Esquimalt, B. C.		8570
	C3AU	Santiago, Chile		8570
	BXW	Seletar Straits Settlements		8570
	C2AH	Valparaiso, Chile		8570
	2AA	Tientsin, China		8570
	RAU	Russia		8570
	OCDA	French West Africa		8570

Channel	Call Letters	Location of Transmitter	Owner	Frequency
8570	IDB	Albania		8570
	PCA	Holland		8570
	2RM	Cuba		8570
	2JT	Cuba		8570
	UR	Costa Rica		8570
	G5DH	Dollis Hill, England		8570
	——	Mexico		8570
	——	Yucatan		8570
	1FMH	San Salvador		8571
	BYC	Horsea, England		8571
	——	Tamatave, France		8571
	BXY	Hongkong, China		8571
	BWW	Gibraltar		8571
	BYB	Whitehall, England		8571
	C3CJ	Santiago, Chile		8580
8590	——		U. S. Government	8590
	——		U. S. Government	8600
	KWT	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	8600
8610	——		U. S. Government	8610
	——		U. S. Government	8620
	CTO	Portugal		8620
	CKN	British Protectorate		8620
8630	BYB	Cleethorpes, England		8630
8650	9XC	Chicago, Ill.	Univ. Wireless Comm. Co.	8650
	2XQ	New York, N. Y.	Univ. Wireless Comm. Co.	8650
	3XE	Baltimore, Md.	Balto. Radio Show, Inc.	8650
	6XT	San Francisco, Calif.	C. L. Watson & R. C. Gray	8650
	6XD	Portable	D. B. McGown	8650
	1XAC	Providence, R. I.	C. E. Manufacturing Co.	8650
	2XBY	Jersey City, N. J.	Walter C. Von Brandt	8650
	LPX	Monte Grande, Argentine		8645
8670	DIW	Königs Wüsterhausen, Germany		8670
8690	PJC	Curacao, Dutch West Indies		8690
	GLKY	SS *Carinthia*, England		8690
	LPI	Buenos Aires, Argentine		8690
	C2AK	Vina del Mar, Chile		8690
	C3CL	Santiago, Chile		8700
	HBC	Berne, Switzerland		8700
	HBC	Münchenbuchsee, Switzerland		8700
	VWZ	India		8700
	AYF	Venezuela		8700
	VIS	Australia		8700
8710	KNN	Honolulu, Hawaii	Mackay Radio & Teleg. Co.	8720
8730	——		U. S. Government	8730
	——		U. S. Government	8740
8750	——		U. S. Government	8750
	LCHO	Oslo, Norway		8750
	OCX	Morocco		8750
	RZA	Monrovia, Liberia		8750
	——		U. S. Government	8760
8770	——		U. S. Government	8770
	BXC	Nore, England		8770
	GBI	Grimsby, England		8780
8790	CF	Drummondville, P. Q.		8795
	CFH	Halifax, Nova Scotia		8795
	KHAS	Airplane *Maid of Detroit*, USA	H. G. McCarroll	8800
	——	India		8800
	——	England		8800
8810	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	8810
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	8810
	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	8810
	WFA	(Portable)	Cmdr. Richard E. Byrd	8810
	WFE	(Portable)	Cmdr. Richard E. Byrd	8810
	WFD	(Portable)	Cmdr. Richard E. Byrd	8810
	KFK	(Portable)	Cmdr. Richard E. Byrd	8810
	IDM	Rhodes, Italy		8810
	IDO	Rome, Italy		8810
	PCA	Amsterdam, Holland		8818
	LGN	Norway		8818
	GBJ	Bodmin, England		8820
	CRA	San Jose, Costa Rica		8820
	SLO	Stanleyville, Congo, Belgium		8820
	PCUU	The Hague, Holland		8820
	QCK	Tientsin, China		8820
	——	SS *Jervis Bay*		8820
	XDA	Mexico		8820
	RKV	Russia		8820
	VPQ	British East Indies		8820

Channel	Call Letters	Location of Transmitter	Owner	Frequency
8810	FW	France		8820
	2RO	Cuba		8820
	CZA	Mexico		8820
	LPI	Buenos Aires, Argentine		8820
	——	Yucatan		8820
	——	Greenland		8820
	——	Mexicali		8820
8830	2JG	San Salvador		8823
	PCUU	The Hague, Holland		8824
	UR	Cartago, Costa Rica	Tropical Radio Teleg. Co.	8830
8850	KNW	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	8850
	——		U. S. Government	8860
8870	——		U. S. Government	8870
	NAZ	Managua, Nicaragua		8870
	——		U. S. Government	8872
	——		U. S. Government	8880
8890	——		U. S. Government	8890
	VNB	South Africa		8900
8910	——	Königs Wüsterhausen, Germany		8920
	LP1	Monte Grande, Argentine		8920
8930	——	Sayville, N. Y.	Mackay Radio & Teleg. Co.	8930
	DIV	Königs Wüsterhausen, Germany		8930
8950	WNBT	Elgin, Ill.	Elgin Nat'l. Watch Co.	8950
	WEL	Rocky Point, N. Y.	Radio Corp. of America	8950
	——	Choshi, Japan (Proposed)		8950
8970	KNW	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	8970
8990	WEC	Rocky Point, N. Y.	Radio Corp. of America	8990
	6XB	Bolinas, Calif.	Radio Corp. of America	9000
	PCA	Amsterdam, Holland		9000
	JPN	Palaos, Japan		9000
	UL	Managua, Nic.		9000
	JRW	Japan		9000
9010	KEJ	Bolinas, Calif.	Radio Corporation of America	9010
	——	Spain		9020
	GBS	Rugby, England		9020
9030	KTF	Midway Island	Mackay Radio & Telegraph Co.	9031
	CFH	Halifax, Nova Scotia		9040
9050	KHAD	Airplane	Zenith Aircraft Corp.	9050
	——		U. S. Government	9050
	CFH	Halifax, Nova Scotia		9055
9070	KNN	Honolulu, Hawaii	Mackay Radio & Teleg. Co.	9070
	9AI	Toronto, Ont.		9060
	9AQ	Nipigon, Ont.		9060
9090	IDO	Rome, Italy		9085
	KIXB	SS *West Cheswald*		9085
	YZ	Issy les Moulineaux, France		9085
	VPS	Hongkong, China		9085
	——	Santa Marta, Colombia	Tropical Radio Teleg. Co.	9085
	HZM	Brazzaville, Fr. Equatorial Africa		9090
	JES	Osaka, Japan		9090
	RZA	Monrovia, Liberia		9090
	SQBE	Bahia, Brazil		9090
	LCHO	Norway		9090
	OCCO	West Africa		9090
	OCDJ	Morocco		9090
	OCTN	France		9090
	PJC	Curacao, Dutch W. I.		9090
	2IQ	Cuba		9090
	2CF	Cuba		9090
	IDO	Italy		9090
	CF	Drummondville, P. Q.		9091
	CG	Drummondville, P. Q.		9091
	CJ	Drummondville, P. Q.		9091
	UJ	Santa Marta, Colombia	Tropical Radio Teleg. Co.	9100
9110	——	Manila, P. I.		9110
	OCDJ	Paris, France		9115
	——	Paris, France		9120
	——	Nauen, Germany		9120
	SUW	Cairo, Egypt		9118
9150	6XN	Oakland, Calif.	General Electric Co.	9145
	FL	France		9160
9170	WND	Ocean Township, N. J.	Amer. Tel. & Tel. Co.	9170
9190	——	Kootwijk, Holland		9200
	UQ	Bluefields, Nicaragua		9200
9230	PCLL	Kootwijk, Holland		9225
	2YT	Poldhu, England		9225
	——	Paris, France		9230

Channel	Call Letters	Location of Transmitter	Owner	Frequency
9230	OCDJ	Issy les Moulineaux, France		9230
	PCTT	Kootwijk, Holland		9240
	——	Kootwijk, Holland		9240
9250	GBK	Bodmin, England		9260
9270	——	Spain		9280
9290	——	Naha, Japan (Proposed)		9300
	UW	Cape Gracias, Nicaragua		9300
	AYG	Venezuela		9300
9310	AYA	Venezuela		9320
9330	CG	Drummondville, P. Q.		9332
	CG	Quebec, P. Q.		9338
9350	JCX	Naha, Japan		9360
9370	BIH	Paris, France		9369
	PTT	Brazil		9369
	FL	Paris, France		9369
	VIS	Sydney, Australia		9369
	ARDI	SS *C. A. Larsen*		9369
	8XAO	Detroit, Mich.	Station WJR Inc.	9370
	ANE	Java		9370
	JHL	Japan		9370
	VJC	Raboul, New Guinea		9375
	2MK	Cuba		9380
	5CX	Cuba		9380
	HVA	Tonkin, French Indo-China		9380
	H9OC	Switzerland		9380
	LY	France		9380
	OCNG	France		9380
	VQF	Saraw k		9380
	PWA	Cuba		9380
	——	England		9380
	ANH	Java		9380
	H9XD	Switzerland		9380
	JB	Africa		9380
	PCLL	Holland		9380
	PKD	Pokong, Dutch W. I.		9380
	PKX	Java		9380
	OCDJ	France		9375
	IDO	Rome, Italy		9370
	LDW	Bodoe, Norway		9375
	XVX	Papeete, Tahiti, French Oceania		9375
	OCGB	Ivory Coast, French West Africa		9375
	JHL	Hiroshima, Japan		9380
	——	Norway (Proposed)		9380
9390	——	Königs Wüsterhausen, Germany		9400
	——	Nicaragua (Emergency)		9400
9410	WGA	New York City	The Robert Dollar Co.	9410
	KGX	Los Angeles, Calif.	The Robert Dollar Co.	9410
	KGS	Honolulu, Hawaii	The Robert Dollar Co.	9410
	KGR	Seattle, Wash.	The Robert Dollar Co.	9410
	KGQ	San Francisco, Calif.	The Robert Dollar Co.	9410
9430	WEIR	Rocky Point, N. Y.	Radio Corp. of America	9430
	SAS	Carlsborg, Sweden		9434
	——	Nauen, Germany		9440
9450	WES	Rocky Point, N. Y.	Radio Corp. of America	9450
	——	Horomushiro, Japan (Proposed)		9450
	DIU	Königs Wüsterhausen, Germany		9458
9470	WET	Rocky Point, N. Y.	Radio Corp. of America	9470
9490	PCPP	Kootwijk, Holland		9488
	WEF	Rocky Point, N. Y.	Radio Corp. of America	9490
	——	Taihoku, Japan (Proposed)		9500
9510	PTR	SS *N. T. Nielsen Alonso*, Norway		9518
	ARCX	SS *Nilson Alonzo*		9518
	——	Australia		9520
9530	BVJ	England		9525
	PTK	Brazil		9525
	PKP	Java		9525
	SNM	Sweden		9525
9550	UL	Managua, Nicaragua		9550
	——	Brazil		9555
9570	——	Königs Wüsterhausen, Germany		9580
	——	Norway		9580
9590	LGN	Oslo, Norway		9600
	FW	France		9600
9610	LCK	Oslo, Norway		9620
	LDW	Norway		9620

Channel	Call Letters	Location of Transmitter	Owner	Frequency
9630	CF	Drummondville, P. Q.		9630
	CG	Drummondville, P. Q.		9630
	CJ	Drummondville, P. Q.		9630
9650	OCRU	West Africa		9645
	DGU	Nauen, Germany		9650
	2KP	Cuba		9650
	8XAG	Dayton, Ohio	E. T. Flewelling	9660
9670	JBD	Keijo, Japan		9670
	SAD	Sweden		9670
	TUE	SS *William Blumer*, Holland		9672
	SDA	SS *Ragunda*, Sweden		9672
	AGC	Nauen, Germany		9672
	——	Tananarive, France		9677
	AQS	Jan Mayen, Norway		9678
9690	DFF	Nauen, Germany		9690
	2XAL	Coytesville, N. J.	Experimenter Publishing Co.	9700
	——	Königs Wüsterhausen, Germany		9700
	——	Argentine		9700
	ELFP	Monrovia, Liberia		9700
9710	VLB	New Zealand		9710
	PTT	Brazil		9710
9730	DFO	Nauen, Germany		9730
	XDA	Mexico		9725
9750	WNC	Ocean Township, N. J.	American Tel .& Tel. Co.	9750
9770	DFS	Nauen, Germany		9770
	RKI	Russia		9770
	EAM	Spain		9770
9790	——	Argentine		9790
	GBW	Rugby, England		9790
	JKF	Kuji, Japan (Proposed)		9800
9810	DFE	Nauen, Germany		9810
	RCI	Russia		9810
9830	PTQ	Brazil		9835
	LCM	Norway		9835
	——	Nauen, Germany		9840
9850	PJC	Curacao, Dutch West Indies		9850
9870	WMI	Deal, N. J.	American Tel. & Tel. Co.	9870
9890	DGC	Nauen, Germany		9890
	HZAI	Saigon		9900
	SQBD	Brazil		9900
	PWAL	Brazil		9900
	VMF	New Zealand		9950
9910	EAX	Spain		9910
9930	——	Nauen, Germany		9930
	——	Spain		9940
	PCJJ	Holland		9930
	——	France		9930
	PJD	St. Martins		9940
9950	GBU	Rugby, England		9950
9970	KZET	Manila, P. I.	Radio Corp. of Philippines	9961
	IPR	Italy		9975
9990	GBM	Oxford, England		9994
	FTJ	Jacques Cartier, France		9994
	PKH	Java		9994
	GBO	Oxford, England		10000
	JBK	Kagoshima, Japan		10000
	——	Glace Bay, Canada		10000
	LCM	Stavanger, Norway (Proposed)		10000
	B2	Machelen les Brussels, Belgium		10000
	OCRU	Rufisque, Senegal, Fr. W. Africa		10000
	LGN	Norway		10000
	——	Mexico		10000
	——	France		10000
	2LA	Cuba		10000
10010	1XR	Manila, P. I.		10010
	PKH	Java		10005
	9AQ	Nipigon, Ont.		10020
	9AI	Toronto, Ont.		10020
10030	——	Spain		10030
	UOR	Vienna, Austria		10033
	——	Nauen, Germany		10040
10070	——	Nauen, Germany		10080
10110	DIT	Königs Wüsterhausen, Germany		10120
10150	DIS	Königs Wüsterhausen, Germany		10156
10170	KNR	Clearwater, Calif.	Mackay Radio & Teleg. Co.	10170

Channel	Call Letters	Location of Transmitter	Owner	Fre-quency
10170	JFAB	Giran, Japan		10170
	UJ	Santa Marta, Colombia		10170
	SPW	Rio de Janeiro, Brazil		10170
	JES	Japan		10170
	PCTT	Kootwijk, Holland		10170
10190	——	Nauen, Germany		10200
	XGA	China		10200
10210	DGD	Nauen, Germany		10210
	——	Spain		10220
10230	XGA	Mukden, China		10240
10250	——	Scheveningen, Holland		10250
	——	Scheveningen, Holland		10260
10290	——	Spain		10300
10330	PKP	Java		10339
	JPS	Sapporo, Japan		10340
	HJG	Bogota, Colombia		10340
10350	——	Kabarah, French Sudan		10344
	JPS	Sapporo, Japan		10350
10390	KERR	Bolinas, Calif.	Radio Corp. of America	10390
10410	KES	Bolinas, Calif.	Radio Corp. of America	10410
	LAD	Norway		10400
	AND	Java		10415
	PCRR	Kootwijk, Holland		10417
	——	Scheveningen, Holland		10420
	——	Kootwijk, Holland		10420
10450	SNNI	Rio de Janeiro, Brazil		10447
	DGH	Nauen, Germany		10450
	WAX	Hialeah, Fla.	Tropical Radio Teleg. Co.	10450
	WNN	Mobile, Ala.	Tropical Radio Teleg. Co.	10450
10470	WBF	Boston, Mass.	Tropical Radio Teleg. Co.	10470
	WNU	New Orleans, La.	Tropical Radio Teleg. Co.	10470
10490	KNN	Honolulu, Hawaii	Mackay Radio & Teleg. Co.	10490
	——	Königs Wüsterhausen, Germany		10500
10530	RDRL	Russia		10525
	OCLY	Bordeaux, France		10525
	2NE	Australia		10530
	2FC	Australia		10530
10550	WLD	Ocean Township, N. J.	American Tel. & Tel. Co.	10550
10590	JRV	Saipan, Japan		10600
	——	Nauen, Germany		10600
	IXR	Manila ,P. I.		10600
10610	WEA	Rocky Point, N. Y.	Radio Corp. of America	10610
	LP5	Monte Grande, Argentine		10620
10630	WED	Rocky Point, N. Y.	Radio Corp. of America	10630
	AND	Java		10630
	——	Sydney, Australia		10640
10670	——	Königs Wüsterhausen, Germany		10680
10690	PCQQ	Kootwijk, Holland (Proposed)		10699
	JBD	Keijo, Japan		10700
	——	Kootwijk, Holland		10700
10710	GLKY	SS *Carinthia*, England		10708
	SQAZ	Rio de Janeiro, Brazil		10710
	8XX	Koukaza Park, China		10710
	CF	Drummondville, P. Q.		10710
	CG	Drummondville, P. Q.		10710
	CQ	Drummondville, P. Q.		10710
	LP5	Buenos Aires, Argentine		10714
	FUL	France		10714
	OCAT	Atar, Fr. West Africa		10715
	OCCO	Konakri, Fr. Guinea		10715
10730	——	Kootwijk, Holland		10736
	——	Kootwijk, Holland		10740
10750	WKI	Newark, N. J.	Federal Telegraph Co.	10750
10770	UR	Costa Rica		10770
10790	ISP	Italian Somaliland		10790
10810	KNN	Honolulu, Hawaii	Mackay Radio & Teleg. Co.	10810
	DGT	Nauen, Germany		10810
10850	——	Winnipeg, Man.		10845
	DFL	Nauen, Germany		10850
	AGC	Germany		10850
10870	CA	Halifax, N. S.		10870

Channel	Call Letters	Location of Transmitter	Owner	Frequency
10870	GKQ	Dollis Hill, England		10870
	SQCN	Rio de Janeiro, Brazil		10870
	G5BH	England		10870
10890	KKC	Palo Alto, Calif.	Federal Telegraph Co.	10900
	——	Nauen, Germany		10900
	JYB	Tokyo, Japan		10900
	HI	Calgary, Alta.		10900
10910	KZED	Manila, P. I.		10903
	G5DH	Dollis Hill, England		10903
	VQG	Australia		10910
	ORU	Belgium		10910
10930	KGS	Honolulu, Hawaii	The Robt. Dollar Co.	10930
	KGR	Seattle, Wash.	The Robt. Dollar Co.	10930
	WGA	New York, N. Y.	The Robt. Dollar Co.	10930
	KGX	Los Angeles, Calif.	The Robt. Dollar Co.	10930
	KGQ	San Francisco, Calif.	The Robt. Dollar Co.	10930
	GLQ	Ongar, England		10930
10950	AIN	Morocco		10950
10970	CA	Geizers Hill, N. S.		10980
10990	——	Kootwijk, Holland		10990
	SABI	Goteborg, Sweden (Proposed)		10990
	SPW	Rio de Janeiro, Brazil		10990
11050	KRK	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	11046
	WHD	New York, N. Y.	New York Times Co.	11040
11110	HI	Calgary, Alberta		11100
	AND	Java		11104
	PCMM	Kootwijk, Holland		11104
	SQBD	Recife, Pernambuco, Brazil		11110
	SQBC	Curityba, Parana, Brazil		11110
	SQBB	Porto Alegre, Brazil		11110
	——	Nauen, Germany		11110
	ICJ	Italy		11110
	JYZ	Tokyo, Japan		11110
	RCRL	Russia		11110
11170	RZA	Monrovia, Liberia		11170
	——	Königs Wüsterhausen, Germany		11180
11200	WKA	E. Pittsburgh, Pa.	Westinghouse Elec. & Mfg. Co.	11190
	OJO	Austria		11190
	WSL	Sayville, N. Y.	Mackay Radio & Teleg. Co.	11200
	WFE	(Portable)	Cmdr. Richard E. Byrd	11200
	WFD	(Portable)	Cmdr. Richard E. Byrd	11200
	KFK	(Portable)	Cmdr. Richard E. Byrd	11200
	WFA	(Portable)	Cmdr. Richard E. Byrd	11200
	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	11200
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	11200
	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	11200
	HBC	Berne, Switzerland		11200
11260	——	Germany		11260
11290	GFA	London, England		11280
	UJ	Santa Marta, Colombia		11280
	AGB	München, Schleissheim, Germany		11280
	WFE	(Portable)	Cmdr. Richard E. Byrd	11300
	WFD	(Portable)	Cmdr. Richard E. Byrd	11300
	KFK	(Portable)	Cmdr. Richard E. Byrd	11300
	WFA	(Portable)	Cmdr. Richard E. Byrd	11300
	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	11300
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	11300
	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	11300
11350	DAN	Norddeich, Germany		11340
11350	XOM	China		11365
11410	WKA	E. Pittsburgh, Pa.	Westinghouse Elec. & Mfg. Co.	11400
	WDJ	Harrison, Ohio	Crosley Radio Corp.	11400
	AFI	Königs Wüsterhausen, Germany		11410
	CG	Drummondville, P. Q.		11413
	GLY	Dorchester, England		11420
	——	Dorchester, England		11425
11440	ANC	Java		11440
	CF	Drummondville, P. Q.		11452
	——	Königs Wüsterhausen, Germany		11460
11500	——	New Zealand		11490
	GBK	Bodmin, England		11495
	——	Königs Wüsterhausen, Germany		11500

Channel	*Call Letters*	*Location of Transmitter*	*Owner*	*Frequency*
11530	CF	Drummondville, P. Q.		11531
	UF	Darrios, Guatemala	Tropical Radio Teleg. Co.	11540
	UB	Almirante, Panama		11540
	VIS	Sydney, Australia		11540
11560	VMG	Samoa		11560
	GBH	Grimsby, England		11575
11590	GBH	Grimsby, England		11580
	DIR	Königs Wüsterhausen, Germany		11580
11620	——	Königs Wüsterhausen, Germany		11620
	DFK	Nauen, Germany		11620
	FUT	Toulon, France		11621
	UB	Almirante, Panama		11630
11650	VIZ	Melbourne, Australia		11655
11680	VIZ	Ballan, Australian Commonwealth		11670
	KIO	Kahuku, Hawaii	Radio Corp. of America	11680
11710	——	Argentine		11720
	CJRX	Winnipeg, Manitoba		11720
11770	JYZ	Tokyo, Japan		11758
	GLKY	SS *Carinthia*, England		11758
	AGC	Nauen, Germany		11758
	AGC	München, Schleissheim, Germany		11760
	UL	Managua, Nicaragua		11780
11800	——	Königs Wüsterhausen, Germany		11800
	——	Vienna, Austria		11801
	OCTN	Toulon, France		11804
11830	——	Nauen, Germany		11840
11890	UL	Managua, Nicaragua		11880
	——	Königs Wüsterhausen		11900
11920	DGS	Nauen, Germany		11920
	ANC	Java		11920
11950	——	Spain		11940
	KKQ	Bolinas, Calif.	Radio Corp. of America	11950
11980	GBO	Leafield, England		11980
	LP	Buenos Aires, Argentine		11980
	FS1	Sainte Assise, France		11985
	CF	Drummondville, P. Q.		11990
	CG	Drummondville, P. Q.		11990
	CJ	Drummondville, P. Q.		11990
	CF	Drummondville, P. Q.		11992
	HZA	Saigon, French Indo-China		11993
	OCLY	Bordeaux, France		11993
12010	UR	San Jose, Costa Rica		12000
	JYZ	Tokyo, Japan		12000
	OCLY	Croix d'Hins, France		12000
	B82	Belgium		12000
	——	Quebec, Can.		12000
	——	Denmark		12000
	RZA	Monrovia, Liberia		12000
	VIY	Australia		12020
	VIY	Ballan, Australian Commonwealth		12025
12040	——		U. S. Government	12045
	FUT	France		12045
	——		U. S. Government	12051
12070	——		U. S. Government	12060
	——	Cuba		12070
	——		U. S. Government	12075
	FW	France		12085
12100	——		U. S. Government	12090
	ANC	Java		12090
	CJ	Drummondville, P. Q.		12093
	——	Recife, Pernambuco, Brazil (Proposed)		12094
	UR	Cartago, Costa Rica	Tropical Radio Teleg. Co.	12100
	——	Horomushiro, Japan (Proposed)		12100
	——	Quebec, Can.		12102
12130	——		U. S. Government	12135
	——	Manila, P. I.		12145
12160	——		U. S. Government	12150
	GBS	Rugby, England		12150
	FWX	Sainte Assise, France		12160
	——		U. S. Government	12165
12190	——		U. S. Government	12180
	FW	Sainte Assise, France		12188
	——		U. S. Government	12195
	JPM	Palaos, Japan		12200
12220	——		U. S. Government	12210
	——		U. S. Government	12225

Channel	Call Letters	Location of Transmitter	Owner	Frequency
12250	GLQ	Ongar, England		12240
	——		U. S. Government	12240
	——	Taihoku, Japan (Proposed)		12250
	——		U. S. Government	12255
12250	——	Dorchester, England		12265
12280	——	Spain		12270
	GBU	Rugby, England		12290
12310	JES	Osaka, Japan		12300
	JAN	Tokyo, Japan		12300
	——		U. S. Government	12315
12340	KFD	Denver, Colo.	General Elec. Co.	12338
	——	England		12350
12400	UJ	Santa Marta, Columbia	Tropical Radio Teleg. Co.	12400
	JRW	Parao, Japan		12400
	PKK	Dutch East Indies		12400
	——		U. S. Government	12405
12460	——		U. S. Government	12465
12490	GBM	Oxford, England		12492
	——	Oxford, England		12500
	JES	Osaka, Japan		12500
	——	Goteborg, Sweden (Proposed)		12500
	KCE	Liepaja, Latvia		12500
	9BE	Toronto, Ont.		12500
	5SW	Chelmsford, Can.		12500
	IRI	Rome, Italy		12500
	JEW	Japan		12500
	G5SW	England		12500
12520	——	Ontario, Can.		12511
	——	Quebec, Can.		12511
12610	——		U. S. Government	12615
12700	KHAH	Airplane *Greater Rockford*	Bert Hassell	12700
	——	Choshi, Japan (Proposed)		12700
	OLQ	Holland		12704
	——		U. S. Government	12705
12760	KTA	Guam, Mariana Island	Mackay Radio & Teleg. Co.	12758
	——		U. S. Government	12765
	PCH	Scheveningen, Holland		12766
12790	——		U. S. Government	12795
	JBD	Japan		12800
12820	JBD	Keijo, Japan		12825
	VCJ	Wakeham Bay, Ont.		12825
	VCJ	Ottawa, Ont.		12825
	CGP	Term Point, N. W. T.		12825
12850	3XK	Washington, D. C.	Jenkins Labs.	12840
	——		U. S. Government	12840
	1XAC	Providence, R. I.	C. E. Mfg. Co.	12850
12880	LAD	Norway		12880
	——		U. S. Government	12885
12910	——		U. S. Government	12900
	JFAB	Giran, Japan		12900
	——	France		12900
12940	WAX	Hileah, Fla.	Tropical Radio Teleg. Co.	12940
	WNN	Mobile, Ala.	Tropical Radio Teleg. Co.	12940
	UOX	Vienna, Austria		12931
12970	WNU	New Orleans, La.	Tropical Radio Teleg. Co.	12970
	WBF	Boston, Mass.	Tropical Radio Teleg. Co.	12970
13000	KNW	Palo Alto, Calif.	Mackay Radio Teleg. Co.	13000
13030	KNN	Honolulu, Hawaii	Mackay Radio Teleg. Co.	13030
	HZG	Numea, France		13043
	RAU	Moscow, Russia		13045
	RLT	Russia		13045
	PKH	Java		13045
	XON	China		13045
13090	——		U. S. Government	13095
13120	——		U. S. Government	13110
	——		U. S. Government	13125
13150	——		U. S. Government	13140
	——		U. S. Government	13155
	PCH	Scheveningen, Holland		13160
13180	DGG	Nauen, Germany		13180
	WFE	(Portable)	Cmdr. Richard E. Byrd	13187
	WFD	(Portable)	Cmdr. Richard E. Byrd	13187
	WFA	(Portable)	Cmdr. Richard E. Byrd	13187
	KFK	(Portable)	Cmdr. Richard E. Byrd	13187
	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	13187
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	13187
	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	13187

Channel	Call Letters	Location of Transmitter	Owner	Frequency
13210	UR	Cartago, Costa Rica	Tropical Radio Teleg. Co.	13220
13270	FY	Syria		13270
13300	——		U. S. Government	13290
	——		U. S. Government	13305
	——		U. S. Government	13308
13330	——		U. S. Government	13320
	——		U. S. Government	13335
	FW	France		13330
	IRI	Rome, Italy		13345
13360	——	Manila, P. I.		13360
	OCDA	Dakar Senegal, French W. Africa		13350
	DGI	Nauen, Germany		13360
13390	WND	Ocean Township, N. J.	American Tel. & Tel. Co.	13390
	——	Nauen, Germany		13400
13420	WHR	Rocky Point, N. Y.	Radio Corp. of America	13420
13450	WEX	Rocky Point, N. Y.	Radio Corp. of America	13450
	HJO	Bogota, Colombia		13450
	UJ	Santa Marta, Colombia	Tropical Radio Teleg. Co.	13460
13480	WAJ	Rocky Point, N. Y.	Radio Corp. of America	13480
13510	GFV	Baghdad, Iraq		13500
	GFJ	Kidbrooke, England		13500
	RKU	Turkestan		13510
	VAJ	Digby Island, B. C.		13520
	SPR	Rio de Janeiro, Brazil		13525
13540	GLH	Dorchester, England		13535
	DFC	Nauen, Germany		13540
	——	Dorchester, England		13540
13570	——		U. S. Government	13575
	GLH	England		13580
13600	6XN	Oakland, Calif.	General Elec. Co.	13603
13630	GKS	Dollis Hill, England		13630
	HJG	Bogota, Colombia		13630
	GKT	Burnham, England		13640
	VIT	Australia		13640
	VIS	Sydney, Australia		13640
	VJZ	Raboul, New Guinea		13640
	8XX	Koukaza Park, China		13640
	RABL	Russia		13640
	RTRL	Russia		13640
	RAU	Russia		13640
	UC	Tela, Spanish Honduras		13640
	UA	Porto Castilla, Sp. Honduras		13640
	KGBB	SS *Sachem*	R. B. Metcalf	13640
	KTA	Guam, Mariana Island	Mackay Radio & Teleg. Co.	13640
13660	GLL	London, England		13660
13690	KKZ	Bolinas, Calif.	Radio Corp. of America	13690
	VAK	Gonzales Hill, B. C.		13700
13720	KLL	Bolinas, Calif.	Radio Corp. of America	13720
	KEB	Oakland, Calif.	General Elec. Co.	13720
	——	Rio de Janeiro, Brazil (Proposed)		13720
13750	6XU	Bolinas, Calif.	Radio Corp. of America	13750
	KTA	Guam, Mariana Island	Mackay Radio & Teleg. Co.	13753
	KEB	Oakland, Calif.	General Elec. Co.	13760
13780	WGT	San Juan, P. R.	Radio Corp. of America	13780
13810	DIQ	Königs Wüsterhausen, Germany		13800
	VAI	Point Gray, B. C.		13800
	SUZ	Abu Zabal, Egypt (Proposed)		13820
13840	WPE	Rocky Point, N. Y.	Radio Corp. of America	13840
13870	2XAS	Rocky Point, N. Y.	Radio Corp. of America	13870
	WIY	Rocky Point, N. Y.	Radio Corp. of America	13870
	KTF	Midway Island	Mackay Radio & Teleg. Co.	13880
13900	WOP	Rocky Point, N. Y.	Radio Corp. of America	13900
	GFV	Baghdad, Iraq		13900
	GFN	Kidbrooke, England		13900
13930	WIK	Rocky Point, N. Y.	Radio Corp. of America	13930
	HK	Winnipeg, Manitoba		13920
	HL	Montreal, P. Q.		13920
13960	——	Oxford, England		13950
	GBO	Leafield, England		13960
13990	WDJ.	Harrison, Ohio	Crosley Radio Corp.	13990
	JOC	Ochufhi, Japan		14000
14020	GBR	Rugby, England		14020
14080	ANK	Java		14080
14200	——	Scheveningen, Holland		14200
14230	IDK	Italy		14220
14290	GLKY	SS *Carinthia*, England		14277
	UF	Barrios, Guatemala	Tropical Radio Teleg. Co.	14290

Channel	Call Letters	Location of Transmitter	Owner	Frequency
14290	UG	Tegucigalpa, Spanish Honduras	Tropical Radio Teleg. Co.	14290
	VIA	Australia		14290
	VIB	Australia		14290
	VIT	Australia		14290
	VIS	Australia		14290
	VJZ	Australia		14290
	RKV	Russia		14290
	——	Dollis Hill, England		14290
14320	PKH	Soerabaja, Java		14311
14350	PKH	Java		14350
14410	——	Nauen, Germany		14400
14440	DIP	Königs Wüsterhausen, Germany		14437
	GBW	Rugby, England		14440
14470	WNC	Ocean Township, N. J.	American Tel. & Tel. Co.	14470
	——	Spain		14480
14500	PCLL	Kootwijk, Holland		14500
	——	Kootwijk, Holland		14500
	——	Scheveningen, Holland		14500
14560	UJ	Santa Marta, Colombia	Tropical Radio Teleg. Co.	14560
	——	Kootwijk, Holland		14560
	——	Scheveningen, Holland		14560
14590	WMI	Deal, N. J.	American Tel. & Tel. Co.	14590
	UQ	Bluefields, Nic.		14600
14620	——	Spain		14620
	PCRR	Sgravenhage, Holland		14625
	——	Japan		14630
	ANF	Java		14630
14680	——	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	14680
	DFD	Nauen, Germany		14680
14710	UW	Cape Gracias, Nic.		14700
	9OB	Ottawa, Ont.		14700
	——	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	14710
14740	——	Sayville, N. Y.	Mackay Radio & Teleg. Co.	14740
14770	GLSQ	SS *Olympic*, England		14769
	——	Sayville, N. Y.	Mackay Radio & Teleg. Co.	14770
14800	——	Nicaragua (Emergency)		14800
	WQV	Rocky Point, N. Y.	Radio Corp. of America	14800
14830	WKU	Rocky Point, N. Y.	Radio Corp. of America	14830
14860	WGA	New York, N. Y.	The Robt. Dollar Co.	14860
	KGS	Honolulu, Hawaii	The Robt. Dollar Co.	14860
	KGX	Los Angeles, Calif.	The Robt. Dollar Co.	14860
	KGR	Seattle, Wash.	The Robt. Dollar Co.	14860
	KGQ	San Francisco, Calif.	The Robt. Dollar Co.	14860
14890	1XS	Newton, Mass.	R. A. Fessenden	14890
	WGA	New York, N. Y.	The Robt. Dollar Co.	14890
	KGS	Honolulu, Hawaii	The Robt. Dollar Co.	14890
	KGX	Los Angeles, Calif.	The Robt. Dollar Co.	14890
	KGR	Seattle, Wash.	The Robt. Dollar Co.	14890
	KGQ	San Francisco, Calif.	The Robt. Dollar Co.	14890
	UL	Managua, Nic.		14900
14920	WAZ	New Brunswick, N. J.	Radia Corp. of America	14920
	PJN	Dutch Guinea		14920
14980	KGDQ	SS *Faith*, U. S. A.	Walden W. Shaw	14991
15010	1XS	Newton, Mass.	Howard A. Fessenden	15000
	C3BD	Santiago, Chile		15000
	C2BF	Vina del Mar, Chile		15000
	C3AC	Santiago, Chile		15000
	——	Kootwijk, Holland		15000
	——	Scheveningen, Holland		15000
	UF	Barrios, Guatemala		15000
	——	Taihoku, Japan (Proposed)		15000
	——	Norway (Proposed)		15000
	JBR	Siberia Maru, Japan		15000
	CF	Drummondville, P.Q.		15000
	CG	Drummondville, P. Q.		15000
	CJ	Drummondville, P. Q.		15000
	VIS	Australia		15000
	XGA	China		15000
	CH	Chile		15000
	GFR	England		15000
	JIPP	Japan		15000
	OCTN	Tunis, Tunisia		15000
	PJC	Curacao, Dutch W. Indies		15000
	RDRL	Russia		15000
	TUK	Russia		15000
15040	WQG	Rocky Point, N. Y.	Radio Corp. of America	15040
15070	DIO	Königs Wüsterhausen, Germany		15075
15100	2XBW	[1]Bound Brook, N. J.	Radio Corp. of America	15100

[1] The frequencies between 15100 and 15200 kc have, in this case, been assigned as one band

Channel	Call Letters	Location of Transmitter	Owner	Frequency
15130	2XBW	[1]Bound Brook, N. J.	Radio Corp. of America	15130
15160	2XBW	[1]Bound Brook, N. J.	Radio Corp. of America	15160
15190	2XBW	[1]Bound Brook, N. J.	Radio Corp. of America	15190
	2XBW	[1]Bound Brook, N. J.	Radio Corp. of America	15200
15220	PCJJ	Eindhoven, Holland		15220
	——	Nauen, Germany		15220
15370	UR	Cartago, Costa Rica	Tropical Radio Teleg. Co.	15380
15430	KWE	Bolinas, Calif.	Radio Corp. of America	15430
15460	KKR	Bolinas, Calif.	Radio Corp. of America	15460
	WBF	Boston, Mass.	Tropical Radio Teleg. Co.	15460
15490	KEM	Bolinas, Calif.	Radio Corp. of America	15490
15520	VLW	New Zealand		15520
	AMF	Malabar, Java		15535
15550	UL	Managua, Nic.	Tropical Radio Teleg. Co.	15540
	UL	Managua, Nic.	Tropical Radio Teleg. Co.	15550
15580	——	Garden City, N. Y.	American Publishers Comm.	15580
	DFR	Nauen, Germany		15580
15610	——	Nauen, Germany		15600
	——	New York, N. Y.	American Publishers Comm.	15610
15640	——	Chicago, Ill.	American Publishers Comm.	15640
15670	——	New York, N. Y.	American Publishers Comm.	15670
15700	——	Floral Park, N. Y.	American Publishers Comm.	15700
	——	Argentine		15710
15730	——	San Francisco, Calif.	American Publishers Comm.	15730
15760	——	Boston, Mass.	American Publishers Comm.	15760
15790	FW	France		15780
	——	Taihoku, Japan (Proposed)		15800
	——	Nauen, Germany		15800
15820	DFN	Nauen, Germany		15820
15850	——	New York, N. Y.	American Publishers Comm.	15850
15880	——	Los Angeles, Calif.	American Publishers Comm.	15880
	BYB	Cleethorpes, England		15880
15910	——	Chicago, Ill.	American Publishers Comm.	15910
15940	DGI	Nauen, Germany		15940
	AND	Java		15950
15970	——	Nauen, Germany		15960
	WKO	Rocky Point, N. Y.	Radio Corp. of America	15970
16000	WKQ	Rocky Point, N. Y.	Radio Corp. of America	16000
16030	WKW	Rocky Point, N. Y.	Radio Corp. of America	16030
16060	——		U. S. Governemnt	16060
	——		U. S. Government	16068
16090	——		U. S. Government	16080
	——		U. S. Government	16100
	TQS	Lisbon, Portugal		16100
	KEB	Oakland, Calif.	General Elec. Co.	16102
16120	KEB	Oakland, Calif.	General Elec. Co.	16112
	——		U. S. Government	16120
16150	AYA	Venezuela		16140
16180	——		U. S. Government	16180
	——	Java		16180
16210	AGC	Nauen, Germany		16206
16270	WLO	Ocean Township, N. J.	American Tel. & Tel. Co.	16270
16300	——	Kootwijk, Holland		16300
	——	Kootwijk, Holland		16304
16330	——		U. S. Government	16320
	——		U. S. Government	16340
	——	Laonda, Angola		16340
	CRHA	Portuguese W. Africa		16340
16360	DIN	Königs Wüsterhausen, Germany		16358
16390	——	Manila, P. I.		16380
16420	——		U. S. Government	16420
	PQS	Lisbon, Portugal		16420
	PQS	Afragide, Portugal		16420
16460	WHD	New York, N. Y.	New York Times Co.	16460
	PJD	St. Martins		16460
	——	Goteborg, Sweden (Proposed)		16480
16500	CHRB	Cape Verde Island		16500
	CHRC	Angola		16500
16540	——		U. S. Government	16540
16580	CHRB	CapeVerde Island		16580
	CRHA	Portugese East Africa		16580
16620	——		U. S. Government	16620
16660	KTA	Guam, Mariana Island	Mackay Radio & Teleg. Co.	16660
	B2	Belgium		16660

Channel	Call Letters	Location of Transmitter	Owner	Frequency
16660	9CH	Geizers Hill, N. S.		16660
	DAN	Norddeich, Germany		16665
	—	Kootwijk, Holland		16670
	—	Nova Scotia		16670
	—	Riga, Latvia		16670
16780	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	16800
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	16800
	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	16800
	WFA	(Portable)	Cmdr. Richard E. Byrd	16800
	WFD	(Portable)	Cmdr. Richard E. Byrd	16800
	WFE	(Portable)	Cmdr. Richard E. Byrd	16800
	KFX	(Portable)	Cmdr. Richard E. Byrd	16800
	WSL	Sayville, N. Y.	Mackay Radio & Teleg. Co.	16800
	RZA	Liberia		16800
16820	—		U. S. Government	16820
	SP	Brazil		16820
16860	WSL	Sayville, N. Y.	Mackay Radio & Teleg. Co.	16850
	GKT	Burnham, England		16845
	IDM	Italy		16850
16900	PJC	Curacao, Dutch West Indies		16900
	ORU	Belgium		16920
16940	KFD	Denver, Colo.	General Elec. Co.	16939
	—		U. S. Government	16940
16980	LR2	Italy		17000
17020	—		U. S. Government	17020
17060	—		U. S. Government	17060
17140	WKI	Newark, N. J.	Federal Telegraph Co.	17130
	—	Oxford, England		17140
	XGA	Mukden, China		17140
17180	—		U. S. Government	17180
	—		U. S. Government	17200
	PJD	St. Martins, D. W. I.		17200
17220	ANE	Java		17240
	GBO	Leafield, England		17240
17260	LPV	Monte Grande, Argentine		17241
	9XB	Culver, Ind.	L. E. Dutton	17270
17300	2XBY	Jersey City, N. J.	Walter C. Von Brandt	17300
	3XE	Baltimore, Md.	Baltimore Radio Show, Inc.	17300
	6XT	San Francisco, Calif.	C. L. Watson & R. L. Gray	17300
	1XAC	Providence, R. I.	C. E. Mfg. Co.	17300
	6XD	(Portable)	D. B. McGown	17300
17340	—	Nauen, Germany		17340
	DIM	Königs Wüsterhausen, Germany		17341
17380	LPI	Argentine		17380
17420	KNN	Honolulu, Hawaii	Mackay Radio & Teleg. Co.	17420
17460	—		U. S. Government	17460
	DGR	Nauen, Germany		17460
	—		U. S. Government	17480
	—	Königs Wüsterhausen, Germany		17480
17500	—		U. S. Government	17500
	AYF	Venezuela		17500
17540	—		U. S. Government	17540
	DFB	Nauen, Germany		17540
	VDB	Esquimalt, Canada		17560
17580	WBF	Boston, Mass.	Tropical Radio & Teleg. Co.	17580
17620	ANH	Malabar		17620
	KFVM	SS *Idalia*, USA	E. R. Parker	17636
	KKC	Palo Alto, Calif.	Federal Teleg. Co.	17640
17660	VJZ	New Guiana		17650
	G2BR	England		17650
	BQ	Machelen les Belgium		17650
	KNW	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	17660
17700	WFE	(Portable)	Cmdr. Richard E. Byrd	17717
	WFD	(Portable)	Cmdr. Richard E. Byrd	17717
	WFA	(Portable)	Cmdr. Richard E. Byrd	17717
	KFK	(Portable)	Cmdr. Richard E. Byrd	17717
	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	17717
	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	17717
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	17717
	—		U. S. Government	17720
17740	—		U. S. Government	17740
	—		U. S. Government	17744
17780	—	Kootwijk, Holland		17773
17820	PCRR	Kootwijk, Holland		17836
	—	Königs Wüsterhausen, Germany		17840
	—	Kootwijk, Holland		17840
17860	DIL	Königs Wüsterhausen, Germany		17850

Channel	Call Letters	Location of Transmitter	Owner	Frequency
17860	WQC	Rocky Point, N. Y.	Radio Corp. of America	17860
17900	WLL	Rocky Point, N. Y.	Radio Corp. of America	17900
	2XAS	Rocky Point, N. Y.	Radio Corp. of America	17900
17940	WQB	Rocky Point, N. Y.	Radio Corp. of America	17940
17980	CF	Drummondville, P. Q.		17964
	CG	Drummondville, P. Q.		17964
	CJ	Drummondville, P. Q.		17964
	KQZ	Bolinas, Calif.	Radio Corp. of America	17980
18020	KQJ	Bolinas, Calif.	Radio Corp. of America	18020
	——	Spain		18040
18060	KUN	Bolinas, Calif.	Radio Corp. of America	18060
18100	GBK	Bodmin, England		18100
	——		U. S. Government	18100
18140	——	Recife, Pernambuco, Brazil (Proposed)		18140
	GBW	Rugby, England		18140
	——	Spain		18150
18180	CG	Drummondville, P. Q.		18169
18220	——	Nauen, Germany		18240
18260	KNW	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	18260
	PCRR	Holland		18260
18300	PCRR	Sgravenhage, Holland		18282
	6XN	Oakland, Calif.	General Elec. Co.	18290
	GBS	Rugby, England		18310
18340	WND	Ocean Township, N. J.	American Tel. & Tel. Co.	18340
18380	——	Kootwijk, Holland		18400
18420	——	Kootwijk, Holland		18405
	VWZ	India		18420
18500	GBI	Grimsby, England		18500
18540	2XT	Rocky Point, N. Y.	Radio Corp. of America	18540
18580	GBJ	Bodmin, England		18580
	JAN	Tokyo, Japan		18600
18620	GBU	Rugby, England		18620
18660	VNB	South Africa		18660
18700	XGA	China		18700
18740	——	Kootwijk, Holland		18740
	JYZ	Tokyo, Japan		18750
	RZA	Monrovia, Liberia		18750
18780	CFH	Halifax, Nova Scotia		18790
	CFH	Halifax, Nova Scotia		18800
	——	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	18780
18820	KGX	Los Angeles, Calif.	The Robt. Dollar Co.	18820
	KGR	Seattle, Wash.	The Robt. Dollar Co.	18820
	KGS	Honolulu, Hawaii	The Robt. Dollar Co.	18820
	KGQ	San Francisco, Calif.	The Robt. Dollar Co.	18820
	WGA	New York, N. Y.	The Robt. Dollar Co.	18820
18860	WKM	Rocky Point, N. Y.	Radio Corp. of America	18860
	——	Nauen, Germany		18880
	——	Königs Wüsterhausen, Germany		18880
18900	WDS	Rocky Point, N. Y.	Radio Corp. of America	18900
	DIK	Königs Wüsterhausen, Germany		18916
18940	WTT	Rocky Point, N. Y.	Radio Corp. of America	18940
	——	Germany		18940
18980	WFX	Rocky Point, N. Y.	Radio Corp. of America	18980
	——	London, England		18980
19020	KQJ	Kahuku, Hawaii	Radio Corp. of America	19020
	——	Spain		19030
19060	GLS	Ongar, England		19050
	GLG	Dorchester, England		19060
19100	PQW	Lisbon, Portugal		19097
	PQS	Lisbon, Portugal		19097
	GLW	Dorchester, England		19100
19140	PQW	Lisbon, Portugal		19140
	——	Spain		19140
19180	PQW	Lisbon, Portugal		19180
	——	Königs Wüsterhausen, Germany		19180
19220	WNC	Ocean Township, N. J.	American Tel. & Tel. Co.	19220
	SPU	Rio de Janeiro, Brazil		19220
19260	SPU	Rio de Janeiro, Brazil		19269
19300	——	Nauen, Germany		19300
	APV	Dutch East Indies		19320
19340	B82	Buccle, Belgium		19360
19380	LP4	Monte Grande, Argentine		19390
	——	Königs Wüsterhausen, Germany		19400
19420	FW3	France		19420
19460	FW3	Sainte Assise, France		19443
	DIJ	Königs Wüsterhausen, Germany		19443
	DFM	Nauen, Germany		19460

Channel	Call Letters	Location of Transmitter	Owner	Frequency
19500	LP3	Buenos Aires, Argentine		19500
19540	DFQ	Nauen, Germany		19540
	——	Palo Alto, Calif.	Mackay Radio & Teleg. Co.	19540
19580	——	Sayville, N. Y.	Mackay Radio & Teleg. Co.	19580
	LP3	Monte Grande, Argentine		19600
19620	——	Sayville, N. Y.	Mackay Radio & Teleg. Co.	19620
	——		Radio Corp. of America	19620
	DFA	Nauen, Germany		19620
	GBO	Leafield, England		19628
19660	B82	Brussels, Belgium		19670
	——	Nauen, Germany		19680
19700	——		Radio Corp. of America	19700
	DFJ	Nauen, Germany		19700
19780	WTF	Akron, Ohio	Firestone Plantations Co.	19780
	WMU	Elizabeth, N. J.	Stan. Oil Co. of New Jersey	19780
	——		Radio Corp. of America	19780
	DGA	Nauen, Germany		19780
19820	WMI	Deal, N. J.	American Tel. & Tel. Co.	19820
19860	KZEN	Manila, P. I.	Radio Corp. of America	19860
	——	Nauen, Germany		19860
	2XV	Long Island City, N. Y.	Radio Engineering Labs.	19867
19900	LP4	Buenos Aires, Argentine		19900
19940	GLS	Ongar, England		19940
	DIH	Königs Wüsterhausen, Germany		19947
19980	CF	Drummondville, P. Q.		19987
	1XR	Manila, P. I.	Radio Corp. of America	19988
	GLS	Ongar, England		20000
	GKS	Dollis Hill, England		20000
	IR2	Rome, Italy		20000
	LCM	Stavanger, Norway (Proposed)		20000
	——	Glace Bay, Nova Scotia		20000
	——	Drummondville, P. Q.		20000
20020	AGA	Nauen, Germany		20020
	DFI	Nauen, Germany		20020
20060	AGA	Nauen, Germany		20055
	AGA	München Schleissheim, Germany		20070
	——	Nauen, Germany		20080
20100	——		U. S. Government	20085
	WQY	Rocky Point, N. Y.	Radio Corp. of America	20100
20140	——		U. S. Government	20125
	——	Nauen, Germany		20140
	——		U. S. Government	20150
20180	WQX	Rocky Point, N. Y.	Radio Corp. of America	20180
	——	Königs Wüsterhausen, Germany		20180
20220	——		U. S. Government	20225
	DIG	Königs Wüsterhausen, Germany		20230
20260	WQQ	Rocky Point, N. Y.	Radio Corp. of America	20260
20300	——	Sayville, N. Y.	Mackay Radio & Teleg. Co.	20300
20300	DIF	Königs Wüsterhausen, Germany		20312
20340	BYC	Horsea, England		20330
20380	——		U. S. Government	20400
	——	Nauen, Germany		20400
20420	DGB	Nauen, Germany		20420
20500	DGQ	Nauen, Germany		20500
	IR2	Italy		20500
20580	——	Rio de Janeiro, Brazil (Proposed)		20580
20620	6XU	Bolinas, Calif.	Radio Corp. of America	20620
20660	DGO	Nauen, Germany		20660
	LP2	Monte Grande, Argentine		20670
20700	FW	France		20700
20740	——	Königs Wüsterhausen, Germany		20730
	DGP	Nauen, Germany		20740
20780	KMM	Bolinas, Calif.	Radio Corp. of America	20780
20820	KSS	Bolinas, Calif.	Radio Corp. of America	20820
20860	——	Königs Wüsterhausen, Germany		20860
20900	BXC	Nore, England		20900
	LP3	Buenos Aires, Argentine		20900
20940	——	Nauen, Germany		20960
20980	FW	Sainte Assise, France		20966
	FW	Sainte Assise, France		20980
	——	Sayville, N. Y.	Mackay Radio & Teleg. Co.	20980
21060	WND	Ocean Township, N. J.	American Tel. & Tel. Co.	21060
21100	——	Königs Wüsterhausen, Germany		21100
21140	KZRC	Manila, P. I.	Radio Corp. of America	21140
21180	DGM	Nauen, Germany		21180
21220	WQA	Rocky Point, N. Y.	Radio Corp. of America	21220
21260	——	Königs Wüsterhausen, Germany		21260

Channel	Call Letters	Location of Transmitter	Owner	Frequency
21300	WQW	Rocky Point, N. Y.	Radio Corp. of America	21300
21340	DGM	Nauen, Germany		21340
21380	——	Sayville, N. Y.	Mackay Radio & Teleg. Co.	21380
	WBU	Rocky Point, N. Y.	Radio Corp. of America	21380
21420	WLO	Ocean Township, N. J.	American Tel. & Tel. Co.	21420
21740	——	Buenos Aires, Argentine		21740
21820	WFB	Airplane *Floyd Bennett*	Cmdr. Richard E. Byrd	21805
	WFF	Airplane *Fokker*	Cmdr. Richard E. Byrd	21805
	WFC	Airplane *Fairchild*	Cmdr. Richard E. Byrd	21805
	WFE	(Portable)	Cmdr. Richard E. Byrd	21805
	WFD	(Portable)	Cmdr. Richard E. Byrd	21805
	WFA	(Portable)	Cmdr. Richard E. Byrd	21805
	KFK	(Portable)	Cmdr. Richard E. Byrd	21805
22040	9CH	Geizers Hill, Nova Scotia		22050
22520	DGE	Nauen, Germany		22520
22580	DGF	Nauen, Germany		22600
22640	——		U. S. Government	22625
	KGQ	San Francisco, Calif.	The Robt. Dollar Co.	22660
	KGX	Los Angeles, Calif.	The Robt. Dollar Co.	22660
	WGA	New York, N. Y.	The Robt. Dollar Co.	22660
	KGS	Honolulu, Hawaii	The Robt. Dollar Co.	22660
	KGR	Seattle, Wash.	The Robt. Dollar Co.	22660
22800	WKA	East Pittsburgh, Pa.	Westinghouse Elec. & Mfg. Co.	22800
23780	LPZ	Monte Grande, Argentine		23809
25700	1XAC	Providence, R. I.	C. E. Mfg. Co.	25680
	3XK	Washington, D. C.	Jenkins Laboratories	25680
27260	GKS	Dollis Hill, England		27270
	G5DH	Dollis Hill, England		27270
27620	DID	Konigs Wusterhausen, Germany		27600
28580	XQM	Yunnanfu, China		28570
28880	DIC	Königs Wüsterhausen, Germany		28874
32240	2XBY	Jersey City, N. J.	Walter C. Von Brandt	34240
	3XE	Baltimore, Md.	The Balto. Radio Show Inc.	34240
	6XT	San Francisco, Calif.	C. L. Watson & R. C. Gray	34240
	1XAC	Providence, R. I.	C. E. Mfg. Co.	34240
	6XD	(Portable)	D. B. McGown	34240
51360	3XK	Washington, D. C.	Jenkins Laboratories	51360
	1XAC	Providence, R. I.	C. E. Mfg. Co.	51360

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 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.

R000. Radio Communication

R060 Dellinger, J. H. The International Union of Scientific Radio Telegraphy. Proc. I.R.E., **16**, pp. 1107–12; Aug., 1928.

(Organization of U.R.S.I. and report of meeting of October 10–28, 1927.)

R100. Radio Principles

R110 Bramley, Arthur. Kerr effect in water due to high frequency radio waves. *Jnl.* Frank. Inst., **206**, pp. 151–158; Aug., 1928.

(Description of an experiment for finding the absorption lines of radio waves (3 to 300 cm) in water. A Kerr tube filled with water and placed between two nicol prisms and a quarter wave plate is used for the work.)

R113.4 Jouaust, R. Les Phenomenes de propagation des ondes radiotelegraphiques. (The propagation phenomena of radio waves.) *Comptes Rendus*, **187**, pp. 208–209; July 23, 1928.

(Calls attention to the fact that the propagation theory is based on a certain law for which the ionic density in the upper atmosphere is taken as a regular function of the altitude. The electrified particles given off from the sun are, however, a discontinuous emission similar to the Schottky effect in tubes.)

R113.7 Kenrick, G. W. Radio transmission formulae. *Phil. Mag.*, **6**, pp. 289–304; Aug., 1928.

(Derives a transmission formula for long-wave work taking the upper reflecting layer into account. The results indicate that the inverse square root of the wavelength in the damping factor of the Austin-Cohen formula has considerable theoretical justification, but the inverse square root of the distance should be used instead of the inverse first power of the distance. A slight change in the numerical constant is needed.)

R116 Frank, N. H. Die Fortplanzung elektrischer Wellen in Kabeln mit zwei Isolationsschichten. (The propagation of electric waves in cables with two insulating layers.) *Ann. d. Physik.*, **86**, pp. 422—34; June, 1928.

* Original Manuscript Received by the Institute, September 14, 1928.

(The velocity of propagation of electric waves along cables with two insulating layers is computed according to Maxwell's theory. A new method is given for measuring the velocity along wires by means of using Lichtenberg-Figures. This gives a means for also determining the dielectric constant.

R116 Nancarrow, F. E. The behavior of a transmission line at radio frequencies. *Post Office Elec. Engrs. Jnl.*, **21**, pp. 165–69; July, 1928.

(Deals with the solution of the propagation of radio-frequency currents along a transmission line. Curves for the surge impedance for different spacings and size of wire are given.)

R125.1 Smith-Rose, R. L. Radio direction finder—the theory of the frame aerial avoiding electrostatic pickup. *Wireless World and Radio Review*, **23**, p. 186; August 15, 1928.

(Discussion of antenna effect and method of screening for its elimination using open loops.)

R127 Brunn, H. Eine einfache Methode zur Messung der Eigenwellenlänge von Antennen. (A simple method for the measurement of the natural wavelength of an antenna.) *Zeits. f. Hochfreq.*, **32**, p. 25; July, 1928.

(A tube wavemeter is loosely coupled to an antenna and the grid dip used for the determination of the natural wavelength.)

R130 Le Boiteux, H. L'influence des émissions secondaires des métaux sur le fonctionnement des lampes à trois électrodes. (Effect on the secondary emission of metals on the behavior of 3-electrode tubes.) Revue Gen. de L'Electricité, **28**, pp. 939–46 and 984–992; June 2, 1928.

(This paper gives a theoretical investigation of the working characteristics of circuits using three-element tubes. The effect of secondary emission is taken into account.)

R130 Podlinsky, M. Equilibres instables et régimes statiques parasites dans les circuits électriques associés aux triodes. (Unstable equilibrium and disturbing conditions in triode circuits.) *L'Onde Electrique*, **7**, pp. 278–306; July, 1928.

(Theoretical treatment of the dynatron action in triode circuits.)

R130 Ballantine, Stuart. Schrot-Effect in high-frequency circuits. *Jnl.* Frank. Inst., **206**, pp. 159–168; Aug., 1928.

(A further theoretical study of the Schrot effect.)

R132.3 Hartshorn, L. Inter-electrode capacities and resistance amplification. *Experimental Wireless and Wireless Engineer*, **59**, pp. 419–430; Aug., 1928.

(A study of resistance capacity coupled amplifiers with respect to distortion and interelectrode capacities and resistance.)

R133 Pfetscher, O. Ueber die Erregung sehr schneller elektrischen Schwingungen in der Dreielektrodenrohre. (On the production of oscillations of very high frequency by means of electron tubes.) *Phys. Zeits.*, **29**, pp. 449–478; July 15, 1928.

(Treats analytically the production of very short waves of tube oscillations and shows like Barkhausen and Kurz that the finite time for the electrons to pass to the respective electrodes produces a phase difference. The Gill-Morell oscillations are treated theoretically. The theory also explains the effect of the grid potential on the frequency even though the external circuit is kept unchanged.)

R133 Martyn, D. F. (A reply to K. E. Edgeworth.) Frequency variations of the triode oscillator. *Phil. Mag.*, **6**, pp. 223–228; July, 1928.

(Deals with the major effects causing a variation in the frequency of a triode oscillator. States that the most important cause of frequency variation is the flow of grid current, especially when the resistance is kept low and the frequency is not too high. Reference is made to generator with zero grid current which kept the frequency within one part in 100,000.)

R134 David, P. La détection par lampe. (Detection by means of electron tubes.) *L'Onde Electrique*, **7**, pp. 313–62; Aug., 1928.

(Theoretical and experimental data for the electron tube as a detector.)

R134.4 van der Pol, B. The effect of regeneration on the received signal strength. Proc. I. R. E., **16**, pp. 1045–52; Aug., 1928.

(Gives the theory and experimental verification of it for the effect of regeneration on signal strength.)

R140 Lion, K. Ein Wechselstromkompensator mit grossem Frequenzumfang. (An alternating current compensator with wide frequency range.) *Elekt. Nach.-Tech.*, **5**, pp. 276–83; July, 1928.

(A phase shifter for audio and high frequency currents is described.)

R142 Mallett, Prof. E. The resonance curves of coupled circuits. *Exp. Wireless and Wireless Engineer*, **59**, pp. 437–42; Aug., 1928.

(An analytical treatment (vectorial method) of coupled circuit with the frequency varied similar to the one described by the same author in the Feb. 1927 issue of *Experimental Wireless and Wireless Engineer* for single circuits.)

R154 Watanabe, Yasusi. Ueber die günstigste Belastung des Hochfrequenz-generators. (On the most favorable load for a high-frequency generator.) *Elekt. Nach.-Tech.*, **5**, pp. 259–267; July, 1928.

(A theoretical article for the best load to connect to a high-frequency alternator.)

R200. Radio Measurements and Standardization

R201 Clapp, J. K. A note on methods of rapidly adjusting a radio frequency oscillator in small steps of frequency. *Jnl.* Opt. Soc. of Amer., **17**, pp. 132–37; August, 1928.

(Describes rapid methods of adjusting the frequency of a generating set by aural methods using auxiliary generating sets and a tuning fork. Discusses accuracy obtainable.)

R201.6 Ferguson, J. G., and Bartlett, B. W. Measurement of capacitance in terms of resistance and frequency. *Bell System Tech. Jnl.*, **7**, pp. 420–37; July, 1928.

(Describes an adaptation of the Wien Bridge for the determination of capacity.)

R214 Wheeler, L. P., and Bower, W. E. A new type of standard frequency piezo-electric oscillator. Proc. I. R. E., **16**, pp. 1035–44; August, 1928.

(Gives a new type of piezo-electric oscillator, for which the oscillations are sustained by an acoustic feedback.)

R214 Hund, A. Notes on quartz plates, air gap effect, and audio-frequency generation. Proc. I. R. E., **16**, pp. 1072–78; August, 1928.

(The effect of supersonic sound waves taking place in a crystal holder is discussed. The energy curve is given with respect to the air gap in the crystal holder. van der Pol's relaxation oscillations are suggested in the circuit for obtaining very accurate low-frequency current from a high-frequency crystal.)

R220 Griffiths, W. H. F. The measurement of small variable capacities at radio frequencies. *Experimental Wireless and Wireless Engineer*, 59, 452–59; August, 1928.

(A new method is given for calibrating small capacities.)

R223 Bryan, A. B., and Sanders, I. C. The dielectric constant of air at radio frequencies. *Physical Review*, 32, pp. 302–10; August, 1928.

(Value of dielectric constant of dry air free from carbon dioxide determined as 1.0005893 for standard conditions of temperature and pressure. The method is a modification of the usual heterodyne beat arrangement.)

R290 Obata, Juichi. The "Ultramicrometer," a new instrument for measuring very small displacement or motion, and its various applications. *Jnl.* Opt. Soc. of Amer., 16, pp. 419–32; June, 1928.

(Describes the construction and various examples of applications of the ultramicrometer for measuring a small displacement or motion utilizing a generating electron-tube circuit. The displacement or motion to be measured is made to produce either a change in capacity or in the eddy current loss, and in consequence a corresponding change in the plate current of the tube.)

R300. Radio Apparatus and Equipment

R342 Jouaust, R., and Decaut, B. Note sur quelques perfectionnements des amplificateurs a courant continu. (Notes on some perfections on d.c. amplifiers.) *L'Onde Electrique*, 7, pp. 306–08; July, 1928.

(A straight two-stage d.c. amplifier is used with the first tube having a large amplification factor. In one case a special tube is employed in the first stage with a narrow mesh grid and a large anode ($\mu = 36$). In another case a double-grid tube is used with the two grids connected together.)

R342 Hund, A. Notes on aperiodic amplification and applications to the study of atmospherics. Proc. I. R. E., 16, pp. 1077–78; August, 1928.

(A circuit for aperiodic amplification is given and the main differences between aperiodic amplification and amplification of harmonic voltages are brought out.)

R342.7 Reppisch, H. Ueber die Spannungsverstärkung mittels Transformatorenkopplung beim Niederfrequenzverstärker. (On voltage amplification by means of transformer coupling for the low-frequency amplifier.) *Zeits. f. Hochfrequenz.*, 32, pp. 22–24; July, 1928.

(A derivation of the relations for transformer coupled amplification (audio frequency).)

R342.7 Kirke, H. L. Microphone amplifiers and transformers. *Experimental Wireless and Wireless Engineer*, 59, pp. 443–51; August, 1928.

(A continuation of the article appearing on p. 370 in the July issue. Deals with the effects of coupling between stages of an amplifier. Takes inter-electrode capacity into account.)

R342.7 Thomson, J. M. Characteristics of output transformers. Proc. I. R. E., 16, pp. 1053–64; August, 1928.

(Discusses analytically and by means of tests, the characteristics of output transformers.)

R343.7 Kimmell, W. J. The cause and prevention of hum in receiving tubes employing alternating current direct on the filament. Proc. I. R. E., **16**, pp. 1089–1106; August, 1928.

(The effect of the filament which is heated with a.c. on the quality of reception is discussed.)

R344 Bell, Eric G. A valve-maintained high-frequency induction furnace and some notes on the performance of induction furnaces. *Proc.* Phys. Soc. (London), **40**, pp. 193–205; June 15, 1928.

(Gives electrical design of an induction furnace and gives a general theory of the behavior of induction furnaces. Experimental results given supporting the theory.)

R344 Hund, A. Générateur des courants de fréquence audible et réglable a stabilisation piézo-electrique. (Generator for audio currents of adjustable frequency with piezo-electric stabilization.) *QST Francais*, **9**, pp. 16–19; August, 1928.

(A translation of Bureau of Standards Scientific Paper No. 569, giving a method of producing audio currents of variable frequency and good wave form.)

R344.4 Wechsung, H. Röhrengenerator grosser Leistung für sehr kurze elektrische Wellen. (Tube generator of large rating for very short waves.) *Zeits. f. Hochfreq.*, **31**, pp. 176–83; June, 1928.

(A circuit is discussed by means of which 700 watts energy for code modulation and 300 watts energy for speech modulation can be generated. Waves down to 4.2 meters were produced.)

R344.4 Hollmann, H. E. Telephonie auf extrem kurzen Wellen. (Telephony with extremely short waves.) *Elekt. Nach.-Tech.*, **5**, pp. 268–75; July, 1928.

(The author describes a system for telephony with wavelengths between 30 and 100 cm. It is also shown that the Barkhausen and Gill and Morrell oscillations can occur simultaneously.)

R344.6 Lübcke, E. Eine Gross-Verstärkerröhre mit Quecksilberdampf. (A power amplifier tube with mercury vapor.) *Zeits. f. Hochfreq.*, **32**, pp. 1–10; July, 1928.

(An amplifier tube using a mercury arc is described. The internal resistance is only 70 ohms and the tube seems promising for heavy current work.)

R374.1 Ogawa, W. Analogy between the crystal detector and a vacuum tube. *Phil. Mag.*, **6**, pp. 175–78; July, 1928.

(The author explains the rectification of a crystal detector by means of a difference of electrons emitted from each electrode. According to his views there is no substantial difference between a crystal detector and a vacuum-tube rectifier except the metallic conduction at the real contact points in the former.)

R374.1 Regler, Fritz. Vorläufige Mitteilung uber die Theorie des Kontaktdetektors. (Preliminary communication on the theory of contact detectors.) *Phys. Zeits.*, **29**, pp. 429–36; July, 1928.

(The author divides contact rectifiers into two classes. For the first class rectification is due to electrostriction (piezo-electric effects); and for the other, due to different values of electron affinity for different materials. Many of his conclusions are based on a paper by G. G. Reisshaus, *Phys. Zeits.*, 28, 223; 1928.)

R374.1 Beck, P. Weitere Mitteilungen zum Kristalldetektor problem. (Further communication on contact detectors.) *Phys. Zeits.*, **29**, pp. 436–37; July, 1928.

(Describes experimental work with galena-silver, galena-copper and galena-stee contact rectifiers. Microscopic observations of the contact surface have been made in addition, and the results seem to be in agreement in several ways with the ones due to G. G. Reisshaus.)

R381 Trogner, A. M. Mica condensers for high frequency. *QST*, **12**, pp. 47–49; September, 1928.

(Gives method of connecting small mica condensers for use in high-frequency transmitting sets.)

R388 Lee, E. S. Cathode-ray oscillographs and their uses. *General Electric Review*, **31**, pp. 404–12; August, 1928.

(Describes principles of cathode-ray oscillograph and commercial instrument, in which photographic records can be made. Illustrations are given for its use on various problems including radio.)

R400. Radio Communication Systems

R432 Jones, L. J., and Osborn, W. M. Humber radio station. *Post Office Elec. Engrs. Jnl.*, **21**, pp. 159–64; July, 1928.

(Description of station located at Mablethorpe, Lincolnshire.)

R470 Dubois, R. Installation télégraphique à haute fréquence avec appareils "Télétype" réalisée sur une lique de transmission d'énergie a 60,000 volt de la Société d'Electricité du Tarn. (Telecommunication over the 60,000-volt transmission line of the Société d'Electricité of Tarn.) *Revue Gen. de L'Electricite*, **28**, pp. 997–1003; June 9, 1928.

(Describes the installation of the "Télétype" system for sending messages over a high-voltage line. The line is 90 km long and rated at 60 kilovolts. The system works entirely automatically and gives the messages directly in ordinary writing.)

R500. Applications of Radio

R522 Krueger, K., and Plendl, H. Zur Anwendung der kurzen Wellen im Verkehr mit Flugzeugen: Versuche zwichen Berlin und Madrid. (On the application of short waves to aeroplanes: Experiments between Berlin and Madrid.) *Zeits. f. Hochfreq.*, **31**, pp. 169–76; June, 1928.

(It was found that 46 m would work over a distance of 1400 km during daytime with 2 watts output, but a distance of 2000 km could hardly be covered even if 300 watts were used. The wavelength between 27 and 30 m seemed to work best during day and night time for a distance of 2000 km. 300 watts energy in the antenna would give a sure communication on ground. For flights, 30 watts gave a fairly dependable service. The band between 16 and 19 m was nearly as good. It was generally found that 300 watts and 30 m wavelength was dependable.)

R536 Experiments in underground communication through earth strata. U. S. Bureau of Mines Technologic Paper No. 433.

(Includes data on radio methods applied to such communication.)

R582 Larner, E. T. Practical television (book). Published by Ernest Benn, Ltd., London.

(Reviewed in *Nature*, 122, No. 3068, Aug. 18, 1928.)

R800. Non-Radio Subjects

517 Berg, Ernst J. Heaviside's operational calculus as applied to engineering and physics. *General Electric Review*, **31**, pp. 444–51; August, 1928.

(Reviews Heaviside's operational calculus for the case of the asymptotic solution.)

534 Hubbard, J. C., and Loomis, A. L. The velocity of sound in liquids at high frequencies by the sonic interferometer. *Phil Mag.*, 5, pp. 1177–90; June, 1928.

(A method is described where the velocity of sound in liquids is determined by means of standing waves generated by a quartz oscillator producing high-frequency vibrations. Thermodynamic coefficients of liquids are computed from the velocities obtained at different temperatures.)

534 Hehlgans, F. W. Uber Piezoquarzplatten als Sender und Empfänger hochfrequenter akustischer Schwingungen. (On piezo-electric quartz plates as sender and receiver of supersonic sound waves.) *Annalen der Physik*, No. 12, 86, pp. 587–627; 1928.

(Experimental investigation of vibrating quartz plates for acoustic work.)

534 Trendelenburg, F. Zusammenfassender Bericht. Uber neurere akustische und insbesondere elektroakustische Arbeiten. (Summary of electro-acoustic methods.) *Zeits. f. Hochfreq.*, 32, pp. 27–34; July, 1928.

(A compilation of acoustic methods used in a radio laboratory.)

535.3 Wynn-Williams, C. E. The application of a valve amplifier to the measurement of x-ray and photo-electric effects. *Phil. Mag.* 6, pp. 324–34; August, 1928.

(The author applies a two-electron tube bridge circuit to the measurement of x-ray and photoelectric effects.)

546.432 Schindelhauer, F. Radioaktive Niederschläge auf Hochantennen (Radioactive effects on antennas.) *Phys. Zeits.*, 29, pp. 479–87; July 15, 1928.

(Uses antennas to study atmospheric potentials. It is shown that the vertical current is mostly due to a radioactive deposit. The current increases with increasing air pressure and with increasing temperature of the ground.)

621.313 Liwschitz, M. Verhalten des selbsterregten Generators bei kapazitiver Belastung. (Control of the speed of d.c. motors by means of electron tubes.) *Wissen. Veroff. aus dem Siemens Konzern*, 6, pp. 23–25; 1927.

(The voltage which is proportional to the r.p.m. is applied to a regular electron tube. The plate current of the latter affects the field of the motor.)

621.385 Küpfmüller, Karl and Mayer, Hans F. Sur les phénomenès transitoires dans les lignes pupinisées et le moyen d'y remédier. (Propagation of signals along conductors using Pupin coils.)

(Deals in detail with phase distortion and suggests filters for overcoming such distortion. Theoretical and experimental data prove their usefulness.)

621.385 Affel, H. A., Demarest, C. S., Green, C. W. Carrier systems of long distance telephone lines. *Bell System Technical Jnl.*, 7, pp. 564–629; July, 1928.

(This paper is a continuation of the development of carrier systems on long distance telephone lines.)

GEOGRAPHICAL LOCATION OF MEMBERS ELECTED
October 3, 1928

Transferred to the Fellow grade

Dist. of Columbia	Washington, Navy Department	Hooper, S. C.
Massachusetts	Cambridge, Harvard University	Kennelly, Arthur E.
New York	Schenectady	Rice, Chester W.

Elected to the Fellow grade

Dist. of Columbia	Anacostia, Naval Research Labs	Wheeler, Lynde P.

Transferred to the Member grade

New Jersey	New Brunswick, P. O. Box 392	Cumming, Kenneth N.
New York	Hollis, 100–23 198 St.	Hotopp, Alfred H., Jr.

Elected to the Member grade

Illinois	Chicago, 623 S. Wabash Ave.	Smith, K. R.
Maryland	Chevy Chase, 6619 Summit Ave.	Walls, H. J.

Elected to the Associate grade

California	Fullerton, 113 E. Commonwealth	Finseth, E. B.
	Los Angeles, 6019 S. Broadway	Newman, William H.
	Monterey Park, 1012 E. Columbia St.	Sanmann, Edgar J.
	San Diego, 4741 32nd St.	Wright, Robert E.
	San Francisco, 511 Matson Bldg.	Attmore, William B.
	San Francisco, 245 Market St.	Kellogg, Richard B.
	West Hollywood, 871 Hilldale St.	Threlkeld, Howard M.
Colorado	Hereford	Nichols, Fred A.
	Pueblo, 2409 Pine St.	Glasscock, Glen R.
Connecticut	Wilson, 8 Garden Street	Appleby, Bertie
Delaware	Wilmington, 2303 Franklin St.	Boylan, Brandt
Dist. of Columbia	Washington, Federal Radio Commission	Blackwell, G. C.
Georgia	Atlanta, 366 Augusta Ave.	Walker, Joseph R.
Illinois	Chicago, 2641 S. Michigan Ave.	Doyel, Lee C.
	Chicago, 3100 N. Harding Ave.	Kobberup, J.
	Chicago, 5042 W. Superior St.	Remde, J.
	Chicago, 3843 N. Ridgeway Ave.	Sorensen, Carl P.
	Downers Grove, 720 Maple Ave.	Johnson, Arthur R.
Massachusetts	Boston, 332 A Street	Baird, Hollis S.
	Chatham, Radio Marine Corp. of Amer.	Weik, Adolf L.
	Concord	Hall, Henry D.
	East Springfield, 26 Prentice St.	Hurff, Jos. L.
	Lowell, 31 Princeton St.	Morton, Clarence F.
	Springfield, 491 Wilbraham Rd.	Der Bedrossyan, Mark
Michigan	Lapeer, Drawer A.	Margraf, Frank J.
New Jersey	Camden, Victor Talking Machine Co.	Cooley, Elihu H.
	Hoboken, Cooper Hewitt Elec. Co.	Dana, David W.
	Hoboken, 624 Washington St.	Izzo, Anthony
	Netcong, P. O. Box 393	Mack, Paul
New York	Brooklyn, 1536 E. 54th St.	Abraham, Irving
	Brooklyn, Y. M. C. A. Hanson Place	Donner, Louis F.
	Brooklyn, 654 East 23rd St.	Stobbe, John A.
	Buffalo, 225 Massachusetts Ave.	Pfleegor, Carroll M.
	Buffalo, 572 Elmwood Ave.	Vanacore, Thomas
	New York City, 66 Broad St.	Beltz, Willis H.
	New York City, 237 W. 100th St.	Jones, Dramin D.
	New York City, 463 West Street	Koerner, Allan M.
	New York City, 1054 Grant Av. Bronx	Siegal, Jos A.
North Carolina	Charlotte, c/o Radio Sta. WBT	Callahan, Thomas G.
	Charlotte, c/o Radio Sta. WBT	Reid, Ralph J.
	Gastonia, c/o A. Kirby & Co.	Jenkins, Russell A.
	Gastonia, 413 Broad St.	Morris, Robert S.
Ohio	Cleveland, 15305 Huntmere Ave.	Melrose, James W.
Oregon	Portland, Reed College, Physics Dept.	O'Day, Marcus

Pennsylvania	Philadelphia, 1603 Ellsworth St	Caporate, Peter
	Pittsburgh, 2012 Noble St	Bricker, James O.
	Pittsburgh, 328 Stratford Ave	Wallace, H. E.
	Wilkinsburg, 442 Franklin Ave	Haller, G. L.
Tennessee	Athens, 12 Euclid Ave	Knight, Gaylord A.
Chile	Valparaiso, 98th Tubildad St	Basaure, Auro
China	Tientsin, 10 Recreation Rd	Chen, Ying-Chien
England	Dorset, Long Crickel, Wienborne	Harris, R.
	Essex, 11 Argyll Rd. Westcliff-on-Sea	White, Thomas G.
	Gloucester, 29 Lannett Rd	Myers, Geo. T.
Japan	Tokyo-Fu, Electro Technical Lab	Iinuma, H.
	Tyko, Electro Technical Lab	Matsumura, Sadao
	Kumamotoshi, c/o Shimizu Hosojo	Shimayama, Tsurno
Scotland	Glasgow, 105 Douglas St	Carnie, Ben

Elected to the Junior grade

Massachusetts	Marion, c/o R. C. A	Carson, Jos.
Minnesota	Mapleton	Norgrant, Lawrence A.
	Minneapolis, 2515 Irving Av. So	Gould, Payson R.
New York	Buffalo, 39 Charleston Av	Patterson, Curtis B.
Pennsylvania	Philadelphia, 1533 Pine St	Gilson, Walter E.
Texas	Amarillo, Route 3, Box 99-B	Reville, T. A., Jr.

APPLICATIONS FOR MEMBERSHIP

Applications for transfer or election to the various grades of membership have been received from the persons listed below, and have been approved by the Committee on Admissions. Members objecting to transfer or election of any of these applicants should communicate with the Secretary on or before December 1, 1928. These applicants will be considered by the Board of Direction at its December 5th meeting.

For Transfer to the Member grade

California	Los Angeles, 800 North Spring Street	Sohor, P. H.
England	Shipley, Yorkshire, 14 Bankfield Drive	Wright, Sidney R.

For Election to the Member grade

Illinois	Elmhurst, 265 W. North Avenue	Kenney, M. W.
Germany	Berlin, Wittenau, Robertstr	Runge, Wilhelm T.
Japan	Tokyo, Setagaya, 429 Taishido	Fujimoto, Tadashi

For Election to the Associate grade

Arkansas	Blytheville, 304 Davis Avenue	Lintzenich, C. L.
California	Glendale, 408 Wing Street	Shomler, H. B.
	Hollywood, 1030 N. Western Avenue	Finstein, Paul
	Hollywood, 1345 North New Hampshire Avenue	Sarver, Frank M.
	Los Angeles, 4503 Paulhan	Andersen, H. W.
	Los Angeles, 1444 So. Norton Avenue	Buffinger, William
	Los Angeles, 1441 W. 51 Place	Hill, Alfred LeRoy
	Los Angeles, 1050½ Cloverdale	Stevens, Sterling M.
	Sterling City	Overton, D. C.
	Stockton, 1520 N. Eldorado Street	Holt, Pliny E.
Georgia	Atlanta, c/o General Electric Co., P.O. Box 1698	Bussey, H. E.
	Atlanta, 1331 Lucile Avenue, S. W.	Wallace, Lawrence T.
	Columbus, c/o Columbus Electric and Power Co.	Farris, Herbert Talley
Illinois	Chicago, 100 W. Monroe St.	Fillmore, Harry Philip
	Chicago, 2247 Calumet Avenue	Hauser, Albert
	Chicago, c/o R. C. A., 100 W. Monroe Street	Kennedy, W. J. B.
	Chicago, 1544 North Dearborn	Nourse, Philip R.
	Chicago, 4430 Clifton Avenue	Turner, C. G.
	Dixon, 521 McKenney Street	Hall, Howard J.
	Kewanee, 219½ West Second Street	Larson, Clifford L.
	Urbana, Dept. of Elec. Eng., University of Illinois	Hershey, Arthur W.
Indiana	Indianapolis, 1036 Eugene Street	Byers, Russell R.
	Valparaiso, 402 Monroe Street	Alexander, Leslie Alpheus
	Valparaiso, 555 So. College Avenue	Imler, Glenn M.
Iowa	Hale, Box 29	Kruse, Gerald D.
Louisiana	Baton Rouge, 830 North Street	Webre, Andrew S.
	New Orleans, 3624 Magazine Street	de Otter, G.
	New Orleans, 1222 Eagle Street	Pasquet, Jean E.
	New Orleans, 2655 Canal Street	Rabito, A. Paul
Massachusetts	Cambridge, Massachusetts Institute of Technology	Barrow, W. L.
	Cambridge, 28 Gorham Street	Shen, Pinlu
	Cambridge, General Radio Co.	Worthen, Charles E.
	North Attleboro, Old Post Road	Barrett, Kerman R.
	Roxbury, 38 Atherton Street	Collins, Lewis R.
	Swampscott, 12 Humphrey Terrace	Humphrey, Stanley M.
Michigan	Detroit, 295 Ferry Street	Line, F. M.
Minnesota	Minneapolis, Francis Drake Hotel	Brooks, Kenneth E.
	St. Paul, Federal Bldg., Room 413	Heiser, Edwin S.
New Jersey	Boonton, 804 Main Street	Pittenger, Arthur W.
	Hackensack, c/o Gotham Electric Sales Corp., 272 Main St.	Slocum, K. W.
	Jersey City, 96 Duncan Avenue	Palmer, C. Walter
New York	Brooklyn, 289 Henry Street	Kearney, L. E.
	Brooklyn, 446 Ocean Avenue	Thomas, Howard H.
	Brooklyn, 167 Clinton Avenue	Welker, Paul L.
	Brooklyn, 2526-85th Street	Yonofsky, Harry
	Buffalo, 79 Roanoke Parkway	Beyer, Glen R.

	Buffalo, 1204 Kensington Avenue	Carmody, Raymond P. M.
	Buffalo, 62 Mandan Street	Deane, Harold A.
	Buffalo, 291 South Elmwood Avenue	Flutka, Ralph M.
	Buffalo, 778 Washington Street	Lord, Harry Raymond
	Buffalo, 116 Hartwell Road	Morrison, John F.
	Buffalo, 131 Peabody Street	Pritchard, John A.
	Buffalo, 176 Laurel Street	Wright, George A.
	New York City, 1343 Herschell Street, Bronx	Bender, Martin, Jr.
	New York City, Cooper Union, Cooper Square	Fairburn, A. J. B.
	New York City, 72 Cortlandt Street, Room 301	Moore, E. B.
	New York City, 50 Church Street, Room 1467	Kichijiro, Kobayashi
	New York City, 252 Lexington Avenue	Vaughan, Carroll B.
	Tonowanda, R.F.D. No. 1	King, Francis N.
Ohio	Alliance, 209 E. Prospect Street	Mitchell, H. J.
	New Philadelphia, 252 Second Street, N. W.	Murray, Charles J.
	Ravenna, Box No. 4	Rettig, Floyd A.
	Youngstown, 106 Carroll Street	Wilkins, Bernard T.
Pennsylvania	Aldan, Delaware Co., 57 Glenwood Avenue	Trainer, George T.
	Erie, Hotel Ford	McHenry, Charles E., Jr
	Philadelphia, 1421 Arch Street	Frederick, Calvin M.
	Philadelphia, 4302 Ogden Street	Rabinowitz, Meyer
	Philadelphia, 6162 Algard Street	Roberts, Richard Pebworth
	Pittsburgh, N. S., Bellevue, 520 Bayne Avenue	Dauber, Albert Edward, Sr.
	Pittsburgh, N. S., 9 Magnet Street	Hayer, Henry J.
	Reading, Avenue Radio & Electric Shop, 460 Schuylkill Ave.	Good, Horace D.
Washington	Seattle, 570 First Avenue So.	Foster, Nick Hight
	Seattle, 5744-28th Avenue N. E.	Kuhn, Frederick S.
West Virginia	Fairmont, 1109 Alexander Place	Beerbower, Robert Glenn
Canada	Kitchener, Ont., Benton Street	Pollock, Carl A.
	London, Ont., 599 King Street	Crittle, W. J.
	Long Branch P. O., Ont.	Wood, Hubert T. W.
	Niagara Falls, Ont., P. O. Box 160	Dibbles, John
	Toronto, Ont., 374 Jane Street	Bayne, R. R.
	Toronto, Ont., 139 Sunny Side Avenue	Cormack, William A.
	Toronto 2, Ont., Canadian Westinghouse Co., Ltd.	Thompson, Frank
China	Shanghai, Admiralty House	Chen, C. C.
England	Blackford, Lancs, 6 Springfield Road	Cohen, Samuel H.
	Great Harwood, Lancs., 20 St. Huberts Street	Hodkinson, Henry
	North Stockport, Northdene, High Lane	Warner, Frederick F.
	Sowerby Bridge, Yorks, "The Hollins"	Whiteley, George M.
Germany	Bielefeld, Oberntorwall 29	Mann, Theodore H.
Japan	Hiroshima, No. 14 Kamiyanagi-machi	Tsumura, Kazuo
	Ibaraki-ken, Makabe-gun, Katchi-mura, Funyu	Fujikura, Keijiro
	Shimane-hen, Tobisumura Hikawa-gun	Sonoyama, Harutoshi
	Marunouchi, Japan Wireless Telegraph Co.	Kanko, Go
	Kojimachi, Yaesucho, 1-Itchome, Japan Wireless Tel. Co.	Simbori, Masayosi
	Tokyo, Nihonbashi-ku, Hongin 2–3, c/o G. Fujiwara	Yamaguchi, Usaburo
South Africa	Vereeniging, Transvaal, P. O. Box 27	Yapp, William Gustavus

For Election to the Junior grade

Indiana	Valparaiso, 712 Calumet Avenue	Sterns, Clarence C.
Louisiana	New Orleans, 3706 Danneel Street	Dover, M. H.
Massachusetts	Cambridge, 57 Gorham Street	Chu, Y.
New York	Buffalo, 219 Goodell Street	Weiss, Earl
	New York City, 897 Faile Street, Bronx	Sherman, Jesse B.
	Rochester, 322 Hazelwood Terrace	Clonick, Theodore
Pennsylvania	Philadelphia, 1507 Porter Street	Doherty, George H. M.
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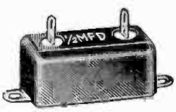

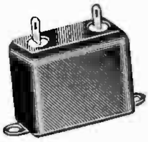

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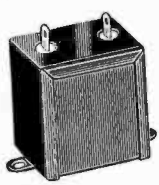

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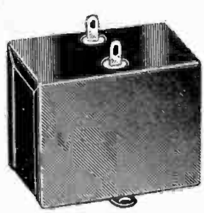

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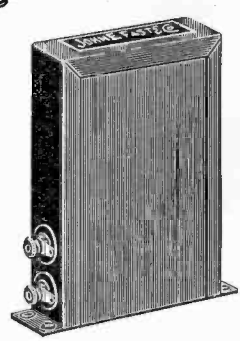

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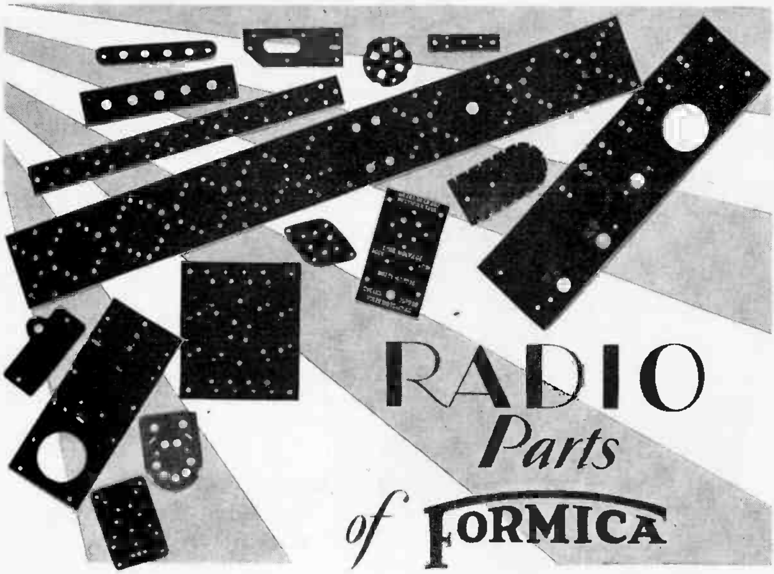

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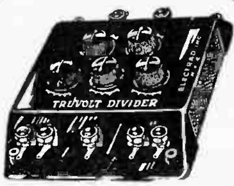

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AN ADJUSTABLE RESISTANCE BANK to be used in B and C sections of power supply designed to take care of any desired load with a generous safety factor. It is flexible to all receiver current conditions. It is invaluable in laboratory work, where a minimizing of routine mathematical calculations and rewirings increases experimental efficiency.

The adjustable taps of the Divider are calibrated and desired voltages can be ascertained merely by use of convenient tables and graphs.

Can be mounted flat or upright on wood, bakelite or metal sub-panel. No need of output panel. Soldering lugs are provided on each tap for connecting by-pass condensers.

Price $12.50 complete

Send for free descriptive booklet giving hook-up diagrams, curves and tables.

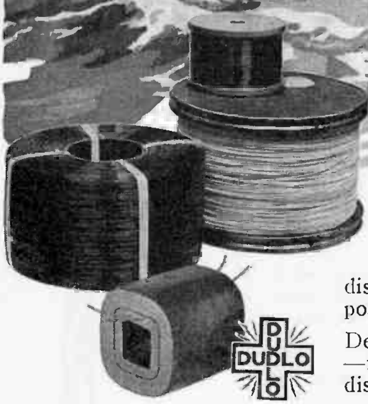
Electrad specializes in a full line of controls for all Radio purposes, including Television.

Dept. A-11, 175 Varick Street, NEW YORK

ELECTRAD Inc.

The Guiding Hand

Hour after hour a graceful monoplane throbs across a vast ocean, searching a path from continent to continent through fog and storm. Like a mighty helping hand rising from the depths, radio points the way and keeps a wondering world informed.



DUDLO

THE tiny wires which constitute the radio apparatus are the unseen nerves which are sustaining the navigator of the air on his trackless route. They must respond instantly to every command. Without the radio apparatus, which is an essential part of every long distance plane, the conquest of the air would be impossible.

Dependable magnet wire and coils are indispensable—for one failure—one short circuit—might mean disaster.

Dudlo takes pride in its belief that in making copper wire products which stand the severest tests, it is contributing to man's triumph over the elements.

DUDLO

DUDLO MANUFACTURING CO., FORT WAYNE, IND.

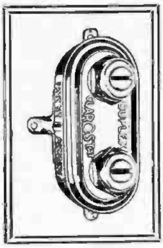
Division of the General Cable Corporation

56 Earl Street	105 West Adams St.	4143 Bingham Ave.	274 Brannan St.
NEWARK, N. J.	CHICAGO, ILL.	ST. LOUIS, MO.	SAN FRANCISCO, CALIF.

Radio "First Aids"

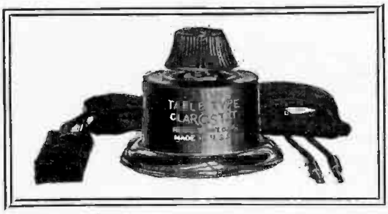
TO those who service existing sets under all kinds of conditions, quite as much as those who design and produce radio products, the Clarostat line must always be a first-aid proposition.

There is the Clarostat *Antenna Plug,* which converts any electric light socket or outlet into an ideal wave interceptor, either alone or in combination with an antenna. It solves the problem of the radio "dead spot" in most instances.



There is the *Duplex Clarostat,* which provides two fixed resistances of any value determined by the mere twist of your screw-driver.

There is the *Table Type Clarostat,* which provides adjustable resistance in handy form for plate voltage, loud-speaker, sensitivity or other control.



And there are many other Clarostat devices intended for those who render first aid to radio listeners-in, as well as for those who supply the initial equipment.

Write for data describing the full line of Clarostat devices as well as their applications. If you are an engineer for a radio manufacturer, write on your firm letterhead and we shall place your name on our technical bulletin mailing list.

Clarostat Manufacturing Company, Inc.

MEMBER R.M.A.

Specialists in Variable Resistors

289 N. Sixth St. :-: Brooklyn, N. Y.

CLAROSTAT

REG. U. S. PAT. OFF.

SMOOTH Power for Dynamic Speakers from the AC Line with the ELKON DRY Rectifier

Dynamic Speaker Series, especially designed to meet the needs of Manufacturers

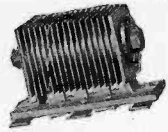
THE Elkon Engineers have worked exceedingly closely with many of the manufacturers of dynamic speakers. The result of this work is an intimate knowledge of the problems of supplying smooth power to moving coils, and a complete series of rectifiers supplying just the voltage and current desired.

Already the Elkon Dry Rectifier has been specified by a majority of the Dynamic Speaker manufacturers. We would like to work with you as we have with them. Simply tell us your specifications, and we will submit a sample rectifier—May be supplied with or without power transformer.

Self healing, the Elkon Rectifiers have an exceptionally long life, are noiseless and require no attention or adjustment.

Let Rectifier Headquarters solve your problems. Send the coupon which will bring you the Engineering Bulletins on the Elkon Rectifiers and High Capacity Dry Condensers.

Radio Department
ELKON, INC.
350 Madison Ave.
New York City



ELKON DRY RECTIFIER for "A" Eliminators

The Elkon Dry Rectifier has long been considered the ideal rectifier for "A" Eliminators. Standard equipment on the leading eliminators last year, and already specified this year by additional manufacturers.

The "A" Eliminator type is especially treated, ensuring smoothness and noiselessness. When used with the proper filter system including Elkon Dry Condensers the milli-volt ripple is only from 3 to 6!

Elkon Rectifiers are Self Healing

Self healing, the Elkon Rectifiers have an exceptionally long life and require no attention or adjustment. Send the coupon for the Engineering Bulletins on Elkon Rectifiers and High Capacity Dry Condensers.

Row upon row of Elkon Rectifiers being seasoned under the careful eyes of skilled workers

Every junction must have just the right pressure—16 meters to watch in this operation

ELKON, INC., Dept. E-40, 350 Madison Ave.
New York City.

We are interested in Elkon Rectifiers for .... Dynamic Speakers

.... "A" Eliminators. Send the Engineering Bulletins to

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....

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MAIL addressed to members of the Institute as listed below, has been returned by the Post Office Department as being unclaimed. Members knowing the present address of any of these members will render a service to the Institute by advising the Secretary thereof.

Albert, Wm. V., c/o General Delivery, Reading, Pa.

Annett, Earl, 1054 S. Main St., Ann Arbor, Mich.

Fink, Wm. D., 418 S. Orange Ave., Newark, N.J.

Flynn, Roy M., 2510 Grand Ave., Dallas, Tex.

Halligan, W. J., Fairview Ave., Randolph, Mass.

Harrington, F. H., 1538 Wilcox Ave., Hollywood, Calif.

Houdyshell, Lowell B., 1056 S. Normandie Ave., Los Angeles, Calif.

Hull, Capt. W. J. H., c/o Messrs. Lloyds Bank, Ltd., 6 Pall Mall, London, Eng.

Hunt, Henry T., Jr., 2632 Clienview Ave., Cincinnati, Ohio.

Kelly, Claude H., 231½ W. 19th St., Houston, Tex.

Kent, Oliver C., 1332 W. 41st Pl., Los Angeles, Calif.

Lighty, Russel D., Ludington, Mich.

McElroy, W. R., c/o W. R. McElroy Co., Federal Reserve Bldg., Pittsburgh, Pa.

Mossman, F. B., 5212 Ravenna Ave., Seattle, Wash.

Paggi, Martin M., Radio KFWO, Avalon, Catalina Island, Calif.

Soderberg, Arnold J., 2552 Foothill Blvd., Oakland, Calif.

Sturtevant, J. W., 1242 Bonnieview Ave., Lakewood, Ohio.

Swanson, John W., 273 Tessamine Ave., Yonkers, N.Y.

Whitney, Chas. L., Tropical Radio Telegraph Co., 321 St. Charles St., New Orleans, La.

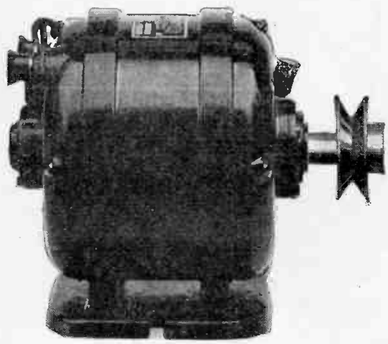
Woodcock, Norman A., 66 West 88th St., Brooklyn, N.Y.

Alphabetical Index to Advertisements

"ESCO"

Synchronous Motors for Television

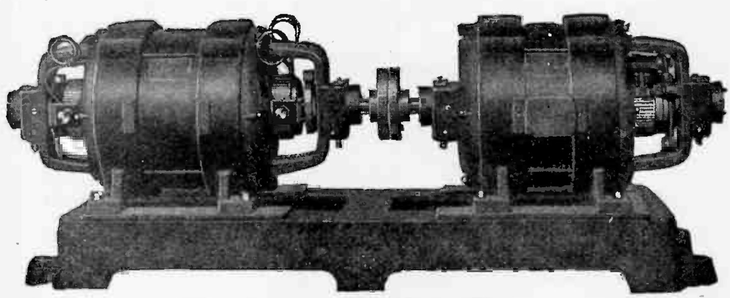
In addition to building reliable and satisfactory motor generators, "Esco" has had many years of experience in building *electric motors* for a great variety of applications.



Synchronous motors, small, compact, reliable, self starting are now offered for *Television* equipment. They require no direct current for excitation, are quiet running and full guaranteed.

Other types of motors suitable for Television may also be supplied.

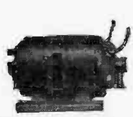
Write us about your requirements.



Type P Three Unit Motor Generator

"ESCO" two and three unit sets have become the accepted standards for transmission. The "ESCO" line consists of over 200 combinations. These are covered by Bulletin 237D.

How can "ESCO" Serve You?



ELECTRIC SPECIALTY COMPANY

TRADE "ESCO" MARK

300 South Street **Stamford, Conn.**

"When flits this cross from man to man, Vich Alpine summons to his clan."
When a Scottish chieftain desired to summon his clan, a fiery cross was placed in the hands of relays of the swiftest runners. Over hill and dale they sped calling to arms every man from sixteen to sixty. On one occasion during the civil war of 1745, the fiery symbol was carried over a tract of thirty-two miles in three hours.

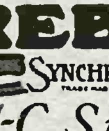
Get it *Better* with a Grebe

Doctor Mu

GREBE RADIO
TRADE MARK

Clannishness might be a well-chosen word to describe the spirit of the Grebe organization of radio engineers which, after the manner of an Old World guild-hall, have for nineteen years contributed so materially to the complete enjoyment of radio.

Throughout all these years they have been working together to produce *the* receiver that has so eagerly been awaited by all radio enthusiasts—the alternating current receiver that does away with the bother of batteries. The Grebe Synchrophase A-C Six is their contribution to perfect radio reception. Not merely a non-battery receiver, but one that combines convenience and ease of operation with superb tone qualities, unbelievable range and selectivity, freedom from A-C hum and other new Grebe improvements for better local and distance reception.



The Grebe Synchrophase A-C Six will convince you of the wisdom of the careful Grebe method of production. Hear it today, or send for Booklet I, which fully describes the distinctive features of this new receiver.

Other Grebe sets and equipment: Grebe Synchrophase Seven A-C, Grebe Synchrophase Five, Grebe Natural Speaker (Illustrated), Grebe No. 1750 Speaker.

GREBE SYNCHROPHASE

A-C Six

RADIO

A. H. Grebe & Co., Inc., 109 W. 57th St., New York City
Factory: Richmond Hill N. Y. *Western Branch:* 443 S. San Pedro St., Los Angeles, Cal.
Makers of quality radio since 1909

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN