VOLUME 17 NOVEMBER, 1929 NUMBER 11

PROCEEDINGS
of
The Institute of Radio Engineers

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Institute of Radio Engineers

Forthcoming Meetings

BUFFALO-NIAGARA SECTION
Buffalo, N. Y., November 14, 1929

CINCINNATI SECTION
Cincinnati, Ohio, November 19, 1929

CLEVELAND SECTION
Cleveland, Ohio, November 20, 1929

CONNECTICUT VALLEY SECTION
Hartford, Conn., November 27, 1929

DETROIT SECTION
Detroit, Mich., November 15, 1929

LOS ANGELES SECTION
Los Angeles, Calif., November 18, 1929

NEW YORK MEETING
New York, N. Y., December 4, 1929

PITTSBURGH SECTION
Pittsburgh, Penna., November 12, 1929

SAN FRANCISCO SECTION
San Francisco, Calif., November 21, 1929

TORONTO SECTION
Toronto, Ont., Canada, November 13, 1929

WASHINGTON SECTION
Washington, D. C., November 25, 1929

Eastern Great Lakes District Convention

November 18-19, 1929, Rochester, N. Y.

PROCEEDINGS OF

The Institute of Radio Engineers

Volume 17 November, 1929 Number 11

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Technical Papers

The Institute of Radio Engineers

GENERAL INFORMATION

The PROCEEDINGS of the Institute is published monthly and contains papers and discussions thereon submitted for publication or for presentation before meetings of the Institute or its Sections. Payment of the annual dues by a member entitles him to one copy of each number of the PROCEEDINGS issued during the period of his membership.

Subscription rates to the PROCEEDINGS for the current year are received from non-members at the rate of $1.00 per copy or $10.00 per year. To foreign countries the rates are $1.10 per copy or $11.00 per year.

Back issues are available in unbound form for the years 1918, 1920, 1921, 1922, and 1926 at $9.00 per volume (six issues) or $1.50 per single issue. Single copies for the year 1928 are available at $1.00 per issue. For the years 1913, 1914, 1915, 1916, 1917, 1918, 1924, and 1925 miscellaneous copies (incomplete unbound volumes) can be purchased for $1.50 each; for 1927 at $1.00 each. The Secretary of the Institute should be addressed for a list of these.

Discount of twenty-five per cent on all unbound volumes or copies is allowed to members of the Institute, libraries, booksellers, and subscription agencies.

Bound volumes are available as follows: for the years 1918, 1920, 1921, 1922, 1925, and 1926 to members of the Institute, libraries, booksellers, and subscription agencies at $8.75 per volume in blue buckram binding and $10.25 in morocco leather binding; to all others the prices are $11.00 and $12.50, respectively. For the year 1928 the bound volume prices are: to members of the Institute, libraries, booksellers, and subscription agencies, $9.50 in blue buckram binding and $11.00 in morocco leather binding; to all others, $12.00 and $13.50, respectively. Foreign postage on all bound volumes is one dollar, and on single copies is ten cents.

Year Books for 1926, 1927, and 1928, containing general information, the Constitution and By-Laws, catalog of membership etc., are priced at seventy-five cents per copy per year.

Contributors to the PROCEEDINGS are referred to the following page for suggestions as to approved methods of preparing manuscripts for publication in the PROCEEDINGS.

Advertising rates for the PROCEEDINGS will be supplied by the Institute's Advertising Department, Room 802, 33 West 39th Street, New York, N. Y.

Changes of address to affect a particular issue must be received at the Institute office not later than the 15th of the month preceding date of issue. That is, a change in mailing address to be effective with the October issue of the PROCEEDINGS must be received by not later than September 15th. Members of the Institute are requested to advise the Secretary of any change in their business connection or title irrespective of change in their mailing address, for the purpose of keeping the Year Book membership catalog up to date.

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

All correspondence should be addressed to the Institute of Radio Engineers, 33 West 39th Street, New York, N. Y., U. S. A.

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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 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 proportion.

Abbreviations—Write a.c. and d.c., (a-c and d-c as adjectives), kc, μf, $\mu\mu$f, e.m.f., 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 galley proof a reprint order form is sent to the author. Orders for reprints must be forwarded promptly as type is not held after publication.

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WASHINGTON	C. B. Jolliffe	J. B. Brady, Ouray Bldg., Washington, D. C.

John V. L. Hogan

Member, Board of Direction, 1929

John V. L. Hogan was born in Philadelphia, Pa., February 14, 1890. He attended Sheffield Scientific School, taking an electrical engineering course. In 1906–1907 he was a laboratory assistant to Lee de Forest in experimental radio telephone work. In 1908–1909 Mr. Hogan was engaged in experimental work at Sheffield Scientific School Graduate Research Laboratory. He joined the staff of the National Electric Signalling Company as telegraph engineer in December, 1909, where he was associated with Professor R. A. Fessenden in a number of research projects. Early in 1912 Mr. Hogan supervised the erection of the Bush Terminal Station in New York City. He had charge of the test operations between the Navy's first high power station at Arlington, Va. and the *USS Salem* in 1913.

Mr. Hogan was appointed chief research engineer of the National Electric Signalling Company in 1914. In 1917 the company's name was changed to International Signalling Company, and Mr. Hogan was made commercial manager. In 1918 he was made manager of the International Radio Telegraph Company. Since 1921 he has been engaged in consulting radio engineering in New York City.

Mr. Hogan has been a prolific contributor to the literature of the art.

His connection with the Institute dates back to his cooperation in the consolidation of the Institute of Wireless Telegraphy and the Wireless Institute, in 1912. He has been a member of the Board of Direction of the Institute continuously since 1913. He served as vice president of the Institute during the period 1916–1919 and was elected president in 1920. Mr. Hogan has been chairman of a number of the Committees of the Institute in the past, including Membership, Publicity, and Standardization. He was elected to full membership in the Institute in 1912, and was transferred to the Fellow grade in 1915.

INSTITUTE NEWS AND RADIO NOTES

1930 Year Book

The membership catalog in the 1930 Year Book will be dated as of December 15, 1929 and will contain the names and addresses of all paid members of the Institute on that date.

If any change has been made in either the business title, business address, or mailing address of a member since the 1929 Year Book was issued, the Institute office should be notified thereof on the form found on page XXXV of the advertising section in this issue, *unless such notification has already been given.*

In the absence of other information the 1930 membership catalog will be identical with that of 1929.

October Meeting of Board of Direction

At the meeting of the Board of Direction of the Institute held at 4 P.M. on October 2nd the following officers and members were present: A. Hoyt Taylor, president; Melville Eastham, treasurer; John M. Clayton, secretary; Alfred N. Goldsmith and Ralph Bown, junior past presidents; W. G. Cady, L. M. Hull, C. M. Jansky, Jr., R. H. Manson, R. H. Marriott, and L. E. Whittemore.

The following were transferred or elected to higher grades of membership in the Institute: transferred to the grade of Fellow: E. E. Bucher, Wm. Dubilier, H. T. Friis, J. W. Horton, D. G. Little, H. B. Richmond, and W. Van B. Roberts; transferred to the grade of Member: E. C. Ballentine, H. W. Baukat, L. S. Brach, Edmond Bruce, C. E. Butterfield, F. E. Canavaciol, R. C. Colwell, P. McK. Deeley, Francis R. Ehle, W. L. Everitt, J. F. Farrington, G. Robert Geit, W. N. Goodwin, Jr., C. W. Hansell, M. P. Hanson, H. D. Hayes, H. H. Henline, C. C. Heselton, W. S. Hogg, Jr., A. A. Howard, I. J. Kaar, G. W. Kenrick, H. M. Lane, C. R. Leutz, H. S. Osborne, and F. X. Rettenmeyer; elected to the grade of Member: E. W. Butler, C. F. Fielding, H. A. Frederick, C. F. Holden, T. H. Kinman, and C. C. Langevin.

One hundred and eighteen Associate members and sixteen Junior members were elected.

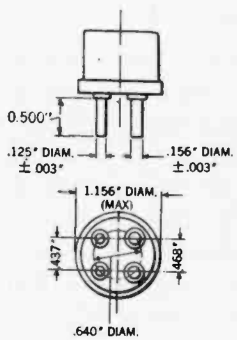
Standard Vacuum-Tube Bases

The Institute of Radio Engineers and the American Institute of Electrical Engineers are joint sponsors of the Sectional Committee on Radio of the American Standards Association. The technical committee on vacuum tubes, C. B. Jolliffe, chairman, has formulated standard specifications for vacuum-tube bases which were formally approved by the American Standards Association on July 26, 1929, as a tentative American standard.

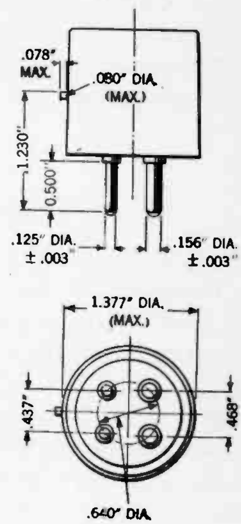
These specifications are as follows:

1. Dimensions

The important dimensions of the standard four-pin vacuum-tube base shall be as shown in the following drawings.



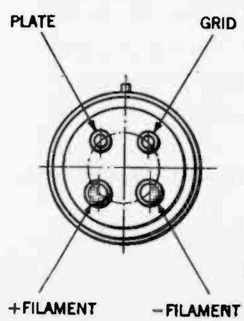
(a) Small Type



(b) Large Type

2. Connections

In a triode it shall be standard to connect the tube elements to the four-pin base as shown in the following drawing.



Single page reprints of these specifications can be obtained from the Secretary of the Institute of Radio Engineers at ten cents a copy.

Institute Meetings

New York Meeting

At the regular New York meeting of the Institute, held on October 2nd in the Engineering Societies Building, 33 West 39th Street, two papers on aircraft radio were presented.

The first, "Radio for the Air Transport Operator," by Lester D. Seymour, general manager of National Air Transport, of Chicago, was presented by M. M. Eells, communication engineer of that organization. The second paper was presented by the author, H. J. Walls, airways radio engineer, Department of Commerce, Bureau of Lighthouses, Washington. The title was, "The Civil Airways and their Radio Facilities."

Both papers will be published in an early forthcoming issue of the Proceedings.

A. Hoyt Taylor, president of the Institute, presided at the meeting which was attended by two hundred and fifty members and guests.

Addresses Before Sections by H. E. Hallborg

During the month of September, H. E. Hallborg presented a paper, "The Radio Plant of RCA Communications, Inc.," before five sections of the Institute. The meetings were arranged as follows:

Buffalo-Niagara section at the University of Buffalo, September 17th. L. Grant Hector, chairman of the section, presided. Seventeen members were present.

Chicago section at the Electric Club, September 20th. B. B. Minnium, vice chairman of the section, presided. Seventy members of the Institute attended the meeting. The paper was discussed by Messrs. Morse, Minnium, Miller, Oxner, Cole, and Packman.

Cleveland section at the Case School of Applied Science, September 18th. Bruce W. David, chairman of the section, presided. Thirty-seven members of the Institute were present.

Detroit section at Leland-Detroit Hotel, September 19th. A. B. Buchanan, chairman of the section, presided. Fifty members of the Institute were present. A lengthy discussion of the paper followed.

Toronto section in the Electrical Building, University of Toronto, September 16th. V. G. Smith, chairman of the section, presided. The attendance was sixty. The paper was discussed by Messrs. Pipe, Kinnear, Lowry, Dalton, Thompson, Choat, and Richardson.

Cincinnati Section

A meeting of the newly organized Cincinnati section was held on September 16th in the Chamber of Commerce Building, Cincinnati.

Officers of the section were elected as follows: Ralph H. Langley, chairman; W. C. Osterbrock, vice chairman; and W. W. Boes, secretary-treasurer. Mr. Langley announced the appointment of the following committees: Meetings and Papers, Publicity, and Membership.

Two papers were presented at the meeting. The first by Ralph P. Glover was entitled "Notes on Day to Day Variations in Sensitivity of Broadcast Receivers." The second paper by F. T. Flewelling was on "Short-Wave Transmission and Reception." Messrs. Langley, Loftis, and Israel discussed these papers.

Forty-one members and guests attended the meeting.

Los Angeles Section

The first fall meeting of the Los Angeles section was held on September 16th in the offices of The Southern California Telephone Company, 740 S. Olive Street. Thomas F. McDonough, chairman of the section, presided.

Through the courtesy of Mr. Stannard, division manager of The Southern California Telephone Company, C. E. Lilly, engineer in charge of the telephoto division, gave a lecture covering the operation of the telephoto apparatus. Following Mr. Lilly's talk there was a demonstration of picture transmission.

Due to the unusual interest in this program it was necessary to divide the meeting into groups in order that all could witness the demonstration and hear the lecture.

One hundred and thirty-one members and guests attended the meeting.

Pittsburgh Section

On September 17th a meeting of the Pittsburgh section was held in the Duquesne Light Building, Pittsburgh. L. A. Terven, chairman of the section, presided. Saul Levine, of the Pittsburgh office of the General Electric Company, presented a paper, "Vacuum Tubes," illustrated with lantern slides.

Messrs. J. G. Allen, A. Mag, S. I. Davis, J. P. Bucher, R. L. Davis, A. P. Sumergreen, L. A. Terven, S. Skrypzak, R. D. Wyckoff, and C. B. Upp participated in the discussion which followed.

Thirty-six members of the section attended the meeting.

The paper was prepared by the Research Laboratory of the General Electric Company at Schenectady. It was non-technical in nature and dealt with the fundamentals of vacuum-tube construction and tube applications.

Rochester Section

The members of the Rochester section have elected officers for the 1929–1930 season as follows: chairman, Earl C. Karker; vice chairman, Harry C. Gordon; secretary-treasurer (temporary), George Dodson; Board of Directors, Ray H. Manson, Virgil Graham, H. J. Klumb, I. G. Maloff, A. L. Schoen, and A. E. Soderholm.

San Francisco Section

On September 18th a meeting of the San Francisco section was held in the Bellevue Hotel, 505 Geary Street, San Francisco. Donald K. Lippincott, chairman of the section, presided.

W. F. Frederick presented a paper, "The Screen-Grid Vacuum Tube." The paper described some of the characteristics of the screen-grid tube and pointed out certain advantages and disadvantages of using this tube as a radio-frequency amplifier at broadcast frequencies. A circuit for testing the screen-grid tube was described.

Twenty-five members of the section attended the dinner preceding the meeting, at which forty-three were present.

Seattle Section

The September 21st meeting of the Seattle section comprised a trip to Keyport, Washington, to the U. S. Naval Transmitting Station. Five of the Naval transmitters, the largest of which is a 30-kw tube set, were inspected. C. E. Williams, naval engineer and a member of the Seattle section, described in detail this transmitter and four others.

The Seattle section chartered the steamer *Atlanta* to make the trip. Thirty-eight members of the section participated in this tour.

Washington Section

At the meeting of the Washington section held on September 12th in the Continental Hotel, Washington, D. C., K. S. Weaver, of the Westinghouse Lamp Company, presented a paper, "Production Testing of Vacuum Tubes."

The paper is summarized as follows: In order to insure the quality of the product of a factory turning out thousands of tubes of a kind every day, a well-organized system of mechanical and electrical inspection is required. Beside the factory inspection, which is made on all of the product, various control inspections, both regular and special, are used to insure the accuracy of the original inspection.

The ability of a tube to stand the rough handling incident to shipping is of prime importance in design. Information on the strength of tubes is obtained by the use of standard drop tests, the change in characteristics due to the dropping being used as a measure of the strength of a tube.

Beside the above outline of test procedure, the paper deals briefly with the relation between the various characteristics and their significance in set operation.

The elementary circuit arrangements used for the measurement of the most important control characteristics are described, and some of the reasons for the use of different circuit arrangements for different tubes are discussed.

Messrs. Davis, Carroll, Guthrie, Wheeler, Case, Brady, Smith, Amick, Wiseman, and Stevens participated in the discussion of the paper.

Vice Chairman Thomas McL. Davis presided at the meeting.

Following the paper and its discussion, motion pictures by the Western Electric Company on the audion and the telephone repeater were shown.

The next meeting of the section will be held on October 10th at the Continental Hotel.

Committee Work

Sections Manual

The Board of Direction of the Institute at its October 2nd meeting adopted and approved the "Manual for Section Organization and Operation," a document originally prepared by the 1927 Committee on Sections and revised by the 1928 and 1929 Committees.

The present edition contains much information of assistance to members interested in the formation of a section of the Institute. It also includes the approved form of Constitution for Sections.

Members interested in the possibility of a section in their vicinity, where no existing section now functions, may secure a copy of the manual by addressing the secretary of the Institute.

Committee on Admissions

The regular monthly meeting of the Committee on Admissions was held on October 2nd in the office of the Institute at 9:30 A.M. Members present were as follows: J. S. Smith, acting chairman; A. Hoyt Taylor, C. M. Jansky, Jr., and A. F. Van Dyck.

The Committee considered twenty applications for transfer or election to the higher grades of membership in the Institute, approving nine.

Committee on Standardization

J. H. Dellinger, chairman of the Committee on Standardization, called a meeting of the four subcommittee chairmen on September 5, 1929, in the Institute office in New York City. Those present were: J. H. Dellinger, Haraden Pratt, chairman of subcommittee No. 2 on transmitters and antennas; H. A. Frederick, chairman, subcommittee No. 4 on electro-acoustic devices; L. E. Whittemore, acting secretary, Sectional Committee on Radio, American Standards Association; and H. P. Westman, assistant secretary of the Institute.

The meeting was held to coordinate the activities of the subcommittees, to define the scope of their respective fields and their relation to the standardization projects of the manufacturers' groups, and to institute the work of the 1929 committee and subcommittees.

H. P. Westman was appointed secretary of the Committee on Standardization.

Committee on Membership

A meeting of the Committee on Membership was held at 5:30 P.M. in the Institute office on October 2nd. Those present were: I. S. Coggeshall, chairman; A. F. Murray, F. R. Brick, J. E. Smith, and H. C. Gawler.

The committee is assisting the Committee on Admissions in recommending the names of possible candidates for transfer or election to higher grades of membership in the Institute, having approved some one hundred Associate members for transfer to the full Member grade.

The 1928 Committee on Membership, through its suggestions of eligible members, was mainly responsible for the recent transfer of a large number of Associate members to the Member and Fellow grades.

Personal Mention

J. D. Durkee, formerly officer in charge, Radio Central, Navy Department, Washington, D. C., has recently become chief communications engineer of Universal Wireless Communication Company, Inc., with headquarters at Chicago.

J. G. Mullen has been appointed assistant general manager of the Brunswick-Balke-Collender Company of Canada, Ltd., with headquarters in Toronto. Mr. Mullen was formerly located in Baltimore, Md., with the same company.

L. A. Dye, until recently instructor in mathematics at the University of Rochester, has assumed the position of instructor in mathematics in Cornell University.

Sidney Fishberg, formerly manager of the vitreous enamel resistor department of the Electro-Motive Engineering Corporation of New York City, has joined the staff of Micamold Radio Corporation of Brooklyn as supervisor of the synthetic resistor department.

William H. Gerns has resigned from the Brandes Corporation where he was employed as design engineer to become associated with Wired Radio, Inc., of Ampere, New Jersey, as a designer.

R. P. Glover, a former student of the University of Cincinnati, has joined the radio engineering department of the Crosley Radio Corporation at Cincinnati.

Lloyd T. Goldsmith, until recently research assistant, Massachusetts Institute of Technology at the M. I. T. Experimental Station, Round Hill, Mass., is now associated with the Paramount Famous Lasky Corporation in the sound recording department.

William B. Gould is now with the Western Electric Company as equipment engineer. He was formerly radio engineer at Station WTAG.

L. C. Herndon, formerly U. S. Radio Inspector at Baltimore, has been promoted to the office of Supervisor of Radio.

F. L. Hopper is now an engineer in the recording engineering department of Electrical Research Products, Inc., at Los Angeles. Mr. Hopper was formerly engineer with the Pacific Telephone and Telegraph Company at Los Angeles.

A. H. Hotopp, until recently in the department of development and research in the American Telephone and Telegraph Company, is now associated with Kolster Radio Corporation-Brandes Laboratories, Inc., of Newark, New Jersey, as transmission development and research engineer.

Joseph C. Hromada, formerly a student at Armour Institute of Technology, has been appointed junior radio engineer of the Airways Radio Division of the Department of Commerce at Washington.

Harold R. Hunkins has joined the engineering staff of the International Communications Laboratories of New York City. Mr. Hunkins was formerly a student at Harvard Engineering School of Cambridge, Mass.

George W. Kelley, Jr., has been transferred to the design section, Navy Department, Bureau of Engineering, Washington, D. C. from the Norfolk Navy Yard at Portsmouth, Va.

L. E. West, until recently in the engineering department of the

Grigsby-Grunow Company of Chicago, is now engineer with E. T. Cunningham, Inc., of New York City.

Orville M. Dunning, formerly engineer with Acoustic Products Company of New York City, has recently become chief engineer of Sonora Phonograph Company of Buffalo.

C. K. Jen, until recently with the Moore School of Electrical Engineering, University of Pennsylvania, has become affiliated with the electrical engineering department of Rensselaer Polytechnic Institute of Troy, N. Y.

W. G. McConnell has become engineer with the Southern Radio Corporation at Station WMU, Linden, New Jersey.

E. A. Michelman has joined the engineering and test department of Radio-Victor Corporation,of Camden, New Jersey. He was formerly with the Hammond Radio Research Laboratories, of Gloucester, Mass.

Harold R. Miller recently resigned from the Navy Yard, Boston, Mass., to join the radio engineering department of the Westinghouse Electric and Manufacturing Company at their Chicopee Falls, Mass. plant.

Eugene A. Moore, formerly in the engineering department of Steinite Laboratories at Atchison, Kansas, has joined the engineering staff of the Aircraft Corporation, Atchison, Kansas.

C. P. Sweeny has joined the engineering staff of Bell Telephone Laboratories, New York City.

Arthur F. Van Dyck is now manager of the engineering and test department, Radio-Victor Corporation of America at Camden, New Jersey. Mr. Van Dyck was formerly manager of the technical and test department of R. C. A. in New York City. The latter department has been moved to Camden to constitute the new engineering department.

Earl Arnett has recently assumed the position of chief installation engineer in the General Sound Equipment Company, of Toronto, Ontario.

K. Charlton Black has resigned an instructorship at Harvard University to take the position of physicist with the Boonton Research Corporation at Boonton, N. J.

A. B. Chamberlain has resigned from his position as general manager of broadcasting station WHAM to accept a position with the Buffalo Broadcasting Corporation as chief engineer. Mr. Chamberlain was, at the time of his resignation, chairman of the Rochester section of the Institute.

Edwin B. Dallin, until recently in the sound division of the Naval Research Laboratory at Bellevue, D. C., is now associated with the

Wireless Specialty Apparatus Company, of Boston, Mass., engaged in development and design of radio direction-finders and radio compasses.

A. N. Marzulli, formerly teaching fellow in electrical engineering at Valparaiso University, is now radio engeineer with Temple Corporation of Chicago.

W. A. Murray, formerly assistant professor of engineering in Montana State College, is now assistant professor of electrical engineering at Michigan State College.

Alden C. Packard, graduate student of Harvard Engineering School, has become associated with Heintz and Kaufman of San Francisco as radio engineer.

F. L. Shaw, recently radio editor of the *Providence Journal,* is now associated with United Reproducers' Corporation at Dayton, Ohio, as publicity director.

Proceedings of the Institute of Radio Engineers
Volume 17, Number 11 *November, 1929*

GEOGRAPHICAL LOCATION OF MEMBERS ELECTED OCTOBER 2, 1929

Transferred to the Fellow grade

Massachusetts	Cambridge, 30 State St.	Horton, J. Warren
	Cambridge A, 30 State St.	Richmond, Harold B.
	Chicopee Falls, Westinghouse Elec. and Mfg. Co.	Little, Donald G.
New Jersey	Princeton, 155 Hodge Road	Roberts, Walter van B.
	Rumson	Friis, H. T.
New York	New York City, 411 Fifth Ave.	Bucher, E. E.
	New York City, 10 E. 40th St.	Dubilier, Wm.

Transferred to the Member grade

Dist. of Columbia	Bellevue, Anacostia, Naval Research Laboratory	Hanson, Malcolm P.
Illinois	Chicago, 5746 Drexel Blvd.	Deeley, Paul McK.
	Chicago, 2022 the Engineering Bldg.	Hayes, H. D.
	Chicago, 6222 Woodlawn Ave.	Heselton, Chas. C.
	Chicago, 306 S. Wabash Ave.	Howard, Austin A.
Maryland	Annapolis, P. G. School, U. S. Naval Academy	Giet, G. Robert
Massachusetts	Belmont, 350 Lake St.	Lane, Henry M.
	Tufts College	Kenrick, Gleason W.
New Jersey	Newark, 127 Sussex Ave.	Brach, Leon S.
	Newark, 30 Scheerer Ave.	Goodwin, W. N., Jr.
	Red Bank, 27 Buena Place	Bruce, Edmond
	Riverton, 900 Main St.	Ehle, Francis R.
	Westfield, 519 Alden Ave.	Baukat, Henry W.
New York	Brooklyn, 326 Leonard St.	Canaraciol, Frank E.
	New York City, Associated Press, 383 Madison Ave.	Butterfield, C. E.
	New York City, Intl. Com. Lab., 67 Broad St.	Farrington, John F.
	New York City, 33 W. 39th St.	Henline, Henry H.
	New York City, 195 Broadway	Osborne, H. S.
	New York City, c/o Postmaster, *USS Hannibal*	Hogg, W. S., Jr.
	Port Jefferson, 115 Tuthill St.	Hansell, C. W.
	Schenectady, 2024 Euclid Ave.	Ballentine, Edwin C.
	Schenectady, Radio Eng. Dept., General Electric Co.	Kaar, Ira J.
	Woodside, L. I., 41-06 Fiftieth St.	Rettenmeyer, F. X.
Ohio	Columbus, Dept. of Elec. Eng., Ohio State University	Everitt, William Littell
Pennsylvania	Altoona	Lentz, Charles Roland
West Virginia	Morgantown, 332 Demain Ave.	Colwell, Robert Cameron

Elected to the Member grade

California	San Francisco, c/o E. T. Cunningham, 182 2nd St.	Butler, E. W.
	San Francisco, 274 Brannan St.	Langevin, Carl C.
New York	New York City, USS *Wyoming*, c/o Postmaster	Fielding, Charles F.
	New York City, 463 West St.	Frederick, Halsey A.
	New York City, c/o Postmaster (U. S. Naval Mission to Brazil)	Holden, Carl F.
England	Rugby, Bilton Road, "Ladbrooke" House	Kinman, Thos. H.

Elected to the Associate grade

California	Beverly Hills, Fox Film Co.	Larsen, C. W.
	Covina, 165 No. Covina Blvd.	Ross, M. F.
	Culver City, Hotel Washington	Wersen, David T.
	Huntington Park, 2464 Randolph St.	Kirby, Melvin D.
	Los Angeles, 1839 E. Vernon Ave.	Tami, Joseph, Jr.
	Oakland, 7515 Weld St.	Madison, C. E.
	Oakland, 5555 E. Fourteenth St.	Parkhurst, Edgar L.
	Palo Alto, c/o Federal Telegraph Co.	Harrison, Charles I.
	San Diego, 4558 32nd St.	Farnum, Willis H.
	San Francisco, 242A Hartford St.	Arrigoni, Arthur
	Sawtelle, 1446 Saltair Ave.	Spiller, Cecil Charles
Connecticut	West Haven, 12 Ward Place	Phillips, Ed. I.
Dist. of Columbia	Washington, Hqtr's U. S. Marine Corps	Cole, G. C.
	Washington, Naval Research Laboratory	Hentschel, Ernest R.
	Washington, 4107 Ingomar St., N. W.	Norton, Kenneth A.
	Washington, 226 8th St., S. E.	Wilkie, Harry
Illinois	Chicago, 4111 Ravenswood Ave., E.	Beard, J. Gregson
	Chicago, 744 Addison St.	Gay, Paul F.
	Chicago, 5317 Argyle St.	Hansen, Harvey Bennett
	Chicago, 1532 S. Homan Ave.	Levin, Sam
	Chicago, 2005 Prairie Ave.	Lopes, John
	Chicago, 1865 Daily News Plaza	McClintock, W. S., Jr.
	Chicago, 39 N. La Salle St., Room 1117	Scharf, Joachim Barschach
	Chicago, 4536 Magnolia Ave.	Shultise, Q. M.
	Chicago, 3547 Pierce Ave.	Thorsen, Orville T.
	Chicago, 4003 N. Kildare Ave.	Weibler, Carleton T.

Illinois (cont'd)	Great Lakes, U. S. N. Radio Station	Clark, Thomas F.
	Naperville	Stoos, Jos. A.
	Oak Park, 701 S. Kenilworth Ave.	Weiser, Carl
	Streator, 210 W. Lincoln Ave.	Melody, Bernard J.
Indiana	Valparaiso, P. O. Box 292	Norris, Sam
Iowa	Onslow	Koon, Cecil L.
Louisiana	New Orleans, c/o Tropical Radio Tel. Co., 321 St. Charles St.	Nall, Vance
Maine	Portland, 67 Bradley St.	Ryall, Henry
Maryland	Baltimore, 1626 Warwick Ave.	Cohen, H. A.
Massachusetts	Cambridge, General Radio Co., 30 State St.	Bousquet, Arthur G.
	Dorchester, 65 Monadnock St.	Hardy, Carroll N.
	Mattapan, 55 Goodale Road	Parnes, Henry
	Southbridge, 53 Oliver St.	Yates, Wilfred
Michigan	Detroit, 11391 Marlowe Ave.	Geiger, Arthur H.
	Flint, 830 Paddington Ave.	Lutos, Clifford
	Jackson, 214 N. Pleasant St.	Fortier, Raymond C.
	Jackson, R. R. #1, Harding Road	Lee, Kenneth G.
	L'Anse	Fridgen ,Edward N.
Minnesota	Minneapolis, 3519 24th Ave., So.	Kelly, James, Jr.
Missouri	Jefferson City, Radio Station WOS	Sloan, Fergus M.
	Kansas City, 6500 Paseo	Rippeteau, Chas. Wm.
New Jersey	Ampere, P. O. Box 58	Walz, Richard F.
	Deal, P. O. Box 122	Goodall, William M.
	East Orange, 44 Clifford St.	Pickard Richard W.
	Lawrenceville, Box 132	Schwartz, Lyle H.
	Nutley, 31 Burnett Place	Humphrey, Hartley C.
	West Collingswood, 425 Taylor Ave.	Pettit, Albert R.
	West Orange, 2 Mountain View St.	Jenkins, Robert
New York	Astoria, L. I., 2255 33rd St.	Kunicky, Barney F.
	Brooklyn, 2977 W. 3rd St.	Daniels, Lew
	Brooklyn, 734A Fourth Ave.	Francione, Dominick A., Jr.
	Brooklyn, 180 Driggs Ave.	Mullane, John W.
	Brooklyn, 1872 Douglass St.	Peck, William
	Brooklyn, 689 Lenox Road	Renke, Adolph
	Brooklyn, 1430 Flatbush Ave.	Salzer, Arthur H.
	Brooklyn, 64 Linden St.	Thomas, Edward H.
	Brooklyn, 2076 66th St.	Widmann, Erwin
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	Long Island City, 481 Grand Ave.	Holzinger, Theo. E.
	Middletown, 174 W. Main St.	Dempsey, William E.
	Mt. Vernon, 8 Beekman Ave.	Macalpin, William W.
	New York City, Bell Tel. Labs., 463 West St.	Bauer, Brunton
	New York City, Bell Tel. Labs., 463 West St.	Boesche, F. W.
	New York City, 2748 Holland Ave.	Boltson, Jacob A.
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	New York City, c/o E. T. Cunningham, Inc., 370 7th Ave.	Carroll, Michael J.
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	New York City, 3985 Saxon Ave.	Gihring, Herman E.
	New York City, 261 5th Ave., Room 1800	Gladkov, Cyril A.
	New York City, 1056 Boston Road	Hirsch, Harry
	New York City, Bell Tel. Labs., 463 West St.	Hudack, John Martin
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	Schenectady, General Electric Co., Room 419	Ferris, Warren Robert
	Schenectady, General Electric Co., 1 River Road	Thompson, B. J.
North Carolina	Raleigh, c/o Radio WPTF	Newman, John W.
Ohio	Canton, 1030 Clarendon Ave., S. W.	Ellis, Walter R.
	Cleveland, 2049 Cornell Road	Fowler, J. Randall
	Dayton, 521 Negley Place	De Weese, HerbertWilliam
Oklahoma	Asher, c/o Prairie Pipe Line Co.	Lewis, John B.
	Oklahoma City, 103 W. 13th St.	Miller, Wayne
	Oklahoma City, 1633 W. 11th St.	Stokes, Ray
Oregon	Salem, 555 Belmont St.	Churchill, H. B.
Pennsylvania	Lansdowne, 260 Green Ave.	Warren, S. Reid, Jr.
	Philadelphia, c/o Howson & Howson, 123 So. Broad St.	Cerstvik, Stephen
	State College, Acacia Fraternity	Long, Marvin
Rhode Island	Providence, Brown University	Andrews, Howard L.
	Wakefield	Taylor, Alfred R.
Texas	Tyler, Tyler Commercial College	Lowrey, Byron G.

Canada	Kingston, 164 Queen St.	Tanner, Chas. J.
	Montreal, 835 Ave. Laurier est	Tremblay, Jas.
	Toronto, Ont., 64 Hayden St.	Campbell, Henry Lawson
Channel Islands	Guernsey, King's Road, Millbrook	Manning, William Montagu
England	Dorchester, Dorset, Marconi's Beam Transmitting Station	Clarke, Douglas F.
	Plymouth, 49 Greenbank Ave.	Curd, David A.
	Sunderland, Southwick, 12 Dryden St.	Joice, W. S.
	Wisbech, Cambs, Gorefield, "Palestine"	Holmes, Cyril T.
India	Bangalore, Hebbal Post, Indian Institute of Science, Dept. of Elec. Technology	Doraswamy, M. N.
New Zealand	Auckland, Mt. Albert, 9 Veronica Ave.	White, Russell G.
Philippine Islands	Manila, Philippine School of Arts and Trades	del Rosario, Manne S.
South Africa	Klipheuvel, C. P., Wireless Station	Nutt, A.
	Salisbury, S. Rhodesia, Automatic Exchange, Box 391, G. P. O.	Jephcott, Ernest L.
South Australia	St. Peters, 42 Nelson St.	Linnett, Douglas N.

Elected to the Junior grade

Colorado	Durango, P. O. Box 594	Dieckman, Wm.
Illinois	Carbondale, 800 W. Pecan St.	Chapman, David E.
	Chicago, 4509 N. Robey St.	Chadwick, Ray E.
	Chicago, 7404 Bennett Ave.	Nardin, George F., Jr.
	Litchfield, 224 Van Buren St.	Weller, Earl Selwyn
Kansas	Wichita, 605 Laura Ave.	Demuth, G. W.
Massachusetts	Brockton, 17 E. Ashland St.	Sampson, Edward J. F.
	Worcester, Y. M. C. A., Room 319	Anderson, Paul E.
Missouri	St. Louis, 946 Belt Ave.	Martin, J. Douglas, Jr.
New York	New York City, 3164 Grand Concourse	Linde, James E.
Pennsylvania	Philadelphia, 224 E. Sharpnack St.	Bosco, Joseph F.
	Upper Darby, 6994 Ruskin Lane	Slattery, John J.
South Dakota	Sanator	Tilgner, Shelton R.
India	Benares City, 56 Luxa	Ghosh, B. N.

Proceedings of the Institute of Radio Engineers
Volume 17, Number 11 *November, 1929*

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 November 30, 1929. These applicants will be considered by the Board of Direction at its December 4th meeting.

For Transfer to the Fellow grade

Ohio	Cincinnati, 5449 Hamilton Ave.	Langley, Ralph H.

For Transfer to the Member grade

California	Hollywood, 1041 N. Formosa Ave.	Hilliard, John K.
New Jersey	East Orange, 102 N. Arlington	Towner, Orrin W.
New York	New York, Western Union Tel. Co., 195 Broadway	Coggeshall, Ivan S.
Pennsylvania	Wilkinsburg, 435 Avenue D	Beers, G. Lisle

For Election to the Member grade

New York	New York City, Dept. of Commerce, Radio Service, Subtreasury Bldg.	Fish, Arthur S.
Philippine Islands	Manila, Fort Santiago, Radio Cable and Telegraph Office	Rives, Tom C.
Poland	Warsaw, Wspolna 32	Plebanski, Jozef
	Warsaw, Mokotowska 6, Institute Radiotechnique	Sokolcow, Dmitri M.

For Election to the Associate grade

Alabama	Ensley, 3000 Pike Ave.	Sartain, L. B., Jr.
California	Los Angeles, 3686 S. Main St.	Dale, James Albert
	Los Angeles, 315 La Bertha Apts., 960 S. Oxford Ave.	Dickson, H. L.
	Los Angeles, 563 N. Hoover St.	Olmstead, Chas. B.
	Palo Alto, 430 Addison Ave.	Morgan, Nathaniel R.
	Palo Alto, Federal Telegraph Co.	Saunders, Wm. W.
	Palo Alto, 1119 Fulton St.	Thomas, Chas. C.
	Palo Alto, 603 Fulton St.	White, Ray H.
	Palo Alto, c/o Federal Telegraph Co.	Whitwam, Lloyd F.
	San Francisco, 285 Turk St.	Schofield, William D.
	Southgate, 8148 Virginia St.	Ott, Ben A.
Dist. of Columbia	Takoma Park, 218 Cedar St.	Mertie, J. B., Jr.
	Washington, Tower Bldg.	Jardine, W. N.
	Washington, Radio Section, Bureau of Standards	Shankland, Robert S.
Illinois	Chicago, 6900 Constance Ave.	Lahman, Wilford C.
Indiana	Elkhart, 340 W. Crawford St.	May, Frank Darrell
Iowa	McGregor, Box 282	Woods, Talmage DeWitt
Louisiana	New Orleans, 2430 Gen. Taylor St.	Lobe, Henry, Jr.
Maryland	Annapolis, R.F.D. #1, Box #41A	North, J. Harold
Massachusetts	Revere, 36 George St.	Gelardi, Matthew
	Springfield, 2713 Main St.	Wilson, R. A.
Michigan	Detroit, 15412 E. Jefferson Ave.	Krause, Harold F.
	Detroit, 2909 David Stott Bldg.	Rollins, G. K.
	Scottville	Krivitzky, George
Mississippi	Greenwood, 800 Henry St.	Johnson, Vivion A.
New Jersey	Hillside, 121 Clark St.	Short, William P.
	Maywood, 96 Washington Ave.	Kersta, Laurence G.
	Merchantville, Greenluyh Court Apt. C-9	Lamont, J. Cutler
	Newark, Brandes Laboratories	Oman, Nils Johann
	East Orange, 28 Irving St.	Cooper, John W.
	Passaic, 23 Passaic Ave.	Rodgers, George H.
	Newark, Brandes Laboratories, Inc., 200 Mt. Pleasant Ave.	Gordon, Malcolm K., Jr.
New York	Babylon, L. I., 194 E. Main St.	Thompson, Edward Philip
	Brooklyn, 1197 E. 34th St.	Castle, Donald Hewitt
	New York City, Western Union Telegraph Co., 195 Broadway	Arnold, John W.
	New York City, Room 505, 89 Broad St.	Beizer, Harold
	New York City, c/o Postmaster, *USS Galveston*	Daspit, L. Randall
	New York City, Room 1915, 195 Broadway	Franklin, L. W.
	New York City, Bell Telephone Labs., 463 West St.	Hartman, Charles D.
	New York City, 2675 Valentine Ave., Bronx	Lake, Daniel A.
	New York City, 358 Wadsworth Ave.	Venable, Richard Neel

New York (cont'd)	New York City, 1115 College Ave., Bronx	Wettermann, John A.
	Riverhead, L. I., c/o Radio Corporation of America	Smith, Arthur Z.
	Rockville Center, 358 Village Ave	Schabbehar, Edwin A.
	Schenectady, 325 Van Vranken Ave	DeNardo, Federigo
	Schenectady, 205 Seward Pl	Dickinson, Theodore M.
	Schenectady, 509 Craig St	Somers, Brock A.
	Schenectady, 109 Furmon St	Zimmerman, Arthur G.
	Scotia, 136 Glen Ave	Smith, J. P.
Ohio	Cincinnati, 3317 Bishop St., Apt. 210	Baird, Robert E.
	Cincinnati, 103 Inwood Terrace	Nunneker, William H.
	Cleveland, 1280 Norwood Road, N. E	Worst, J. S.
	Columbus, 400 W. 7th Ave	Crisante, Aldo
	Columbus, Dept. of Elec. Eng., Ohio State University	Rosenfeld, Millard
	Dayton, 16 Bremen St	Friedman, Harry
Pennsylvania	Allentown, 953 Cedar St	Williams, Thomas R.
	Allentown, 204 S. Fulton St	Young, Charles S.
	Emporium, 301 Poplar St	Brophy, Thomas L.
	Harrisburg, 17 Evergreen St	Howe, David B.
	Harrisburg, 603 Benton St	Kilheffer, Harold E.
	Harrisburg, 1008 N. 3rd St	Knerr, G. Russell
	Harrisburg, 344 Hamilton St	McGary, Oliver H.
	Irwin, Maple St	Brook, Alf.
	Philadelphia, 3421 A St	Barton, R. W., Jr.
	Philadelphia, 243 S. Upsal St., Mt. Airy	Blackwood, George C.
	Philadelphia, Navy Yard, Bldg. 67	Holden, Ellis Gray
	Philadelphia, 1813 Green St	McCloskey, James Walter
	Philadelphia, Gladstone Hotel, Apt. 26	Pickett, C. E.
	Pittsburgh, 733 Chislett St	Diamond, Hymen
	Pittsburgh, 1636 Broadway Ave	Gemmell, William H.
	Pittsburgh, 7 Verner Court, N. S	Murray, Alex H.
	Pittsburgh, 6801 McPherson Blvd	Nichols, Harry J.
	Pittsburgh, 7211 Thomas Blvd	Overholt, Ralph, Jr.
	Pittsburgh, 530 Kelly Ave.—21	Richardz, Folke
	Pittsburgh, 301 South Ave., Wilkinsburg Branch	Seaverson, Oswald I.
	Pittsburgh, 915 Vista St., N. Side	Wittgartner, J. S.
	St. Mary's, Speer Carbon Co	Abbott, Harold W.
	Swissvale, Union Switch and Signal Co., Research Dept	Bossart, Paul N.
	Turtle Creek, 310 James St	Gunby, O. B.
	Turtle Creek, 160 Brown Ave	Seabert, J. D.
	Turtle Creek, 131 Grant St	Walker, M. C.
	Verona	Wildow, Paul
	Wall	Popsack, Andrew A.
	Wilkinsburg, 8021 Susquehanna St	Aggers, C. V.
	Wilkinsburg, 206 Union St	Ellis, Grenville Brigham
	Wilkinsburg, 1114 South Ave	Gillette, K. G.
	Wilkinsburg, 1643 Maplewood Ave	Grundmann, Gustave L.
	Wilkinsburg, 841 Holland Ave	Karns, Melvin E.
	Wilkinsburg, Westinghouse Club	Upsahl, E.
	Wilkinsburg, 1318 Singer Place	Simpson, Virgil R.
Texas	Waco, 520 Austin Ave	Barnes, Wilmer N.
Washington	Seattle, 904 E. Pike St	Gable, M.
Wisconsin	Milwaukee, 1007 Murray Ave	Paul, Geo. Stewart
	Plymouth, 914 Eastern Ave	Limberg, Raymond A.
Canada	Toronto, Ont., 2373 Bloor St., W., Apt. 3	O'Brien, J. E.
China	Shanghai, Chinese Govt. Elec. Works, 862 Ave. Haig	Tsiang, Cheng-Yen
England	Cardiff, 8 New St., c/o B. W. M. S. Ltd	Yates, Ivan
	Sandenstead, Surrey, 24 Florence Road	Clear, K. Y.
Hawaii	Honolulu, Wailupe, U. S. Naval Radio Station	Hammond, W. Murray
	Honolulu, 80 Merchant St	Hoover, J. F.
Holland	Hilversum, 1 Arnbalaam	Bouman, J. A. J.
Italy	Milano, Corso Sempione 95	Bacchini, Cesare
Nova Scotia	Halifax, c/o Western Union Tel. Co., Cyrus Field	Nelma, Arsene
Scotland	Edinburgh, 6A Royal Circus	Gee, Harry L.
South Africa	S. Rhodesia, Salisbury, Automatic Exchange Box 391	Jephcott, Ernest L.

For Election to the Junior grade

California	Los Angeles, 1136 S. New Hampshire Ave	Bilkie, W.
Georgia	Atlanta, P. O. Box No. 742	Barker, Howard J.
	Atlanta, 65 Roswell Road	Stapp, Jack
Illinois	Chicago, 1758 Sunnyside Ave	Allain, Joseph A.
Massachusetts	Mattapan, 12 Tennis Road	Rothberg, Joseph
Michigan	Detroit, 8959 Clarion	Ludvigsen, Leonard E.
Nebraska	Lincoln, 117 S. 17th St	Koch, J. Wesley
New York	New York City, 1662 Hoe Ave., Bronx	Flaum, Joe
Pennsylvania	Turtle Creek, 839 Maple Ave	Guzik, Joseph
England	Neasden, Middlesex, "Porthmeor," West Way	Floyd, William F.

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Part II

TECHNICAL PAPERS

TECHNICAL ACHIEVEMENTS IN BROADCASTING AND ITS RELATION TO NATIONAL AND INTERNATIONAL SOLIDARITY†

By

Symposium Committee of the Institute of Radio Engineers

Prepared for World Engineering Congress
Tokio, Japan, October, 1929

1. Introduction, by Alfred N. Goldsmith.
2. Radio Broadcasting Transmitters and Related Transmission Phenomena, by Edward L. Nelson.
3. The National Broadcasting Company—A Technical Organization for Broadcasting, by Julius Weinberger.
4. Speech Input Equipment, by D. G. Little.
5. Wire Line Systems for National Broadcasting, by A. B. Clark.
6. Radio Broadcasting Regulation and Legislation, by J. H. Dellinger.

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†The Institute of Radio Engineers was invited by the American Committee of the World Engineering Congress to participate in the technical program of the World Engineering Congress, held in Tokio in October, 1929, and was asked to present a paper on "Technical Achievements in Broadcasting and Its Relation to National and International Solidarity."

The Board of Direction of the Institute accepted this invitation and appointed a Symposium Committee with membership as follows: Alfred N. Goldsmith, chairman; Edward L. Nelson, Julius Weinberger, D. G. Little, A. B. Clark, and J. H. Dellinger.

The papers published in the following pages are the individual contributions from members of the Committee.

C. W. Latimer, who was present as one of the Institute's delegates, presented the papers before the Congress on behalf of the Institute.

Proceedings of the Institute of Radio Engineers
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INTRODUCTION*

By
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A GROUP of radio engineers, upon invitation of the American Committee of the World Engineering Congress to be held at Tokio in 1929, has arranged to present to the Congress a related series of papers on various technical aspects of radio broadcasting. Each of the contributing authors has chosen a section of the subject in which he has specialized, and has presented in his contribution to this symposium a summary of past achievements, present problems, and some of the probable lines of future development of this division of radio broadcasting. In the aggregate, therefore, the symposium papers constitute a general summary of the more important technical aspects of radio broadcasting, though necessarily in compact form and with consideration only for major questions.

In this general introduction to the collected symposium papers, it has seemed advisable to restrict the discussion to certain matters of general importance to any nation in which broadcasting is now carried on. More particularly it is self-evident that national solidarity and radio broadcasting have some definite and vital relations to each other;—a closer examination of the nature of these relations may therefore constitute a suitable preface to the symposium papers.

The radio instrumentalities and methods to be described in these papers are the component elements of the greatest system of mass communication which has as yet been evolved by mankind. The possible accomplishments of this method of mass communication are necessarily limited by the performance of the apparatus and systems in question; and accordingly the future increase in the influence of radio broadcasting will measurably depend upon the technical progress which can be expected. It is therefore also appropriate in this introduction to consider the relationship between the quality of national broadcasting service and the engineering devices and methods which are available for such service.

1. Influence of Transmitter Power on National Broadcasting Service

It has apparently been believed by some that an indefinite increase in the power of transmitting stations would in each case result in a corresponding improvement in broadcasting service. When only the

* Dewey decimal classification: R550. Original manuscript received by the Institute, January 4, 1929.

low powers heretofore used for broadcasting (0.5 to 5 kw) were under consideration, such a belief was comprehensible. However, in order to reach each member of a great audience with clear and acceptably powerful signals, it has now become evident that powers from several tens of kilowatts to hundreds of kilowatts are required. Nevertheless, a limitation of economically feasible and technically desirable power results from the existence of fading phenomena in radio transmission on middle frequencies which, first intruding at distances of approximately 75 to 150 miles (120 to 240 km) from the transmitter, render any increase of power of limited value for improving service in the "fading zone." Whenever fading is so rapid in such regions as to cause quality distortion, an increase of transmitter power can contribute very little to the situation. On the other hand for regions inside the fading area, or for regions considerably outside the rapid fading area (say at distances of from 300 to 400 miles, or 500 to 700 km), increase of power does in general result in an improvement in service, and particularly for the rural listeners. The criterion governing the amount of power to be used is that the transmitter shall lay down a signal which will over-ride interference, either man-made or natural, at the inner boundary of the fading zone without, however, producing excessive local interference near the transmitter (assuming the transmitter to be appropriately located in a relatively sparsely populated neighborhood). As previously stated, it would appear that powers as high as hundreds of kilowatts will be required for broadcasting service capable of meeting such standards. This result should not be entirely unexpected when it is realized that approximately equal transmitter powers are required for reliable telegraph communication over any considerable distance, even with skilled receiving personnel equipped with elaborate receiving apparatus and antennas.

2. Influence of the Assignment of Definite Frequency Bands to Individual Transmitting Stations

The healthy national (and international) expansion of broadcasting is dependent upon an orderly arrangement of broadcasting stations, not only in each country, but in neighboring countries as well. If stations are not assigned to definite frequency bands or channels, or if these channels are haphazard in their arrangement, numerous cases of local interference will result, and radio reception in large areas may well become repellent rather than attractive to the listeners.

For this reason the study of available frequency channels for broadcasting, and their assignment to individual stations in a systematic and carefully planned fashion, are among the major factors in rendering radio broadcasting useful to a nation.

3. Influence of the Network Syndication of Programs on National Broadcasting

It is clear that program-producing facilities will in general be unevenly distributed throughout a nation. Frequently most of the artistic and literary ability suitable for entertainment programs of high quality is concentrated in a relatively small number of large cities. This results from economic and group-concentration causes. If the programs originating in such centers of available program material and showmanship are broadcast only locally, it is obvious that a large portion of the country of average size will fail to receive the major benefit of broadcasting. Without detracting from the value of purely local programs from certain stations, it is clear that network syndication of programs (for example, by wire-line distribution or its equivalent to a group of outlet stations all radiating these programs) is a definite national necessity. It enables the coordinated distribution on a large scale of programs which would otherwise be economically unjustified or physically unavailable except in a few portions of the country.

4. Influence of Increase in Fidelity of Tonal Reproduction in Receivers

One of the limitations of radio broadcasting is found in the quality of reproduction of the receiving set and the loud speaker which may be furnished to the individual listener. Inasmuch as the intelligibility of speech and the quality and naturalness of music are determined by the fidelity of reproduction, the influence and importance of broadcasting to a nation is directly related to the fidelity of the average radio apparatus employed by its citizens. The conclusion may be drawn that the use of obsolescent or obsolete receiving sets by any considerable portion of the population of a country will greatly reduce the influence of radio broadcasting and will warrant strenuous efforts to improve the quality of such inferior receiving equipment.

5. General Technical Aspects of Transmitter Service Area, of Receiver Selectivity, of Network Distribution, and of Receiver Fidelity

Inasmuch as the national influence of broadcasting is dependent upon the extent to which its message successfully reaches great masses of people, and since this extent may be evaluated more or less quantitatively, it is desirable to consider more specifically each of the preceding aspects of radio broadcasting.

The service rendered by a broadcasting station is satisfactory to the population only within a region defined as the "service area." It is difficult to specify exactly the limits of the service area. Rural listeners have been known to be content, or at least not openly rebellious, when the radio service delivered to them corresponds to field strength of received signals of as little as 0.01 mv per meter. It is quite certain, even in the rural districts where man-made electrical disturbances are at a minimum, that such field strengths cannot long continue to satisfy the listener.

Up to a few years ago, it was believed that listeners in urban districts should be well satisfied with field strengths of the order of 10 mv per meter. This value was then thought to be adequate to overcome local man-made electrical disturbances and natural summer atmospheric disturbances. Urban listeners have shown an increasing tendency to regard such signal field strengths as inadequate for satisfactory service; and in some districts appear to regard strengths from 30 to 100 mv per meter as not only reasonable but highly desirable.

The field strength at which interference became objectionable in receiving sets of limited selectivity, such as were used a few years ago, was approximately 20 mv per meter. There is no question that field strengths from 100 to as much as 1,000 mv per meter are now at least tolerated in limited districts in the neighborhood of transmitting stations, particularly if such stations are giving excellent service to large areas.

In summary, it would appear that a full utilization of radio broadcasting by any nation involves acceptance at some reasonable date by each nation of the principle that the field strengths required for rural service are between 1 and 10 mv per meter, and for suburban and urban service from 20 to 100 mv per meter, and that objectionable interference begins at field strength values well in excess of 100 mv per meter. It is not to be expected that the radio art will accept such standards immediately, but they are obviously along the trend of present development.

In the second place, the assignment of definite channels to transmitting stations specifies, in turn, the requisite selectivity. Receivers should be sufficiently selective to enable the separation of all local stations in a given district (unless the listener is located extremely near to one or more of the stations), but should not attenuate the sidebands of individual transmissions to such an extent as to injure noticeably program quality.

In considering the best methods of syndicating programs over wire networks, the existence of the fading zone of each station of adequate power will determine in some measure the proper location of the adjacent outlet stations. Presumably each pair of outlet stations should be so located that the overlap of the service areas of such adjacent stations does not constitute a high percentage of the area served by either station. In general, this will require a separation for stations having a power of the order of 100 kw of something between 100 and 200 miles (160 to 320 km) although local conditions (nature of intervening territory, ground and building absorption, distribution of population, and the like) will require consideration in determining the most effective location of the outlet stations.

In considering the fourth point of fidelity of reproduction by the receiver, it should be remembered that the obvious aim of broadcasting is to create an approximation to the "illusion of reality" in the home of the listeners. That is, the speech or music reproduction should be such that, so far as possible, it gives the impression of the original studio rendition. As yet radio engineering has not enabled more than a fair approximation of this standard to be commercially available. The expansion of national broadcasting involves a continuous raising of standards in this direction among the listeners at large, many of whom are in the unfortunate position of using equipment incapable of giving any fair idea of the qualityof programs transmitted by modern broadcasting stations and received on high-grade receivers.

6. Influence of National Conditions on the Success of National Broadcasting

Inasmuch as it is desired to reach every listener in a country consistently with adequate signal strength, national broadcasting can be best carried out under the following circumstances:

(a) On such transmitting frequencies as will minimize fading and static. The lowest frequencies in the generally used broadcasting band from 550 to 1500 kc are, therefore, suitable for high-power transmission on cleared channels, particularly when absorption in urban areas (which increases rapidly with the transmission frequency) is taken into account.

(b) Over a terrain of such character that no highly absorbing ground conditions exist and that no extensive mountain ranges intervene. Certain types of territory have a marked attenuation for radio waves and render it extremely difficult or impossible to provide a uniform signal distribution to the listeners. At best, it is a serious problem to supply a reasonably constant signal strength to all listeners at approximately the same distance from the transmitter.

(c) In countries of comparatively small extent. If a country having an area of several million square miles must be supplied with broadcasting service, and if portions of this country are sparsely settled, or are of mountainous or desert character, the problem of distribution becomes highly complicated and involves careful planning to give a reasonably satisfactory service on an equitable basis to most listeners.

(d) If the entire country lies within a single time zone. When on the other hand, there is for example a three-hour time difference between the eastern and western sections of any country, there will be but one hour available between 8 o'clock and midnight each evening (which is the most desirable broadcasting period) when all listeners will be able to receive a given program. Obviously, economic considerations make it difficult to distribute sponsored programs (of advertising character) over areas where considerable time differences exist. Time differences reduce the maximum population which can be simultaneously reached by a national or international program, though to a less extent on holidays.

(e) In countries having nearly uniform population density. If large areas in a country are sparsely populated, it will be difficult to serve such areas economically since most of the power transmitted by radio to such regions will be lost. On the other hand, if certain regions include extremely densely populated areas, in general the steel construction in such areas will result in marked attenuation of the signal waves and great difficulty in giving uniform service to the listeners in such regions. Furthermore, such densely populated areas, in general, have a high noise level due to man-made electrical interference. The ideal location of a transmitting station is in a region with scant population within five or ten miles outside of which lies an area of approximately uniformly populated territory. Of course, such conditions do not exist in general; and a compromise location for the transmitting station must be sought in each instance.

7. Influence of Various Systems of National Program Distribution

Assuming as an ideal that it is desired to reach every broadcast listener with reliable program service, there have been proposed a number of possible methods. The utilization in most countries of a single large station to cover the entire country is clearly not feasible because of the limitation of service area resulting from fading phenomena. A great multiplicity of small stations, some of which at least are operated on exactly the same radio frequency (synchronized stations) has also been proposed. The economic limitations imposed by wire-line network costs make such a plan apparently unsuitable for countries of any considerable size.

The present probable trend, for each national network, is toward comparatively high-powered stations (of from fifty to several hundred of kilowatts in the antenna), with perhaps a limited number of smaller synchronized stations operating on the same frequency as the nearest high-powered station and intended primarily to "fill-in" certain highly attenuating districts where the absorption of the radio waves is so high as to preclude reasonably uniform service for any reasonably distant station utilizing an economic amount of transmitter power. Depending upon terrain conditions, areas of from 10,000 to 50,000 square miles (25,000 to 130,000 square km) can be reasonably well served by such a single station.

In order to provide program diversity, two or more groups of such stations have been established or are planned in certain countries, enabling each coordinated group to send out a different network program. This system of multiple network operation of groups of high-powered stations (with perhaps a limited number of synchronized smaller stations to supply service in regions of unusually high attenuation) represents the latest available practice in national program distribution.

8. National Influence of Various Types of Programs

An examination of radio programs at once discloses a line of demarcation between purely local and definitely national programs. Local programs may be broadly defined as those appealing to a limited number of listeners, in a certain locality. They have a personal quality which makes them attractive to such persons, but of comparatively little interest outside of the limited district in question. Clearly such programs are unsuited for national network syndication.

In contra-distinction, there are certain types of entertainment and educational programs of relatively impersonal nature which, nevertheless, appeal broadly to the entire population of any fairly homogeneous country. Such programs generally originate in the centers of culture or entertainment of the country in question and, if carefully planned, are suitable for national distribution.

It is clear that the latter type of program is of importance in the promotion of national solidarity whereas the local program, despite its personal appeal, readily tends toward a purely provincial character. How far each form of program should be encouraged involves a delicate decision as to the relative merits of programs which stimulate national consciousness and those which, while undoubtedly picturesque in many instances, nevertheless, are essentially local or provincial in character. Perhaps a suitable compromise would involve the occasional introduction of a local type of program over the national networks, whereby the entire population of a country may become aware of the peculiar and frequently likable characteristics of a section of the population.

9. General Classification of Programs and Their National Aspects

There are many possible systems for the classification of programs, most of which are more philosophical or ultra-professional than practical. Programs are also rendered comparatively difficult of classification because the boundary lines between various types of programs are necessarily nebulous and individual programs may include a number of diverse constituent elements.

Entertainment programs appear to be most popular and generally comprise musical material, accounts of sporting events, radio dramas or comedies, and the like. When carefully planned, they are a powerful force for the cultivation of a national musical and artistic taste and, by carrying these various types of entertainment even into remote parts of a country, they are bound to reduce any gap in culture existing between different sections of the population. Undoubtedly they are an important factor in the promotion of a homogeneous national taste and spirit.

A certain large group of programs may be classified as educational. This group includes lectures on pure and applied sciences, the arts, industries, (and, in general, such material as may be included in university lecture courses open to the public). It also includes political discussions, and has been held by some to embrace news reports as well.

Such programs undoubtedly are of great value in welding a nation together into a well-defined political unit and also, under favorable conditions, in placing its culture and viewpoint directly before other nations. The spread of knowledge is furthered by such programs which, it may be mentioned, are as well a powerful agency toward the creation of a single language used and pronounced identically in all portions of the country which is served. It is not necessary to point out further the essentially unifying characteristic of such programs for any nation.

A third group of programs which have both national and international aspects are those which are religious in character. Such programs include both sectarian and non-sectarian presentations. In most instances, the latter have been found to be more suitable for national distribution. Tolerance and mutual understanding are promoted by such programs, and it is therefore believed that presentations of religion, ethics, and morals are an important and permanent portion of any well-balanced plan for national broadcasting.

There are in addition numerous non-technical problems involved in connection with the national aspects of broadcasting. Many complicated questions of national policy arise. To what extent shall governments scrutinize or even censor programs in times of peace? In what measure shall the doctrine of the "freedom of the press" be held to apply to national broadcasting? On what basis, if any, shall this great system of mass communication be restricted in scope or choice of material by other forces than the dictates of common sense and good taste?

These and other questions intimately connected with the influence of broadcasting upon national solidarity affect all national legislation and broadcasting procedure and are complicated problems to which only the future evolution of mankind and of broadcasting can give the answers.

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RADIO BROADCASTING TRANSMITTERS AND RELATED TRANSMISSION PHENOMENA*

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THIS paper is a brief discussion of recent developments in American practice concerning radio broadcasting transmitters. Descriptive material and photographs pertaining to several new commercial transmitting equipments are included. Reference is also made to the more important aspects of the related transmission problem. On account of the scope of the subject, the treatment is necessarily superficial, but it may serve to indicate the present status of the transmitter art and its relative position with respect to the industry as a whole. A short bibliography containing some of the more important recent contributions to the subject is attached as an appendix, to which reference may be had for more detailed information.

RADIO TRANSMITTERS

The radio transmitter is essentially a focal point in the present-day broadcasting system, since upon it the program circuits converge and from it the radio distribution network emanates. For this reason, the requirements which have been imposed on transmitting apparatus are extremely rigorous, and all phases of transmitter performance have been subjected to the most careful scrutiny. Under these stimulating influences, the last few years have brought about some very noteworthy advances in this portion of the broadcasting field.

As long as music and entertainment continue to hold a prominent place on broadcasting programs, fidelity of transmission will probably remain the most sought-for characteristic, not only for the radio transmitter itself, but for all of the apparatus units in the system. A very high standard of performance has now been attained in this respect. Fig. 1, below, shows the overall frequency-response characteristic of a new type 50-kw equipment, the first of which has gone into service at one of the leading American broadcasting stations within the past few months. It will be noted that this characteristic is substantially flat between 30 and 10,000 cycles. The greatest departure from the horizontal line which is the ideal characteristic is less than 1 db. The frequency discrimination which this represents is of such a low order

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that it probably could not be detected in ordinary listening tests, even by a skilled musician.

Another recognized prerequisite to a high degree of fidelity is exact proportionality between audio input and sideband output. Increased emphasis on accurate reproduction has recently led to the

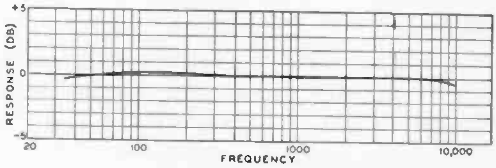

Fig. 1—Frequency-response characteristic of Western Electric 7-A (50-kw) radio transmitter.

introduction of improved technique for checking this important characteristic under dynamic conditions. The method employed consists of impressing a pure sine-wave input on the transmitter at various frequencies throughout the audio range and subjecting the output of a straight-line rectifier to harmonic analysis. One type of harmonic analyzer which has been used with excellent results is that due to Wegel and Moore.[1] This device produces a photographic record, an example of which is shown in Fig. 2. Measurements of this type are

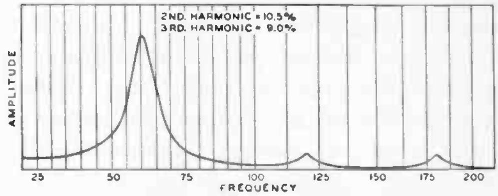

Fig. 2—Harmonic analyzer graph indicating overloading (2nd harmonic, 10.5 per cent; 3rd harmonic, 9 per cent).

of particular importance under present conditions since current American practice is tending toward the extensive use of transmitters in which modulation is accomplished at relatively low power levels and the required power output is obtained by means of subsequent stages amplifying modulated radio-frequency power. Such amplifying stages are susceptible of serious amplitude distortion unless the conditions under which the tubes operate (direct plate and grid voltages and impedance of the connected load) are carefully predetermined. For this

[1] R. L. Wegel and C. R. Moore, "An Electrical Frequency Analyzer," *Bell Syst. Tech. Jour.*, p. 299–323, April, 1924.

purpose, the harmonic analyzer has proved to be invaluable. Through its use, commercial transmitters are now available in which, at the working upper limit of modulation, the harmonics generated are not greater than 5 per cent.

The attainment of such high standards for fidelity leaves little opportunity for progress, and it is improbable that significant advances in this direction will be made in the near future. Accordingly, in continuing their efforts toward further improvements in broadcasting service, transmitter engineers have been led to divert their attention to the problem of rendering less conspicuous and objectionable the background of noise and interference which, in the past, has so seriously impaired the artistic effect of programs except in the immediate vicinity of transmitting stations. This is the principal justification for the present movement toward higher power outputs for broadcasting stations. It has also resulted in increased emphasis on the maintenance of a high average degree of modulation, a development which is rapidly bringing about a very perceptible improvement in general broadcasting conditions.

The degree of modulation of the carrier in a radio telephone transmitter is a somewhat intangible factor which necessarily varies rapidly through wide limits during the rendition of a program. With every transmitter, however, there is a definite modulation limit which is a characteristic of the design and which cannot be exceeded without bringing about serious distortion. This limit is an important performance index which, for lack of a better name, has been called "modulation capability." The modulation capability of a transmitter may be defined as the maximum degee of modulation (expressed as a percentage) that is possible without appreciable distortion, employing a single-frequency sine-wave input and using a straight-line rectifier coupled to the antenna in conjunction with an oscillograph or harmonic analyzer to indicate the character of the output.

For a number of reasons, some technical and some economic, many of the broadcasting transmitters in use have been so constructed that overloading of the audio power stage with consequent distortion occurs whenever the degree of modulation exceeds approximately 50 per cent. The usual practice in placing broadcasting transmitters into service consists of determining, by means of a suitable vacuum-tube voltmeter or other "volume indicator," the audio level at the input of the set for which distortion becomes evident. The average operating level is then established at a suitably lower value, frequently 6–10 db. Recently, by modulating at low power levels, transmitters have been produced which are capable of 100 per cent modulation without noteworthy distortion. It is obvious that, if a transmitter of this latter type is employed and the same margin is observed in determining the average audio input level, the resulting sidebands will be twice the amplitude of those produced by a transmitter whose modulation capability is only 50 per cent. To produce equivalent sidebands with a transmitter capable of but 50 per cent modulation requires that the carrier amplitude be doubled or the power output multiplied by four. In other words, insofar as signal-to-noise ratio is concerned, which is the factor that usually determines the coverage of a broadcasting station, the increase in modulation capability mentioned results in an improvement that in the older type of apparatus could only be had by quadrupling the rated output of the transmitter. From the coverage standpoint, the night range of a given station can be approximately doubled in this manner. Since this is accomplished without increase in the carrier power, the outlying zone in which the station may produce serious beatnote interference with others assigned to the same channel will not be extended. Accordingly, the use of transmitters capable of a high degree of modulation is a notable contribution toward the more effective utilization of the medium, which is the outstanding technical problem in American broadcasting today.

Another important factor, from the standpoint of intensive development of the available frequency band, is frequency maintenance. In a system involving so many stations as are now operating in the United States, accurate maintenance of the assigned frequencies presents a very difficult problem. The maximum deviation permitted by the existing government regulations (± 500 cycles) is somewhat beyond the capabilities of the ordinary wavemeter and difficulty has been experienced in obtaining a satisfactory substitute. In the absence of adequate frequency control apparatus, very serious beatnote interference has been of frequent occurrence. During the past year, however, considerable improvement has been brought about by the extensive adoption of piezo-electric reference oscillators and automatic piezo-electric control. Equipment for the latter purpose capable of a relatively high standard of performance is now being offered commercially and it is probable that apparatus of this type will be installed in the near future by the majority of stations. Its use is expected to avoid entirely heterodyne interference on the "cleared" channels, where the beatnotes are those produced between the carriers of stations having adjoining frequency assignments. There is also reason to believe that the general adoption of such apparatus will materially improve conditions on the "shared" channels, each of which is occupied by several stations located at suitable distances, provided the assigned frequencies can be maintained with sufficient accuracy to preclude the reproduction of audible beats or other objectionable interference effects.

This problem of "synchronization," or preferably "common frequency operation," is beginning to receive considerable attention from all factors in the broadcasting industry. It promises important contributions in at least two directions:

(1) Improvements in the coverage of a common service area by two or more stations all broadcasting the *same* program;

(2) The attainment of minimum geographical spacings between stations operating on the same nominal frequency and broadcasting *different* programs.

The degree of frequency maintenance required for these two cases is apparently quite different. For case (1), the evidence indicates that very rigorous requirements must prevail. The most successful operations of this type have employed wire lines connecting the stations for the transmission of a base frequency from which the carriers were derived by means of harmonic generators. For case (2), however, there is reason to believe that comparatively wide limits will suffice.

Experience has shown that if the entertainment value of a program is not to be seriously impaired by interference, the ratio of wanted to unwanted carrier at the receiving point, in terms of field intensity, must be at least 100:1. From a relative interference standpoint, the significant factors are the wanted sidebands, the unwanted sidebands and the unwanted carrier, each of which produces a component in the detector output by interaction with the wanted carrier. With equal modulation at both stations, which is one of the conditions assumed, the ratio of the audio components due to the sidebands will, in general, be approximately the same as that between the carriers, or 100:1, representing a difference in level of 40 db. Due to the frequency difference between carriers, demodulation of one of the unwanted sidebands will result in the original signal with each of its elements shifted upward in pitch by an amount corresponding to this difference, while the other sideband will produce a signal which is similarly displaced in the reverse direction. The interfering signal may be badly garbled, therefore, but its disturbing effects insofar as enjoyment of the program is concerned will be substantially unaffected. The beatnote, which results from the interaction of the unwanted and wanted carriers, will be 6–10 db above this sideband interference level if average practice, as previously described, is followed. From this analysis, it appears that if the beatnote can be held to a value below the lowest frequency which it is desired to transmit and if one of the circuit elements of the reproducing system can be designed to provide some 10 db discrimination against the beat frequency, interference due to the latter can be so subordinated that the service areas of the stations involved will be defined by the limiting condition assumed for sideband interference, or a 100:1 ratio between carrier field intensities. Under these circumstances, no beatnote interference will be experienced in those areas where reasonably good service can be given. In adjoining regions, where the carrier ratio is less than 100:1, beatnote interference may continue to be observed but is of no importance since satisfactory reception in such areas is precluded by the sideband interference.

To meet the requirements outlined, it is probable that ultimately frequencies will have to be maintained to approximately 10 cycles, which would result in a maximum beatnote near the lower limit of aural frequency response. Such precision seems hardly necessary, however, under the conditions existing at the present moment. Almost all loud speakers now commercially available discriminate notably against frequencies below 100 cycles. A material improvement in beatnote conditions could probably be brought about, therefore, by the adoption of automatic control apparatus capable of maintaining the assigned frequencies to ± 50 cycles. Such performance is within the capabilities of the piezo-electric apparatus now available. Under the circumstances it is expected that considerable progress will be made in this direction during the coming year.

The foregoing considerations lead to the formulation of an important system requirement affecting receiving apparatus, which in this case includes both the radio receiver proper and the loud speaker. In a system involving a relatively large number of stations assigned to cleared and shared channels at 10-kc intervals, such as exists in the United States, beatnote interference in the form of components at approximately zero cycles and at 10 kc is an inherent characteristic. If a maximum frequency deviation of ± 10 cycles is accepted as the ultimate limit, in order to avoid such interference the receiving apparatus must be so designed that at frequencies below 20 cycles and above 9980 cycles there will be introduced sufficient attenuation to suppress effectively the beatnotes likely to be encountered under any practical operating condition. Developed in this manner the proposition is more or less self-evident, but due to the rapidity with which the audio spectrum of broadcasting apparatus is being extended, some emphasis on the matter seems desirable.

Still another factor of importance from a system standpoint is control of radio harmonics. Spurious radiation of all types is inimical to intensive development and must be avoided. The harmonic problem presents unusual difficulties since efficiency requires that the tubes in the final power-amplifier stage be used in such a manner that relatively large harmonic voltages are impressed on the output circuit, yet the harmonic power radiated must be held to an extremely small amount. A measure of the purity of wave form required may be gained from the fact that a 5-kw transmitter operating on a good antenna is capable of establishing an electromagnetic field of approximately 0.5 v per meter at a distance of one mile. Under the circumstances, a harmonic of 0.1 per cent represents a field intensity of 500 μv per meter at the same distance. Acceptable service in many areas is being obtained with field intensities of this order of magnitude. To bring the interfering field down to the static level would probably require reduction of harmonics to 0.01 per cent or less. From an apparatus standpoint, such performance represents a very difficult problem and it is questionable if it can be justified at the present time. Practice on this point is still in a state of flux, but there is reason to believe that some intermediate value, such as 0.05 per cent, will prove to be the proper solution, and will be applied to all broadcasting stations in the near future.

One circumstance that has undoubtedly contributed to the delay in formulating definite requirements concerning the control of harmonics has been the difficulty of obtaining suitable apparatus for the evaluation of such components in quantitative terms. Field strength measuring sets have recently been made commercially available, however, which are capable of covering the necessary range in frequency and intensity. A photograph of one of these sets is shown in Fig. 3. It consists essentially of a sensitive, stable superheterodyne receiver incorporating a calibrated attenuator at the input of the intermediate-frequency amplifier and a supplementary radio-frequency oscillator from which a voltage of the frequency of the station under measurement can be introduced in the antenna circuit. The operating characteristics of such an instrument have been described by Friis and Bruce.[2] By means of a series of removable loops and coils, the set shown is capable of measuring field strengths ranging from approximately 0.01 to 7000 mv per meter throughout the band 250 to 6000 kc. Apparatus of this type is now in use by the radio inspection division of the Department of Commerce.

In the light of this discussion of present trends in transmitter development, a brief description of some recent transmitting equipments may be of interest. A particularly noteworthy example of

[2] H. T. Friis and E. Bruce, "A Radio Field-Strength Measuring System for Frequencies up to Forty Megacycles," PROC. I. R. E., 14, 507—519; August, 1926.

current practice is the 50-kw Western Electric transmitter, one of which has been placed in service within the past few months by the

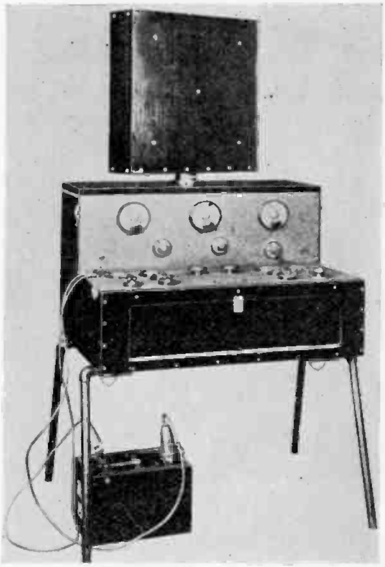

Fig. 3—Commercial field-strength measuring set. Range: 250—6000 kc, 0.01—7000 mv per meter.

Crosley Radio Corporation at Mason, Ohio. Views of this equipment are shown in Figs. 4, 5, 6, 7, and 8. The transmitter proper

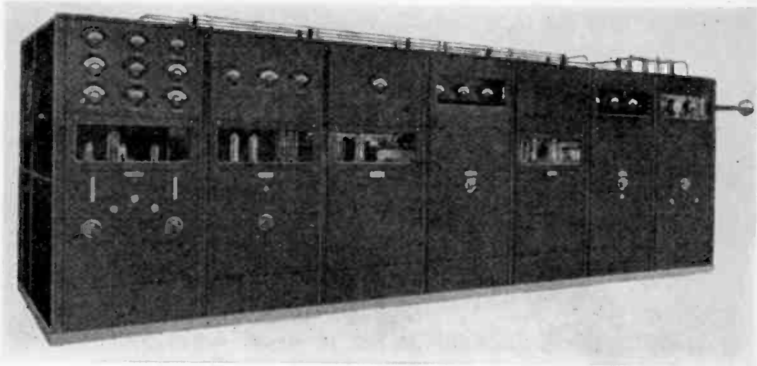

Fig. 4—Western Electric 7-A (50-kw) radio transmitter. Oscillator-amplifier assembly.

is shown in Fig. 4. As will be seen, it consists of seven panel units with a screen enclosure in the rear. The first unit on the left is the oscillator-modulator. This is essentially a low-power transmitter capable of an output of 50 watts and 100 per cent modulation. It is followed by three push-pull stages amplifying modulated radio-frequency power. The first power-amplifier stage, which employs two 250-watt tubes, occupies the second unit. The tubes for the second power stage, which are water cooled, and the associated tuned output circuit are contained in the third and fourth units, respectively. The final power stage, incorporating six water-cooled tubes each capable of a peak output of approximately 40 kw, occupies the fifth unit. The last two panels constitute the front of an electrically screened enclosure housing the output circuits for this latter stage. All of the panels are aluminum covered with several coats of black lacquer grained by rubbing with abrasive paper. A full complement of meters is provided, the cases of which are either grounded or mounted behind glass for the protection of the operating personnel. In designing the equipment, special consideration has been given to safety. Access to the apparatus in the rear of the panels can be had only through the door on the left which is held closed by a bolt operated by the handwheel shown. The rotation of this wheel opens the transmitter control circuits putting the equipment out of operation. It then grounds the high-voltage supply busses and finally withdraws the bolt. As an additional precaution a manually operated disconnect switch for the main power supply is provided just inside the gate which can be opened on entering. Access to some of the tubes is had by opening the glass windows in the various panels, but these are secured by electrically operated latches unless the wheel is in the grounded position. Door switches are provided in the control circuits which prevent the transmitter from being placed in operation unless all doors and windows are closed.

The power panel and rectifier assembly is shown in Fig. 5. The general arrangement corresponds to that of the transmitter proper and similar safety features are provided. In the power panel, which is on the left, are centralized the necessary power distribution and control facilities. The equipment requires a 3-phase input of approximately 250 kw at 440 volts. The control arrangement is such that the transmitter can be started and stopped by means of a single set of push buttons, the various circuits being energized in proper sequence by means of suitable relays and contactors. The central unit is a three-phase half-wave rectifier supplying power at 1600 volts to the plates of the air-cooled tubes. The six-tube rectifier on the right supplies plate power at 17000 volts for the water-cooled tubes. The filament and plate transformers and smoothing filter for the latter are located in the power room on the floor below. The filter consists of two units, one for each side of the push-pull circuit, employing a 6-μf condenser and a 12-henry inductance. Two 24-volt, 550-ampere direct generators (one a spare) supply power to the filament circuits. These machines are slot wound and employ composition brushes, a filter consisting of a 1-mh inductance and four 1000-μf electrolytic condensers being used to suppress commutator and slot ripples. Grid bias voltages are obtained from a 2-kw, 300-volt unit, which is

Fig. 5—Power panel and rectifier assembly for 50-kw radio transmitter.

also installed in duplicate. The only other rotating apparatus is that associated with the water-cooling system. The tubes are cooled by means of distilled water which is conducted to the anodes of the amplifier tubes through insulating hose coils. The total heat transferred by the cooling water is approximately 175 kw. A flow of 75 gallons per minute is maintained. Four 56-in. by 58-in. radiator units are employed, each consisting of a bank of copper tubes with spiral fins over which air is blown by a 37-in. fan. Ample radiator capacity is provided to maintain the water below 180 deg. F under all atmospheric conditions.

To promote antenna efficiency and to reduce the intensity of the electric field in the station building, the equipment is arranged to deliver its output to the antenna through a radio-frequency transmission line approximately 500 ft. long. The line is balanced to ground and is designed for a characteristic impedance of 600 ohms. The antenna coupling and tuning unit is shown in Fig. 6. It is intended for installation in a small building with a grounded copper roof located at the base of the antenna downlead. It consists of two tuned circuits, each housed in separate shielded compartments. In the photo-

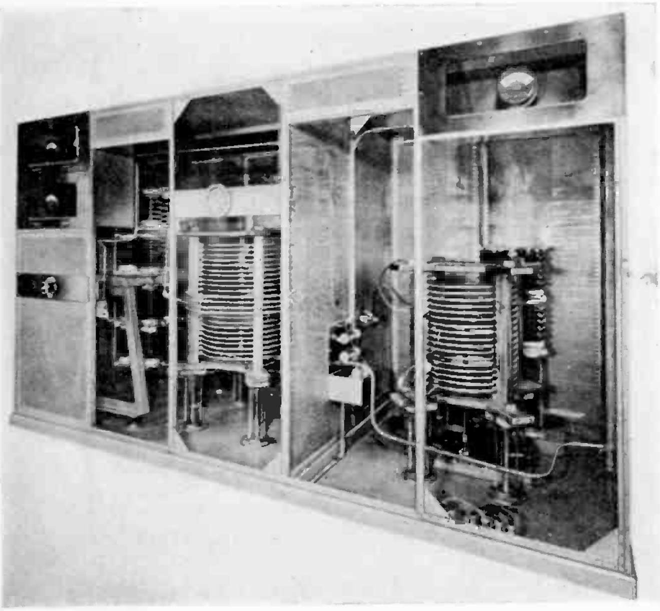

Fig. 6—Antenna coupling and tuning unit for 50-kw radio transmitter.

graph the doors and two of the screen panels have been removed to show the interior arrangement. The line is terminated by the parallel tuned circuit on the left which is inductively coupled to the antenna circuit to preserve an approximate balance to ground. The antenna is tuned by means of the series condenser and coil shown on the right. Accurate adjustment of the inductance of the coil is provided for by means of a short-circuited single-turn secondary which is located within the coil and arranged so that it can be rotated through approximately 90 deg. by the motor mounted on the floor beneath. The latter may be controlled from the operating room by a reversing switch placed on the right-hand panel of the transmitter assembly.

A polyphase position indicator is provided to indicate the angle and movement of the secondary. The direct-current circuit of the thermal ammeter in the antenna circuit is also carried back to a bracket-mounted instrument on the end of the transmitter. These facilities permit the antenna tuning to be checked and adjustments made to compensate for minor variations in antenna conditions without leaving the operating room.

Another feature of interest is the artificial antenna shown in Fig. 7. This unit is essentially a 600-ohm non-inductive resistance

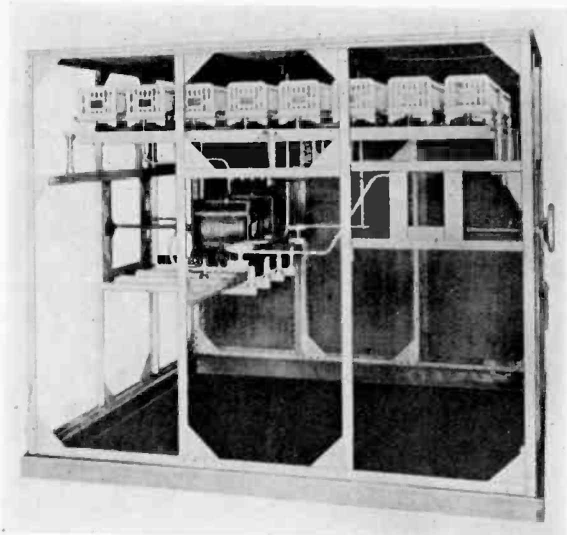

Fig. 7—Artificial antenna for 50-kw radio transmitter.

capable of dissipating approximately 75 kw which can be connected to the output circuit of the final power amplifier stage in place of the transmission line. The heat dissipating elements consist of a series of woven wire grids mounted in the units at the top of the framework. The resistance of these grids is substantially independent of frequency, but the combination presents a slight inductive reactance which is compensated for by means of the condenser and coil combination shown. These elements are inserted into the circuit symmetrically in order to maintain an approximate balance to ground. The structure is completely shielded and is fitted with safety door and grounding switches similar to those already described.

The piezo-electric crystal mounting and temperature-control apparatus which is a part of the oscillator-modulator unit is shown in Fig. 8, dismantled to facilitate inspection. The quartz plates employed are approximately one and a quarter inches square and are cut parallel to one of the faces of the natural rock crystal. This plate is mounted between two lapped metal plates and covered with a porcelain cap carrying a terminal to which the upper electrode is connected by means of a short section of metal foil. The mounted crystal is supported by a brass block, through the center of which extends a spiral bimetallic thermostat. The top of the block is also lapped and the crystal mounting is secured to it by means of the four springs shown. The heating element consists of a winding of resistance wire inserted in the block concentric with the thermostat. The assembly is mounted in a thermally insulated box, shown on its side

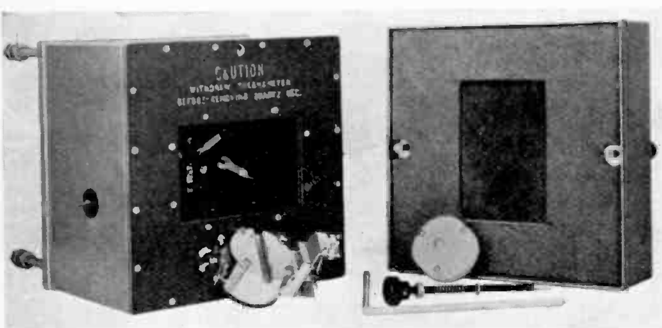

Fig. 8—Piezo-electric crystal mounting and temperature control apparatus.

in the photograph. Two of these units are provided, one located on each side of the oscillator-modulator unit directly below the window. A detachable handle for adjusting the contacts of the thermostat and a suitable thermometer extend through the box to the front of the panel. The brass mounting block is provided with a groove to receive the bulb of the thermometer. The thermostat does not operate directly in the heater circuit but controls the grid bias of a vacuum tube in the plate circuit of which a suitable relay is placed. The quartz plates are ground to oscillate at the assigned frequency at approximately 50 deg. C, and the final adjustment is made by varying the operating temperature. The temperature coefficient of the plates varies from 30 to 100 parts in a million per deg. C. The degree of constancy attained necessarily depends on the diligence of the operating personnel. With proper maintenance the maximum deviation has been held to $\pm$ 30 cycles for long periods of time.

A simplified circuit schematic is shown in Fig. 9. Features of the electrical design are the modulation system, the push-pull amplifier

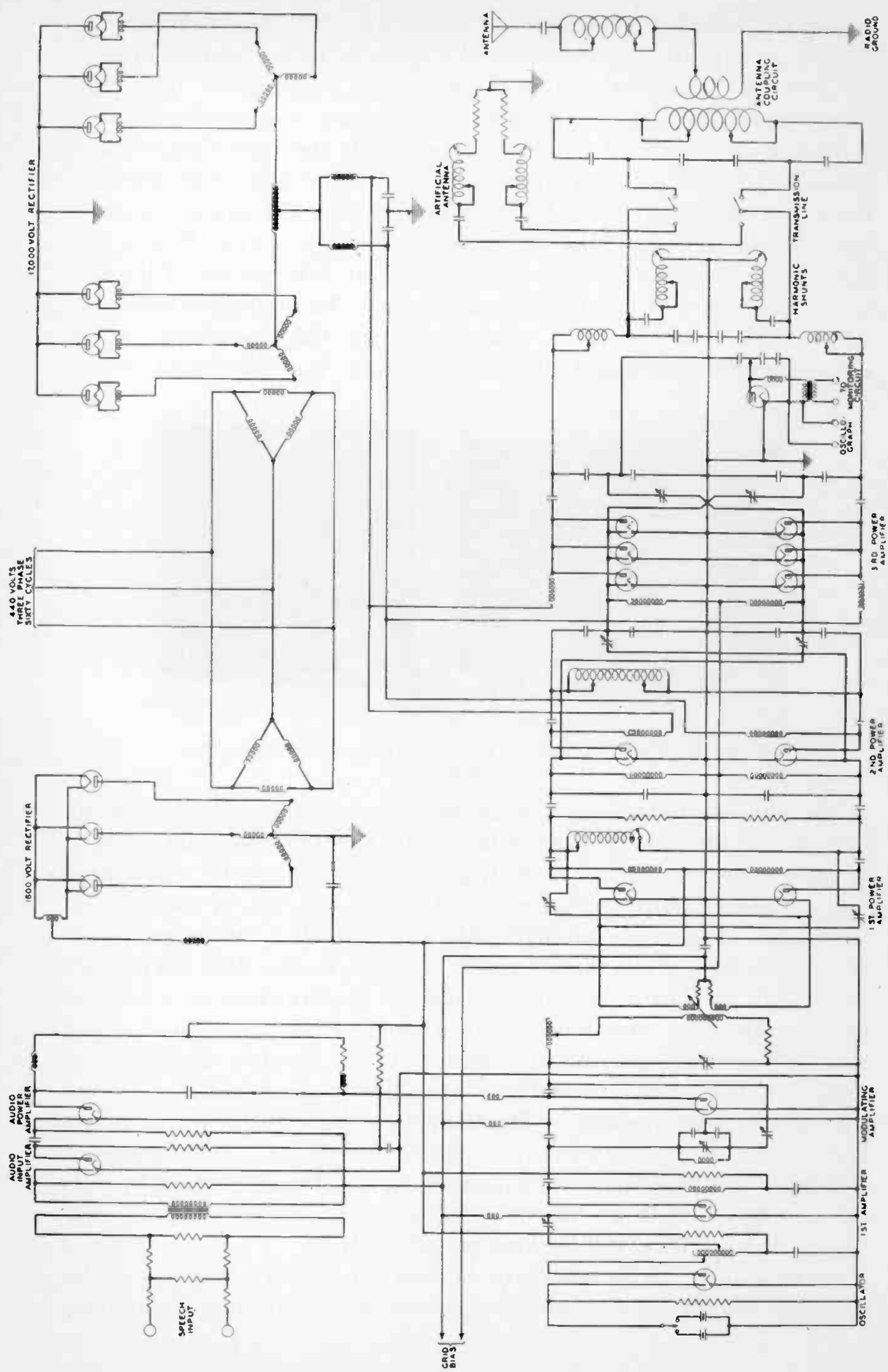

Fig. 9—Simplified circuit schematic of 7-A (50-kw) radio transmitter.

stages with cross neutralization, the capacity coupling arrangement used to facilitate control of parasitic oscillations, and the provisions for the suppression of harmonics. The modulating amplifier is a 50-watt tube operating at 750 volts. The audio power stage employs a 250-watt tube at 1500 volts. In this manner, ample audio-frequency voltage and power are provided to effect complete modulation without distortion in the audio tube. With so powerful an equipment, the suppression of radio-frequency harmonics to a satisfactory degree becomes a difficult problem. The push-pull circuits, capacity coupling, three tuned circuits in cascade, shielding of all coils, and the two tuned

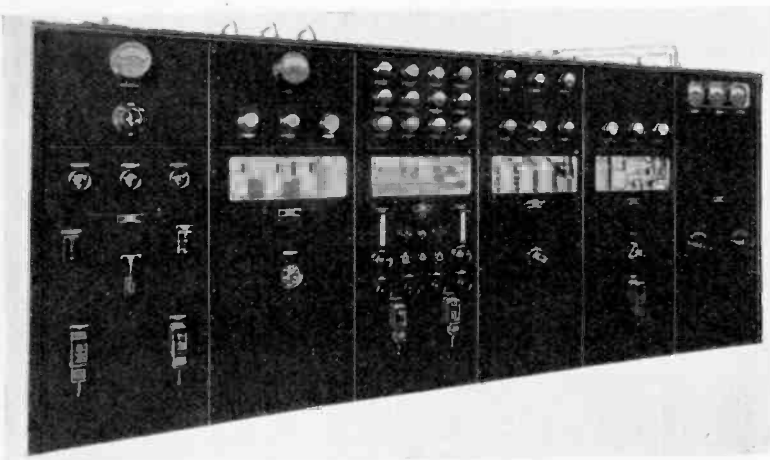

Fig. 10—Panel assembly for Western Electric 5-C (5-kw) radio transmitter.

shunts adjusted to the second harmonic which are connected between each side of the transmission line and ground all contribute to superior performance in this respect. The amplitude of the harmonics radiated, as determined by field strength measurements, is less than 0.03 per cent.

A 5-kw equipment of similar general design is shown in Figs. 10 and 11. It consists of six units: A power panel, a 10,000-volt rectifier for the water-cooled tubes, a piezo-electric oscillator unit, an intermediate amplifier unit, a power amplifier unit employing two 10-kw tubes, and an output unit. An air-cooled transformer for the rectifier, the associated filter, and an artificial antenna are assembled in a screened enclosure in the rear of the panels. Three motor-generator sets are provided to supply filament power, grid bias, and plate power for the air-cooled tubes. A 3-phase power input of 30 kw at

220 volts is required. The equipment is capable of fidelity in transmission comparable with that of the 50-kw unit. The amplitude of the harmonics radiated is held to approximately 0.2 per cent.

A 1-kw equipment of the same type is shown in Figs. 12 and 13. It involves only two panels, a piezo-electric oscillator unit and an amplifier unit. The final power stage employs a 4-kw water-cooled tube. Two motor generators are used, one supplying 24 volts and 250 volts for filaments and grid bias, the other 2,000 volts and 4,000 volts for the plates of the air-cooled and water-cooled tubes, respectively. A power input of 10 kw is required.

Radio Transmission Phenomena

Radio transmission phenomena in the broadcasting band have been given considerable study, and the general nature of the effects

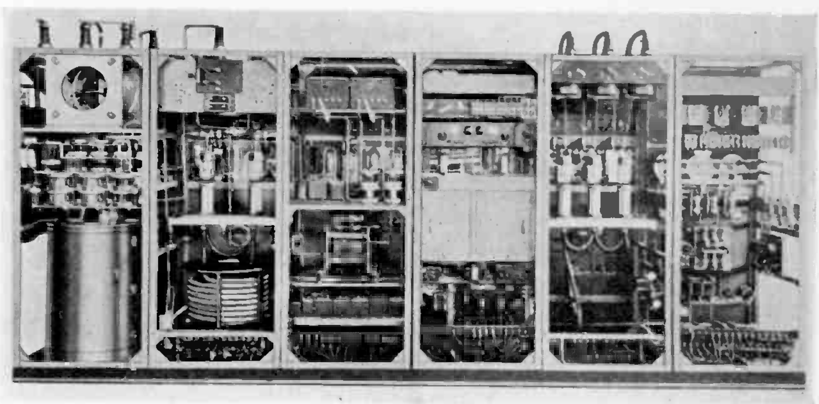

Fig. 11—Rear view of panels in 5-C radio transmitter.

likely to be encountered are fairly well understood. Important contributions have been made by Bown and Gillett, by Bown, Martin, and Potter, by Goldsmith, and by Espenschied.[3] The second paper referred to is particularly noteworthy on account of the insight which it affords into the complexities of the process of transmission and the evidence which it presents concerning the injurious effects of frequency modulation. The latter has not yet fully received the attention which it deserves; many otherwise well designed transmitters are still in operation that are subject to frequency changes of the order of ± 1000 cycles during modulation. This condition is not only conducive to impaired fidelity at moderately distant receiving points,

[3] See attached list of references.

but it increases interference and precludes successful common frequency operation. Fortunately, the use of automatic frequency control apparatus in its present form is effective in minimizing this effect as well as in limiting frequency variations of much longer period. It is probable, therefore, that with the more general use of automatic piezoelectric control, this matter will rapidly cease to be a problem.

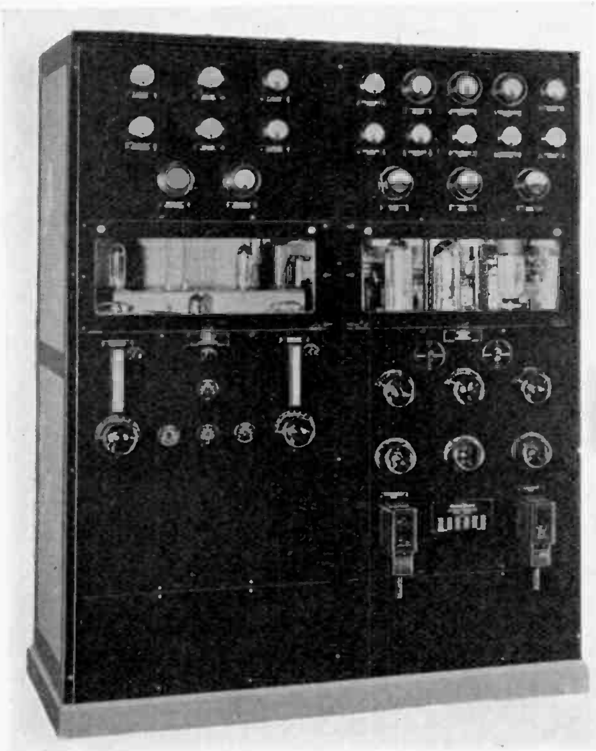

Fig. 12—Western Electric 6-B (1-kw) radio transmitter.

As might be expected, the attention being given to intensive development has materially stimulated interest in transmission. There is a very evident need for much information of a more quantitative nature than is now available. Data concerning attenuation over city and rural areas as a function of frequency, suitable separations between stations of various powers operating on a common carrier frequency, allowable distances between transmitting stations and nearby populous communities, relative day and night ranges, relative summer and winter ranges, time of the day and season of the year at which the transition occurs, and other questions of a similar nature have become of great practical importance. The problem is rendered particularly difficult by the range in climatic, topographic, and cultural conditions which exist in the United States. Under the circumstances, there are excellent opportunities for important work in this field.

A significant tendency disclosed by recent measurement work in a number of city areas is public acceptance of and demand for field

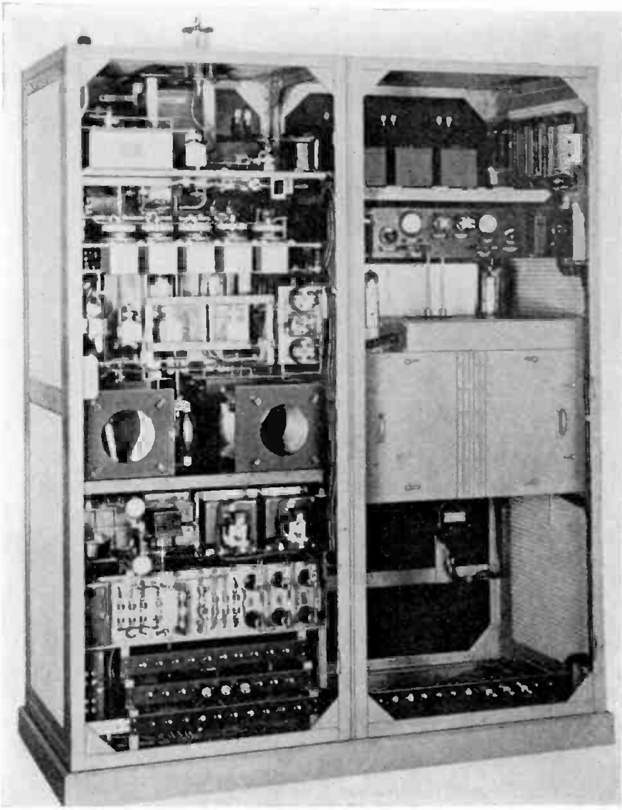

Fig. 13—Rear view of 6-B radio transmitter.

intensities which a few years ago would have been considered objectionably high. For some time it has been more or less generally agreed that a field intensity of 10 mv per meter would afford a satisfactory high-grade broadcasting service. Recently, however, in spite of increased effectiveness due to higher degrees of modulation and in spite of continued improvement in the sensitivity of commercial receiving sets, stations establishing field strengths of 10–15 mv per meter have been greatly handicapped in competing with others capable of producing 30–50 mv per meter in the same areas. In several densely populated districts measurements have disclosed field intensities of 300–500 mv per meter without any noteworthy number of complaints provided the programs were of a high character. There is little to indicate whether this tendency is the result of a decreased interest in distant stations, a desire for higher standards in reproduction involving lower noise levels, or a combination of these factors with others, but it is evidently a matter which must be given careful consideration in engineering future installations.

It is interesting to contrast this situation with that existing in some of the large rural districts as exemplified by the recent survey of conditions in the Middle West by Jansky.[4] Here over large areas acceptable service is being obtained with field strengths of 50 and 100 μv per meter. Giving due consideration to the difference in noise levels, which is undoubtedly a factor of great significance, such a discrepancy can only be reconciled on the basis of a vast difference in service standards. That such conditions will be allowed to continue for any considerable period of time is very doubtful. This is further evidence indicating that the movement toward more powerful stations is technically sound.

One phase of the transmission problem which deserves increased attention is antenna performance and design. It is an interesting circumstance that while the accurate rating of broadcasting stations is a matter of great practical concern to the industry, to date consideration has been confined to the power delivered to the antenna. Variations in the efficiency of the latter have been almost entirely neglected in spite of the fact that, due to this cause, the power actually radiated can be shown to vary through a range of four to one, or greater. There is little doubt that stations should be rated, either directly or indirectly, in terms of field intensity measurements. That such a system of rating has not already been put into effect is probably due to the lack of suitable measuring apparatus. With such equipment now available, rapid progress in this direction is expected.

An interesting feature of current American practice with respect to broadcasting antennas is a definite tendency toward the use of higher supporting structures. For the past few years, most of the towers erected have been from 150 to 225 ft. in height. Several of the more recent stations are employing 300-ft. towers, and it is not improbable that some 400-ft. structures will be put up in the near future. Since the natural frequency of grounded steel towers of these dimensions falls in the broadcasting band and may approximate

[4] See attached list of references.

the assigned operating frequency, low-capacity porcelain insulators are inserted at the base. The latter effect a considerable increase in the natural frequency of the towers and preclude serious distortion in the field intensity pattern due to heavy induced currents in the steel. The antennas themselves are of such dimensions that the current antinode is positioned well up on the vertical section. The effect is to concentrate the radiated power along the ground plane and to increase materially the field intensity in the local service area. Such antenna systems promise a better economic balance between the investment for generating modulated radio-frequency power and that for radiating it.

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THE NATIONAL BROADCASTING COMPANY, A TECHNICAL ORGANIZATION FOR BROADCASTING*

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RADIO broadcasting on a nationwide scale commenced in the United States approximately in 1920. Late that year, and during the years immediately following, the Westinghouse Electric and Manufacturing Company and General Electric Company set up broadcasting stations at several of their manufacturing plants and began to give programs of speeches and music, at first of an experimental nature, but soon of a high quality and systematic character.

In July, 1922, the American Telephone and Telegraph Company, anxious to study the possibilities of this new medium, just as it had previously studied the possibilities of radiotelephony in private or point-to-point communication, inaugurated Station WEAF in New York City and began to give a regular series of programs.

The free and unrestricted growth of broadcasting which soon followed was characteristic of the United States. Begun at first for the purpose of encouraging the sale of radio equipment to the general public by radio manufacturing companies, the potentialities of this means of organized mass communication were soon realized by newspapers, commercial houses, banks, theatrical organizations, schools, churches, and private individuals. Anyone who felt that he had a message that would be of interest to the public set up a broadcasting station, and by August, 1924, a total of 1105 stations were in operation. The cycle of development soon became established, with the broadcaster first sending out programs, then the community expressing its interest and support by equipping its homes with radio receivers, back again to the broadcaster increasing his efforts by way of better programs and service in keeping with his increasing audience, followed by still more and better receiving facilities.

During the early part of this period of growth, little cognizance was taken of the cost of broadcasting. Those operating stations felt, for a time, that the good will or educational value of their work justified the expense. As time went on and program standards gradually rose, the high cost of broadcasting began to have its economic effect. By 1926 the number of stations had dropped to 533, or less

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than half the number in operation in 1924. "Who shall pay for broadcasting?" became the question of outstanding importance. Other nations, following us in the matter of inaugurating a broadcasting service, had applied strict licensing laws regarding the installation of radio receivers and were exacting licensing fees as a means of defraying the cost of broadcasting. The listeners of many countries were made to pay the bill, and they do so today. However, it would have been impossible to establish such a system in America, due partly to the inherent nature of the people and partly to the widely diversified control under which broadcasting had grown up.

Aside from the economic burden of broadcasting, there was a second factor which led to the early mortality of stations. This was the paucity of really suitable broadcasting program material. Stations in smaller centers, which had begun with an apparently ample supply of available talent in their community, soon found themselves nearing the exhaustion of their local program resources. They were hard pressed for good programs whereby to maintain the interest of their audiences.

On the other hand, the programs of such stations as WJZ and WEAF, located in or near New York City,—the amusement center of the nation and the scene of its most important events—were steadily improved and extended in scope. It was soon apparent that such stations could develop and maintain a program standard of greater breadth, interest, and value than the stations less fortunately situated.

After the original wonder of broadcasting wore away, the companies engaged in the manufacture and sale of radio receiving equipment soon recognized that the demand of listeners was for programs of greater and greater interest and importance. It became obvious that if radio broadcasting was to perform a great public service in this country, it would be necessary to develop chains of stations, linked together by telephone wires, in a system which would be capable of picking up the best program material anywhere in America and broadcasting it everywhere. This was not only necessary in order to render a public service, but it was necessary if the market for radio receiving sets was to be extended and enlarged.

Formation of the National Broadcasting Company

This company was organized to meet the two obvious necessities of advanced broadcasting, namely, (1) adequate financial strength, *ultimately self-sustaining;* and (2) adequate program material, with an organization and equipment capable of coordinating and presenting this material in the most desirable manner.

A most important step in the direction of making broadcasting self-sustaining had been taken by the management of station WEAF of New York City, then the American Telephone and Telegraph Company. This station originated the practice of selling its services to commercial organizations for advertising purposes. It was the intent that an advertiser would provide a program of interest to the radio listeners, incidentally mentioning his product, thus creating useful goodwill toward his wares, and pay the station for its time and facilities. At first, many of those interested in the radio field felt that the introduction of this type of broadcasting would ruin the industry. However, it has proved to be the only foundation from which a self-sustaining broadcasting service in the United States can be built up, as practiced today under the term, "sponsored programs."

In addition, this station had formed a telephone wire network linking together some nineteen broadcasting stations, operating under a wide variety of managements in seventeen different cities, known as the "red network." The programs of WEAF were supplied, for part of the day, to these so-called "outlet stations." The total network comprised at that time approximately 3600 miles of special telephone lines.

One of the first steps of the newly formed National Broadcasting Company was to purchase this station and to lease its existing telephone line network, the American Telephone and Telegraph Company then retiring from the broadcasting field.

In the meantime, the organizations which had formed the National Broadcasting Company had placed in operation eight broadcasting stations, partly connected by telephone wires, in various important cities. These stations were generally of higher power than most of those of the red network, and therefore with correspondingly greater coverage. They were formed into a second network completely connected by telephone lines, known as the blue network.

With the above as a nucleus, the National Broadcasting Company soon expanded rapidly. Stations were added, telephone line mileage increased, and the staff and studio facilities greatly enlarged, until today we have a completely capable technical and program organization which has to its credit a remarkable record of achievement. Its present status will now be taken up in detail below.

Organization of Personnel

For the purpose of illustrating the interrelationship of the technical, commercial, and artistic personnel which forms the National Broadcasting Company, there is shown in Fig. 1 a general organization chart of the company.

The functions of some of the divisions are as follows:

(*1*) *Advisory Council.* In order that the public might cooperate in the development of the company, Owen D. Young invited eighteen recognized leaders in public life to act as an advisory council. This was done so that the organization might have the guidance of the ablest people in putting its facilities to the best possible use. This council also acts, when necessary, as a court of appeals in studying suggestions or complaints from the public. Special committees on agriculture, church activities, education, labor and women's activities have been formed from the membership of the council, which hold

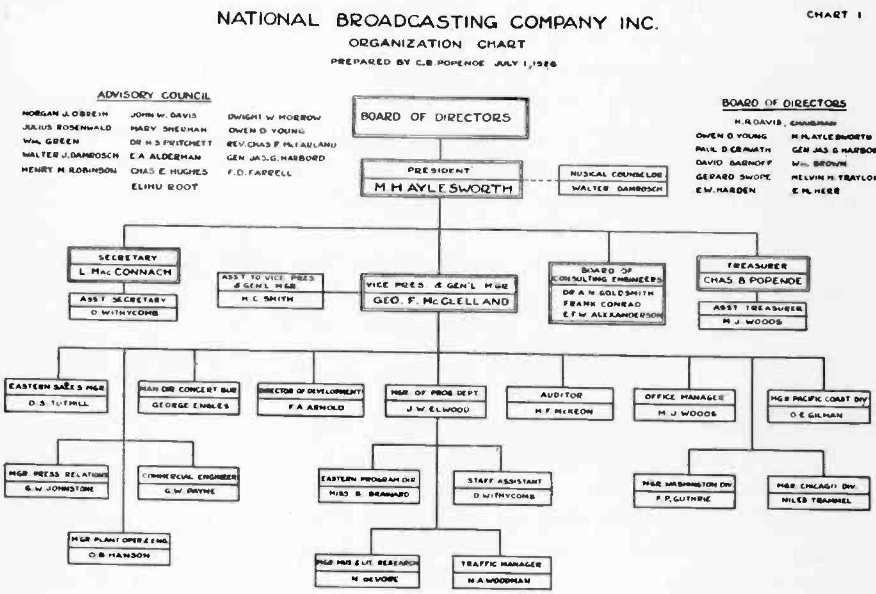

Fig. 1

meetings at regular intervals and submit recommendations to the President. It is upon these recommendations that the program policies of the company are largely based.

(*2*) *Program Department.* This is in itself an extensive organization, including trained musicians, continuity writers, announcers, vocal and instrumental artists and three complete "stock" companies—the National Grand Opera Company, the National Light Opera Company, and the National Players. There is a Department of Musical and Literary Research to investigate and authenticate the various selections and to guard against infringement of copyrights. There is an extensive library, which provides music of every description, and this department regularly composes special music for individual programs.

The program department, in addition to the basic duty of preparing the material and selecting the artists for the program, must also arrange and conduct as many rehearsals as are necessary to insure adequate presentation. Then, finally, before the program goes "on the air," it is picked up and reproduced on loud speakers in the monitoring rooms, to which the program director and his assistants listen attentively, so that the performance as it will be heard may realize the full intention of the program.

(3) *Plant Operation and Engineering.* This is the technical department of the company, and its functions include all the work connected

Fig. 2—National Broadcasting Company's building.

with the installation and operation of the technical equipment, supervision of the quality of outgoing programs, observation of the programs delivered from the telephone wires connecting the various networks, and maintenance of telegraphic contact with all of the outlet stations connected to these networks. The entire department comprises 106 engineers, operators, maintenance men, draftsmen, machinists and similar personnel, located partly at the New York City headquarters, and in other cases in various cities of the United States where studio facilities are maintained or where important events may occur.

The functions of other departments are mainly self-evident from their titles.

It may be of interest in passing to mention the fact that the entire personnel of the company is now in excess of 600 persons.

Studio Facilities and Apparatus

The principal New York City studios of the National Broadcasting Company are situated at 711 Fifth Avenue, which is close to the city's musical, theatrical, and artistic centers. During 1927 the company arranged with the constructors of a new 16-story building at this location to have the four uppermost floors especially designed so as to house its broadcasting studios, offices, and engineering staffs. This building represents the first comprehensive, scientific effort to

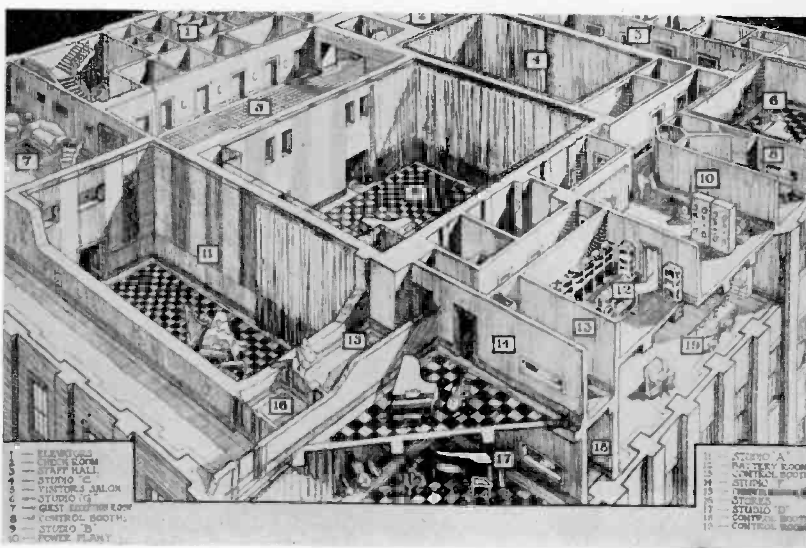

Fig. 3—New studios and control of the National Broadcasting Company at 711 Fifth Avenue, New York City.

create an ideal broadcasting center, provided with every known facility for the advancement of the art. The design is due to Mr. O. B. Hanson, Manager of Plant Operation and Engineering.

The twelfth floor of this building houses the general offices of various departments, including the Program Department and library. The thirteenth and fourteenth floors are occupied by studios, reception rooms, control rooms, and the offices of the Plant Operations and Engineering Department. A general view of the building is shown in Fig. 2 and a cross-sectional view of these floors is shown in Fig. 3.

Studios *A*, *B*, and *C*, which are numbered in the diagram 11, 9, and 4, respectively, open directly on the main foyer of the thirteenth floor and are readily accessible from the reception room. The ceilings of these three studios are nineteen feet high extending through to the fourteenth floor. Observation windows which can be seen in the drawing in guest reception room (7) and the visitors' salon (5), on the fourteenth floor, permit visitors to see the artists while they are broadcasting. Two other studios, *D* (17) and *E*, which is not visible in the drawing, are on the thirteenth floor in addition to a main plant control room (19), foyer and artists' reception rooms. The area of this floor is approximately 13,000 square feet.

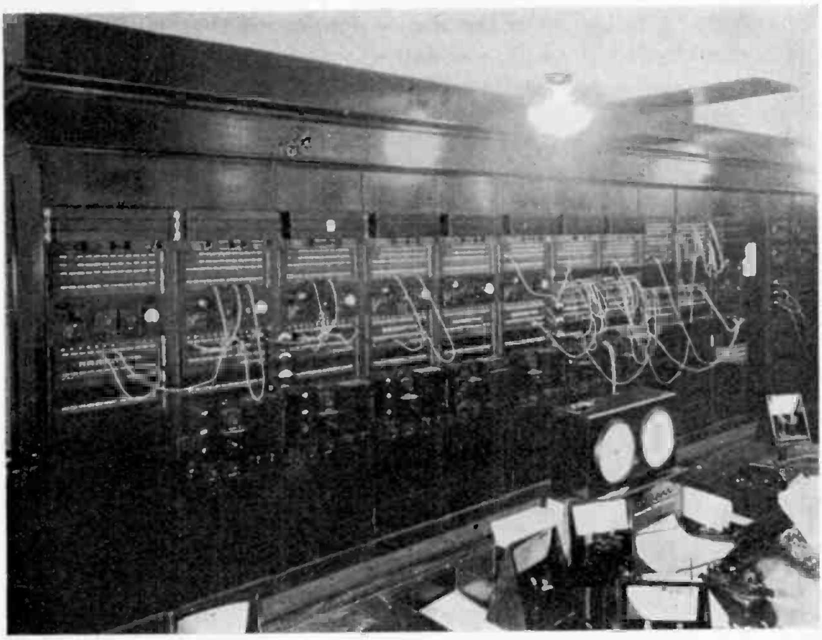

Fig. 4—Partial general view of main control room at National Broadcasting Company

Studio *B* is the largest on the thirteenth floor, measuring fifty-one feet long and thirty-six feet wide. The other studios, *A* and *C*, measure forty feet long by twenty-five feet wide. Studios *D* and *E* are located on the Fifty-fifth Street side of the building and are approached by wide corridors leading off the main foyer. These smaller studios are twenty-one feet by thirty-two, with ceilings eleven feet high.

The architectural treatment of the studios is distinctive and varied, the architect having striven to create a different effect in each of the studios. A different shade of color is used in each, studios *A*, *B*, and *C* being hung respectively in light fawn, old red and gold ochre drapes.

Studios *D* and *E*, the two smaller studios on this floor, are draped respectively in cadmium and burnt orange. With a lacquered cork tile floor the studios have the appearance of ballrooms. One or two small rugs are used in each studio.

Orchestral grouping has been simplified by placing numbers and letters along the mop board in all studios which enable the studio staff to designate positions by giving the performer a number and letter, rather than having to approximate his position to the microphone.

Each studio has a separate control room (13), (18), and (8), with apparatus. A full view of the studio is afforded the man on duty in the control booth through a sound-proof observation window. The

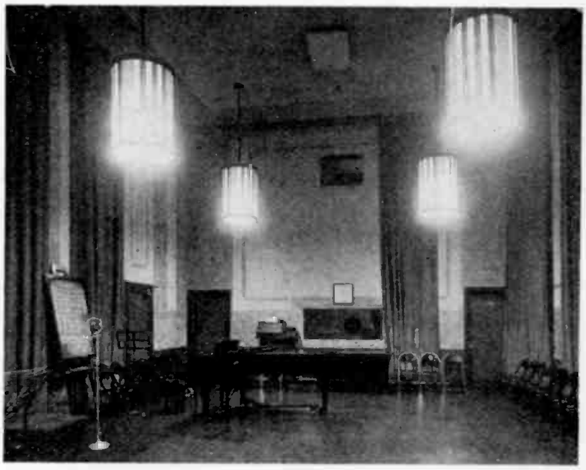

Fig. 5—General view of one of the small studios.

announcer's controls are located adjacent to the booth so that he is in constant touch with the monitor. A master control room, which contains the bulk of the apparatus, is centrally located to the five studios enabling quick access to the individual control and monitoring rooms and studio.

Amplifiers and detail apparatus of control are located in the central plant control room (19). This is where the wire networks terminate and where the various programs picked up throughout the metropolitan area are coordinated. The master control supervisor is on duty here at a desk resembling the console of a grand organ. Through an intricate system of switches and "jacks" he supervises the individual studio controls. Other equipment located here includes a temperature recorder for all studios, a master clock for synchronizing time schedules for the wire networks, and special testing apparatus required in broadcasting network programs. The ceiling of this room has been acoustically treated in a manner similar to that used in the studios in order that the supervisor can judge the quality of transmission.

On the fourteenth floor immediately above this room are the generators, master power boards, storage batteries, and the cross-connection room (12) and (10), where all the wires carrying either program material, or power, are distributed to the various parts of the building. Two more studios are on this floor, studios *F* (14) and *G* (16), which are the same size as *D* (17) and *E* (not shown) on the thirteenth floor. Due to the height of the ceilings of *A* (11), *B* (9),

Fig. 6—One of the reception rooms.

and *C* (4), there are no studios immediately over these three on the fourteenth floor. In addition to the foyer and visitors' reception rooms there are dressing rooms and shower baths for members of the NBC staff and also several green rooms for distinguished artists and internationally known celebrities.

On the fifteenth floor, which is not shown in the sketch, is located the largest studio, with dimensions of 40 by 80 ft., and with a 20-ft. ceiling. This is a small auditorium and is capable of seating approximately 250 people, should this be desired at any time. An indirect lighting system has been provided which utilizes more than 700 incandescent lamps which are used to create various color effects as desired. A stage has been provided at one end, and a pipe organ has been included in the construction of this studio. A spacious foyer opens into this auditorium-studio. The rest of this floor is used for offices of the National Broadcasting Company's executives.

The acoustical treatment of each studio consists of acoustical plaster on the walls and ceiling, the cork tile floor, and a small quantity of draperies and rugs. The latter are placed in back of and on the walls near the microphone, so that the artists work in a relatively "live" studio space, while the space in the immediate region of the microphone is more heavily damped. This method of operation is preferable to a uniformly highly damped studio, as it provides satisfactory acoustical conditions for both artists and microphone. The desirability of a "live" or moderately reflecting working space for performers

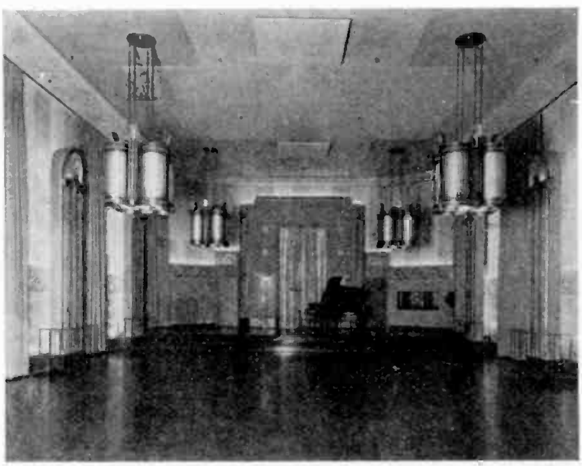

Fig. 7—General view of auditorium on 15th floor.

and an acoustically "dead" space for listeners, in theatres or concert halls, has been recently brought out in the work of Professor F. R. Watson of the University of Illinois.[1] Similar arrangements have proved equally desirable in broadcasting studios, where the microphone takes the place of the listener.

The placement of artists or orchestras with respect to the microphone in these studios has been thoroughly covered in an article[2] by Carl Dreher, staff engineer of the National Broadcasting Company, and will therefore not be gone into here.

A number of photographs are reproduced in Figs. 4, 5, 6, and 7,

[1] F. R. Watson, "Ideal Auditorium Acoustics," Jour. of the American Institute of Architects; July, 1928; or *Science*, p. 335, March 30, 1928.

[2] Carl Dreher, "Acoustics and Microphone Placing in Broadcast Studios," Proc of the Radio Club of America, 5, numbers 5 and 6. May and June, 1928.

which show a portion of the main control room, some of the studios and a reception room.

The control room equipment consists of high quality amplifiers, volume indicators, and metering equipment of the standard broadcasting type, connecting to the individual small control rooms associated with the various studios. By means of this apparatus, supervision is maintained over the outgoing programs, but the actual regulation of intensity and placing of microphones is carried on in the small control rooms. The main control room also maintains contact, by means of telegraph circuits, with all of the radio stations associated with the various wire networks and supervises the linking up of the broadcasting telephone circuits which compose these networks. More detailed descriptions of this type of apparatus are given in the paper by D. G. Little, which appears as part of this symposium.

An interesting part of the plant is the "air conditioning" system. This was manufactured and installed by the Carrier Engineering Corporation of Newark, N. J. The equipment supplies fresh air at a constant temperature and humidity to all the studios and control rooms. The air taken in from out-of-doors is first washed free of dirt and dust; next it is dehumidified (that is, the excess of moisture over a certain amount is removed by cooling); and then the air is distributed at a temperature such that a comfortable room temperature is obtained. In summer the air is cooled to the proper temperature, and in winter it is heated by heating the cleansing water. In addition, it has recently been found advantageous to introduce ozone into the air, so as to precipitate smoke particles and to impart an exhilarating effect to the artists and staff.

Wire Facilities and Outlet Stations

The programs originating in the New York studios, or in any other part of the United States, are supplied over a large telephone wire network (leased from the American Telephone and Telegraph Company) to numerous radio stations of various powers. Three radio stations are owned or leased by the National Broadcasting Company itself (WEAF and WJZ near New York, and WRC in Washington, D. C.), four are owned by the Westinghouse Electric and Manufacturing Company (KDKA in Pittsburgh, Pa., KYW in Chicago, Ill., WBZ in Springfield, Mass., and WBZA in Boston, Mass.), and three are owned by the General Electric Company (WGY in Schenectady, N. Y., KOA in Denver, Colo., and KGO in Oakland, Cal.). The remainder, now numbering 48 stations, are owned by a variety of interests including newspapers, automobile sales agencies, radio and electrical companies, municipalities, public utilities, department stores, and hotels.

The National Broadcasting Company maintains studios in Washington, Chicago, and San Francisco. In these cities permanent tele-

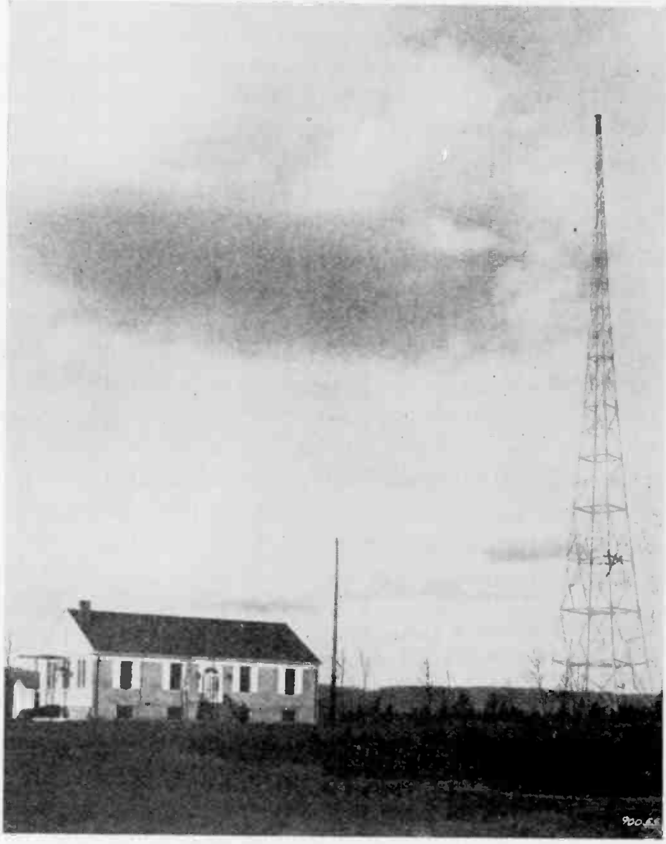

Fig. 9—General view of transmitter house and one of the antenna towers, Station WJZ.

phone wires are also installed to theatres or other places where program material may originate. In addition, temporary wire connections are set up to any cities in which an event of importance will occur, and connected into the station network.

Fig. 8 illustrates the locations of the various outlet stations.

Some facts in connection with this system may be of interest.

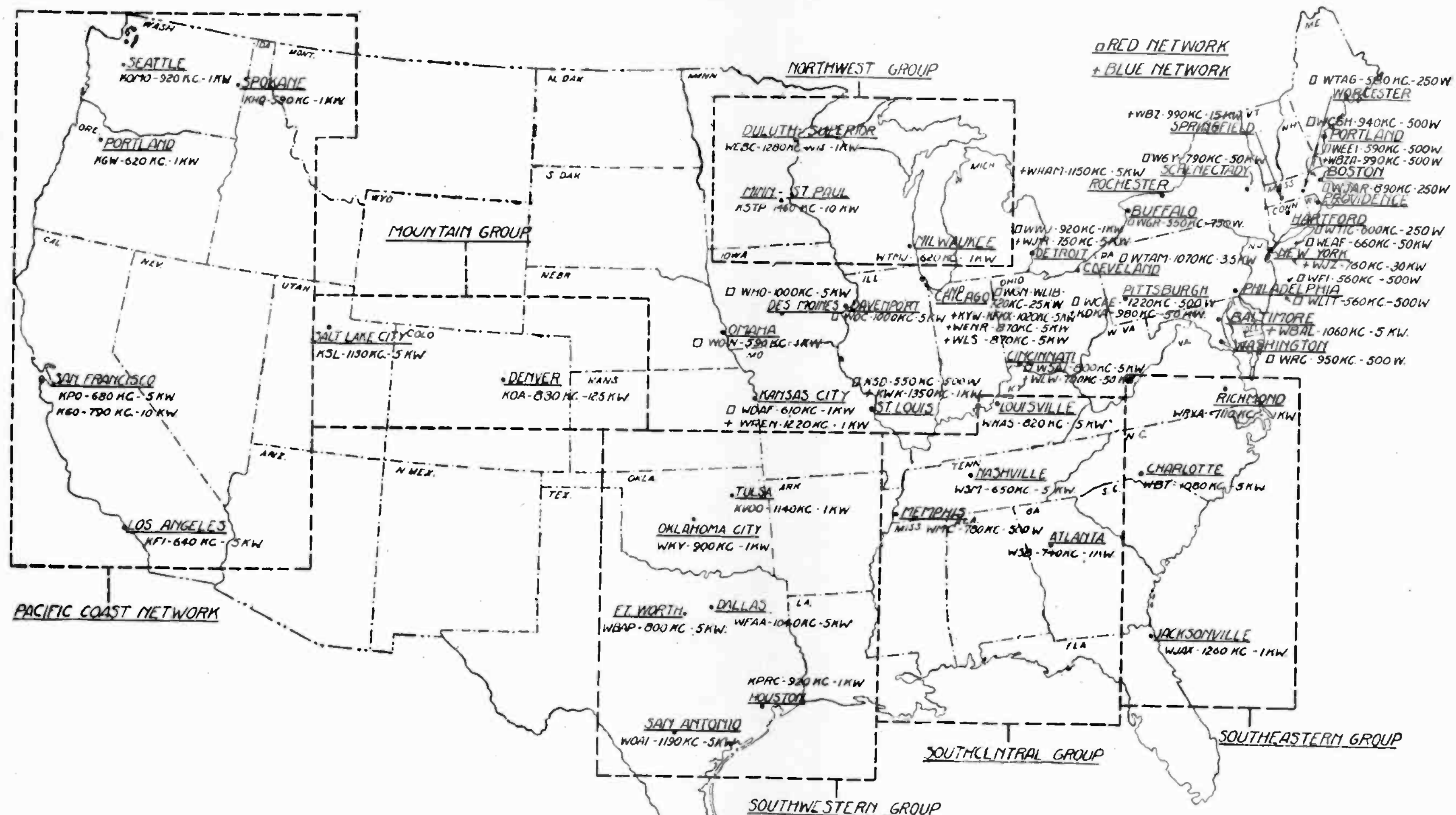

Fig. 8—Network stations of National Broadcasting Company

The total wire lines are in excess of 10,000 miles. The rental charges for these lines in 1927 were in excess of $1,350,000.

During 1927, also, the expenditure for radio programs to supply this network was about $6,000,000. Of this, over $2,000,000 was spent

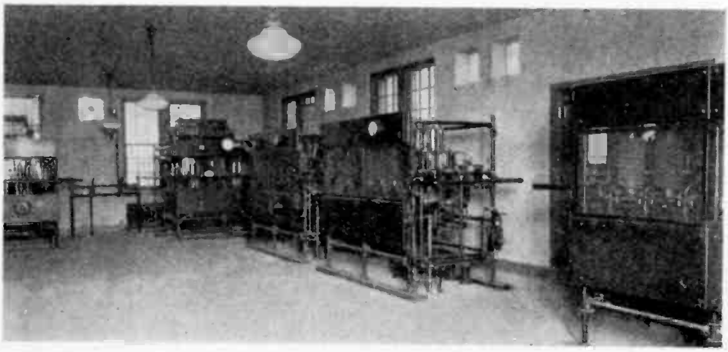

Fig. 10—General view of transmitting apparatus, station WJZ.

for talent alone on "sponsored" programs presented by some fifty American industries who are clients of the company.

The programs supplied are either "sponsored" or "sustaining." The former are paid for by industrial establishments, for the purpose

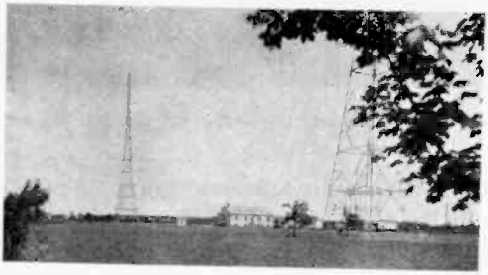

Fig. 11—General view of transmitter house and antenna towers at station WEAF.

of creating goodwill towards their products. The latter are furnished by the National Broadcasting Company to occupy those periods during the day when sponsored programs are not available. The outlet stations share with the National Broadcasting Company in the payments received for the sponsored programs, but make moderate payments to the National Broadcasting Company for the sustaining programs. As it works out at the present time, the sponsored program payments to the stations more than compensate for their payments for sustaining programs, so that the system operates profitably, at least so far as the outlet stations are concerned. The National Broadcasting Company itself operated at a considerable deficit during the first year of its existence, but as sponsored programs have come to occupy a greater proportion of the total time, operations have become less unprofitable.

As exemplifying typical practice in high power American broadcasting stations, some views of the National Broadcasting Company's New York Stations, WJZ and WEAF, are shown in the accompanying figures.

Fig. 12—Transmitting apparatus at station WEAF.

Station WJZ produces an antenna power of 30,000 watts and is located at Bound Brook, N.J., about 35 miles from New York City. Station WEAF, with an antenna power of 50,000 watts, is located at Bellmore, N. Y. (on Long Island), about 25 miles from New York City.

Fig. 9 is a general view of the transmitter building and of one of the antenna towers of WJZ. Fig. 10 shows the transmitting equipment. Power transformers, motor-generator sets, and other heavy apparatus are located in the basement of the building, immediately below the equipment shown in Fig. 10.

Fig. 11 is a general view of the station WEAF, and Fig. 12 shows the transmitting apparatus. As in the case of WJZ, the heavy equipment is located in the basement of the building, below the equipment shown.

Typical Program Achievements of the National Broadcasting Company

Among the outstanding events in broadcasting made possible through the organization of the National Broadcasting Company were the following:

(1) The inaugural program of the company on November 15, 1926, was heard by an audience of more than 10,000,000 people. This program featured such great operatic stars as Titta Ruffo and Mary Garden, such theatrical celebrities as Weber and Fields, Will Rogers, Walter Damrosch and the New York Symphony Orchestra, Harold Bauer, the distinguished concert pianist, Edwin Franko Goldman and his band, as well as leading organizations in the field of more popular music. The event proved that there were no physical confines to the broadcasting studio. Mary Garden's voice was "picked up" from Chicago; Will Rogers spoke from Independence, Kansas, and the entire program was rendered as though hundreds of miles did not separate these performers from the broadcasting stations.

(2) On New Year's Day, January 1, 1927, there was broadcast for the first time in the history of the service an event originating on the Pacific coast, through the entire network. Millions of listeners on the eastern seaboard heard in the cold of midwinter a play-by-play report of the football game between Leland Stanford and Alabama Universities, which is played annually on New Year's Day in the Bowl of Roses at Pasadena, California.

(3) The first nationwide transmission of grand opera from the stage was accomplished by the National Broadcasting Company on January 21, 1927. This was the reproduction of the performance of the opera, *Faust*, presented in the Civic Auditorium in Chicago.

(4) On February 22, 1927, the address of the President of the United States, in commemoration of the anniversary of the birthday of George Washington, was broadcast through forty-two stations to an estimated audience of more than twenty millions of people.

(5) In June, 1927, during the Mississippi flood, the National Broadcasting Company, in a splendid effort to galvanize the relief activities of the nation at large, broadcast a special Red Cross relief program through its red and blue networks, reaching many millions of people and inspiring them to contribute their mites to the alleviation of the suffering. This event was notable in that it demonstrated strikingly the highly developed organization of the National Broadcasting Company and the entire feasibility of broadcasting programs of national interest from widely separated points in instantaneous sequence. At the beginning of this program an announcer in the studios

of WEAF at New York presented Secretary of Commerce Hoover. Instantly the skilled technical staff of the National Broadcasting Company shifted the circuits, and without pause Mr. Hoover, in the studios of WMC at Memphis, began to speak, from the very center of the flood area. After fifteen minutes the announcer in New York again went "on the air," introducing Al Jolson, the famous comedian, who began to speak from the studios of KYW in Chicago. Throughout this historic program there was not a single hitch, evidencing remarkably the highly developed capacities of the National Broadcasting Company, as well as the unimaginable potentialities of radio as an instrument of simultaneous nationwide intercommunication in time of need.

Fig. 13—Broadcasting election returns throughout the United States.

(6) The historic airplane flights of Captain Charles A. Lindbergh and the other pioneers in transatlantic aviation were followed closely, and periodic bulletins broadcast to millions of waiting listeners as these flights progressed. The receptions accorded to these aviators on landing in the United States were similarly transmitted.

(7) On Thursday, July 21, 1927, through the courtesy of the Scripps-Howard newspapers, some forty millions of people in all parts of the world listened to Graham McNamee's graphic portrayal of the Dempsey-Sharkey bout at the Yankee Stadium, broadcast through the network of the National Broadcasting Company from fifty-one stations, two of which, WGY (Schenectady) and KDKA (Pittsburgh), broadcast on their short wavelengths as well as their regular frequencies, thus making the program available to interested auditors as remote as Europe, South America, Australia, and Africa.

(8) The Presidential election held during November, 1928, furnished a splendid opportunity for demonstrating the advantages

of the system of the National Broadcasting Company. The returns from the various states were received in a room at the headquarters of the National Broadcasting Company and reported to trained newspaper writers. These men maintained a constant flow of comment on the individual reports, which were handed to an announcer who read them into a microphone, whence they were transmitted through the entire network. Fig. 13 shows the group of men at work on that occasion.

Obviously, such immense coordinated undertakings would be entirely beyond the scope of any save a great organization like the National Broadcasting Company.

The "events" cited are outstanding because of their nationwide interest and the extraordinary facilities used to broadcast them; but the real influence of present day radio, as the National Broadcasting Company has developed it, lies in the less spectacular programs broadcast regularly through its own stations and varying numbers of the network stations. Among these are programs that at times include many prominent personages, such as the President of the United States, the Vice President, the Governors of states, the Prince of Wales, Premier Stanley Baldwin, eminent jurists, authors, journalists; famous operatic and concert stars; great conductors, symphony orchestras, and noted stars of the stage. Other types of programs include carefully adapted operatic and dramatic performances, general educational, and informative topics.

These programs, received regularly in millions of homes, are rationally and consistently extending and improving the culture of the nation. The effect is bound to be truly magnificent as the art progresses and evolves, since radio combines the functions of both amusement and education.

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SPEECH INPUT EQUIPMENT*

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SPEECH input equipment is broadly understood to comprise the necessary apparatus to convert sound into electrical energy of a kind and amount suitable for use in broadcast transmitters. In addition to the equipment employed to pick up, amplify, and control the speech or program, supplementary apparatus for monitoring, intercommunicating, and power supply will also be described.

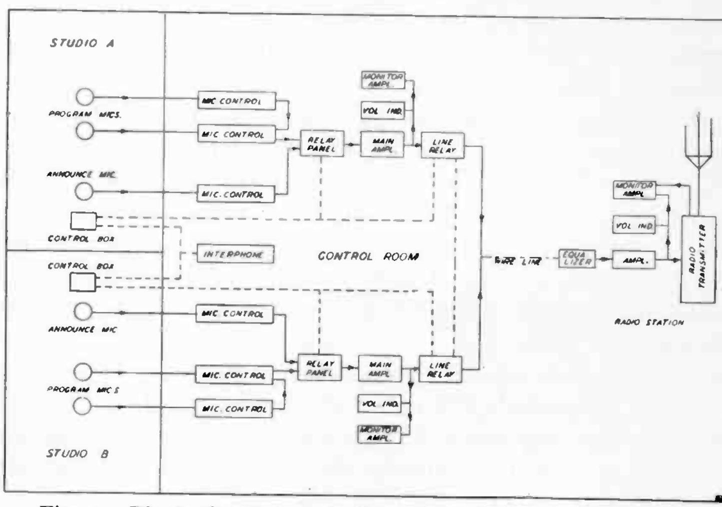

Fig. 1—Block diagram of studio and control room apparatus.

Each broadcast station has one or more studios where indoor programs are enacted. Each studio has its microphones connected to a group of amplifiers and control apparatus generally located in an adjacent control room. The program from any of these studios may be broadcast from several remotely located radio transmitters at the same time by the closing of interlocking relays which connect the various studio channels to the wire lines leading to the radio transmitting stations. The most elaborate and complete installation of this kind is that of the National Broadcasting Company at 711 Fifth Avenue, New York City, where eight studios are used to furnish programs to

* Dewey decimal classification: R610. Original manuscript received by the Institute, April 11, 1929.

both the red and blue networks of wire lines connecting as many as sixty stations widely located throughout the United States. The detailed electrical features and characteristics of all the apparatus required for the operation of the National Broadcasting Company system in New

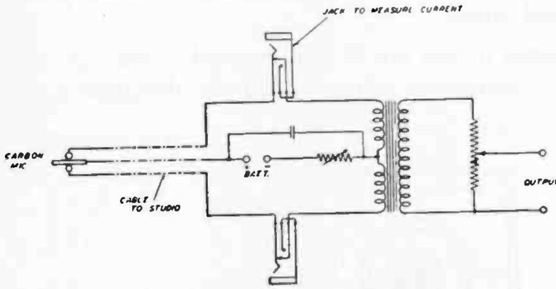

Fig. 2—Carbon microphone and control panel circuit diagram.

York City are so involved as to be beyond the scope of this article. However, the general features of an ordinary broadcast system will be given in their relative order in the circuit from microphone to transmitter. This is best described by referring to the block diagram, Fig. 1.

Fig. 3—RCA condenser microphone unit.

In general, frequencies between fifteen cycles and twenty thousand cycles per second are called audio frequencies, since sounds heard by the human ear are within this range. It is not necessary to cover this entire range of frequency in order to give quite satisfactory speech and music quality to our broadcast programs. Speech input equipment is usually designed to have a flat or uniform frequency characteristic from 60 to 6000 cycles. Performance characteristics of speech input equipment are usually given in TU (transmission units) which is a mathematical relation of the power output of a given amplifier or network to its power input.[1] Energy level, expressed in TU, refers to signal intensity or volume at a given point and time and is based upon an adopted standard of zero level in TU as being a power of 10 mw in six hundred ohms.

Microphones in use are of two general types: (a) carbon granule type, and (b) condenser type. Both are designed for high quality,

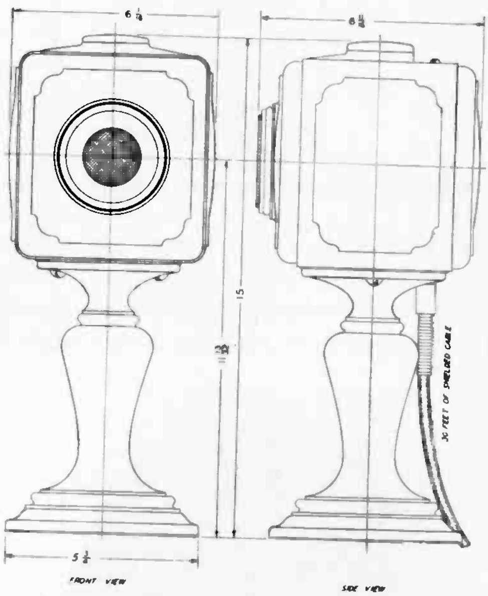

Fig. 4—Microphone amplifier and stand for table or desk mounting.

that is, to have a substantially flat frequency characteristic from 60 to between 5000 and 10,000 cycles.

The carbon microphone employs two carbon variable resistance elements, called buttons, one on either side of a tightly stretched hard aluminum diaphragm. The circuit is shown in Fig. 2. In practice, the direct current through the carbon microphone flows from the stretched diaphragm to the buttons and is regulated by a rheostat on a microphone control panel to between 10 and 20 ma per button which assures the desired life of the device. The output level of this type of micro-

[1] Note: The gain or loss of energy in transmission units (TU) is expressed as follows:

$$TU = 10 \log_{10} P_1/P_2$$

Where P_1 = power at one set of terminals of the apparatus, and P_2 = power at at the other set of terminals.

phone is between -40 and -60 TU, depending upon the nature of the sound source and the distance from the microphone.

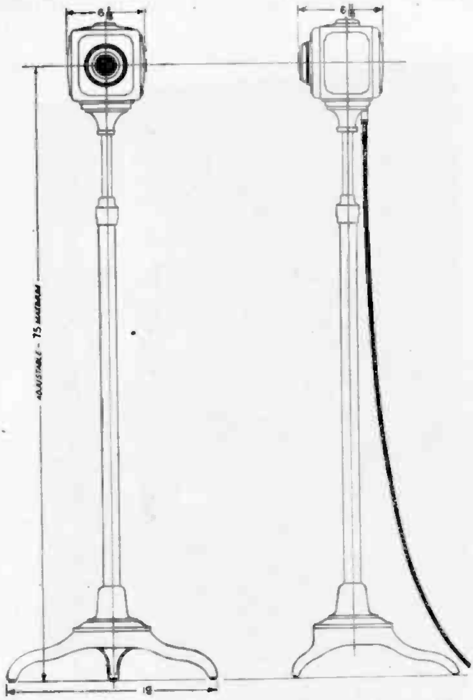

Fig. 5—Microphone amplifier and stand.

The condenser microphone is fast replacing the carbon for program work, being desirable where the slightly greater ground tone of

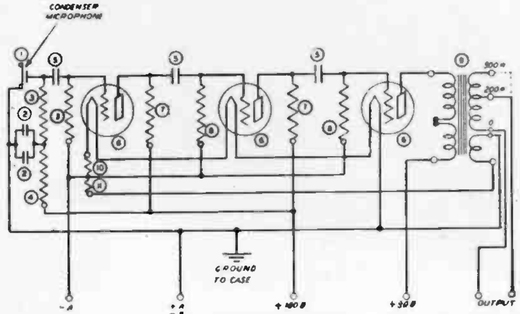

Fig. 6—Condenser microphone and amplifier circuit diagram.

the carbon type might be objectionable. A stretched diaphragm similar to that used in the carbon microphone is spaced about two thousandths of an inch from a carefully insulated back-plate, thus form-ing a condenser that is varied in capacity by movement of the diaphragm under the influence of sound waves. A d-c potential of approximately 180 volts is applied between the diaphragm and insulated

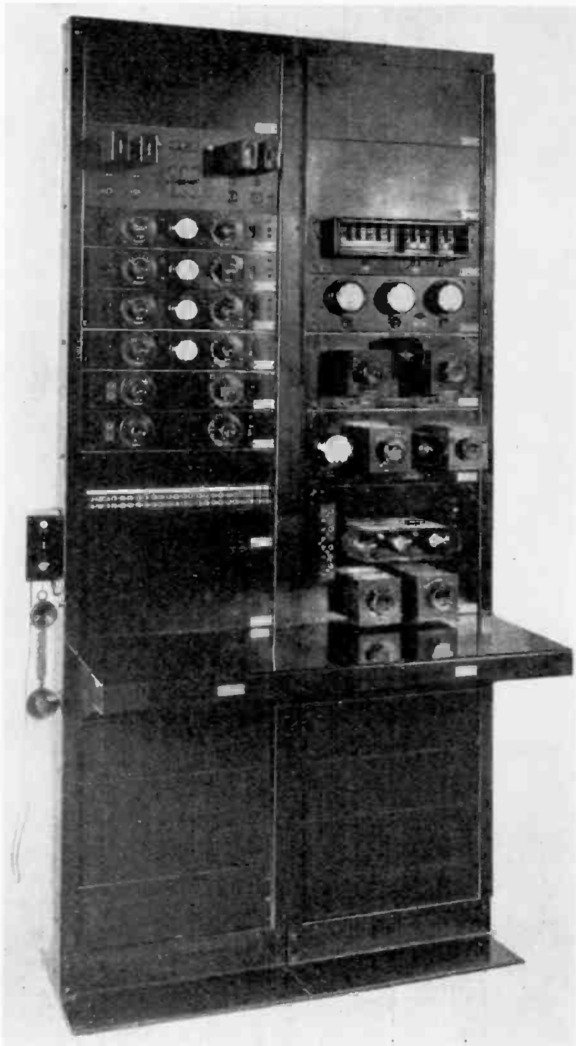

Fig. 7—Control room panels for two studios.

back-plate through a high resistance. Variation in capacity, due to movement of the diaphragm under the influence of sound waves, causes an audio-frequency voltage to build up across this high resistance which is amplified by a local amplifier to an energy level approximately that of the carbon microphone. Because of the very low energy level

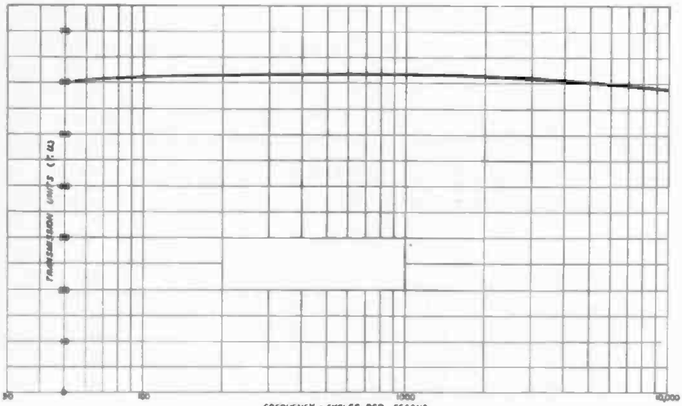

Fig. 8—12A, 3-stage amplifier frequency characteristic.

at the output of the condenser element, and the relatively low capacity of this element, it is common practice to locate the first or local am-

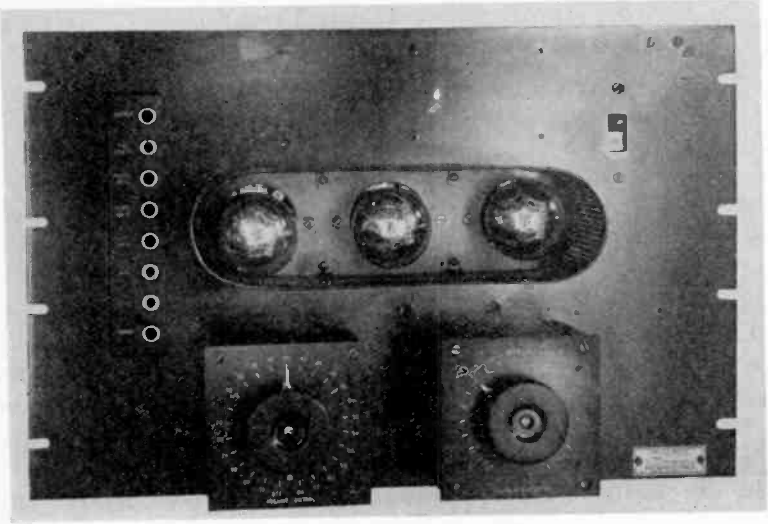

Fig. 9—12A, 3-stage amplifier.

plifier close to or in the same unit with the condenser element. Fig. 3 shows the RCA type of condenser element; Figs. 4 and 5 show the amplifier in which this condenser element is mounted. Fig. 6 is the circuit diagram. A five-conductor cable connects the complete microphone unit with its control panel where the amplifier tube filament voltage is regulated and the audio output adjusted.

The microphones described above are, of course, located in the studio or at the point of "pick-up." The outputs of the microphones are controlled, switched, and further amplified in the control room in panel type equipment mounted on vertical racks. Fig. 7 shows control room apparatus for two studios, in which a single set of amplifying and monitoring equipment is used for the outputs of both studios. The audio output of any microphone is adjustable by a potentiometer

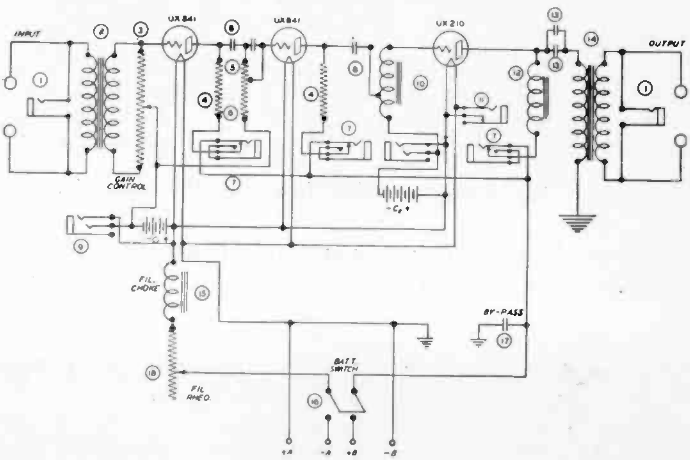

Fig. 10—21A, 3-stage amplifier circuit diagram.

on its control panel. This adjustable output is connected through a relay panel and a jack panel to a multistage amplifier which raises the energy level to a value suitable for application to the telephone line going to the radio transmitter. This output energy is usually about zero level. The frequency characteristic of a typical three-stage amplifier is given in Fig. 8, and photograph of the unit in Fig. 9. The circuit diagram is shown in Fig. 10. The maximum gain from input to output terminals is between 60 and 64 TU, and the maximum output without overloading is a level of +16 TU.

In case the line between studio and station is of considerable length or is lead cable, a line compensating unit or filter must be used. This unit is usually known as a line equalizer and compensates for the frequency characteristic of the line which attenuates high frequencies more than low frequencies. A unit of this kind is shown in Fig. 11.

At the radio transmitting station, further amplification of the program is sometimes necessary in order to compensate for line losses and equalization losses and to raise the energy to approximately zero TU level, the input required for most transmitters.

Having followed the path of the program from the microphone in the studio through its various controls and amplification circuits to

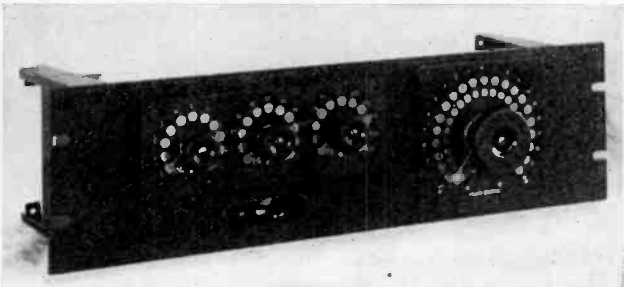

Fig. 11—Line compensating unit.

the radio transmitter, accessory, monitoring, and inter-communicating apparatus will now be considered. This accessory apparatus, although not traversed by the program itself, is of great importance. Fig. 1 shows this accessory apparatus as associated with the main audio channels.

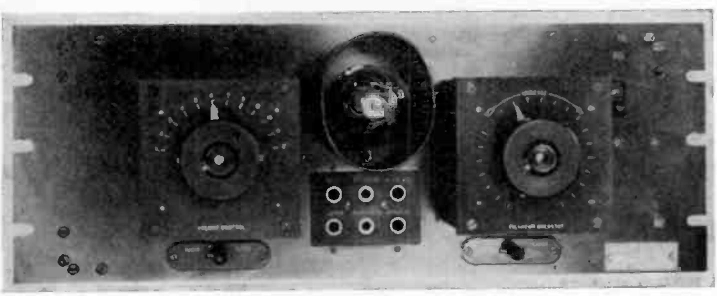

Fig. 12—Monitoring amplifier.

For conveying general information, such as the arrangements for the various parts of a program, etc., intercommunicating telephones connect the control room with the studios and with the radio station. A Morse telegraph circuit generally connects the control room and radio station. If the distance is short, this circuit may be "phantomed" onto the program line. The necessary switching of circuits during a program is usually made by the control room operator and the announcer through interlocked relays. These relays operate lamp signals between studios and control room and continuously display the circuit setup.

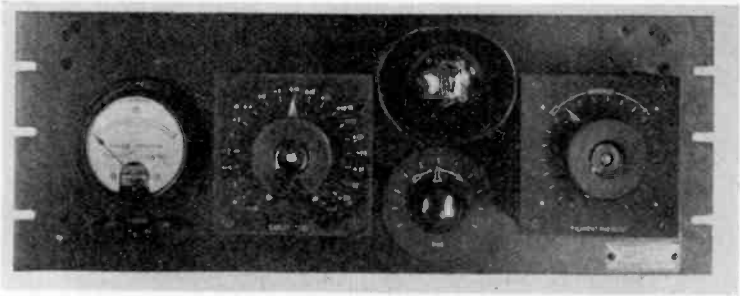

Fig. 13—Volume indicator.

In the control room, a monitoring amplifier and loud speaker keep the operator in touch with the program. Sometimes a second monitor-

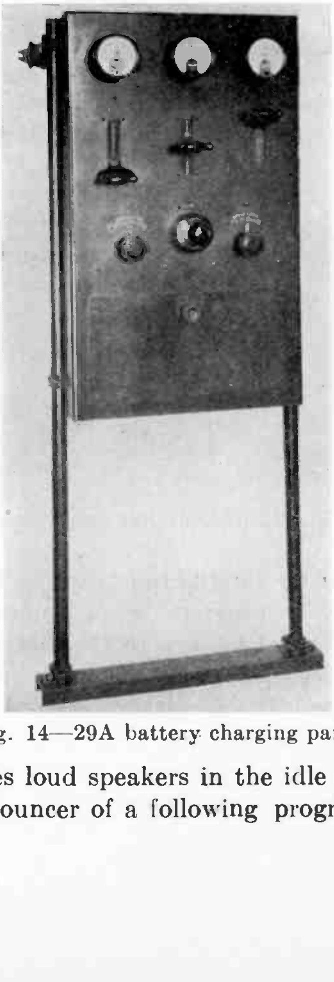

Fig. 14—29A battery charging panel.

ing amplifier supplies loud speakers in the idle studios for auditions and permits an announcer of a following program to hear when the preceding program ends. Otherwise, he depends upon lamp signals for this indication. In case of programs from two or more studios going simultaneously through the same control room, head tele-

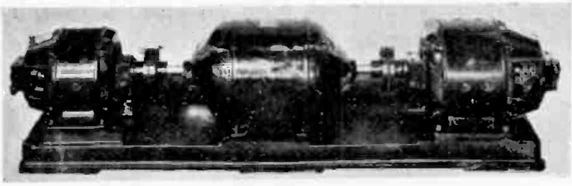

Fig. 15—Battery charging motor-generator set.

phones may be employed for monitoring. Fig. 12 shows one type of monitoring amplifier.

A volume indicator or vacuum-tube voltmeter calibrated in TU is shown in Fig. 13. At least one of these units is used at every studio

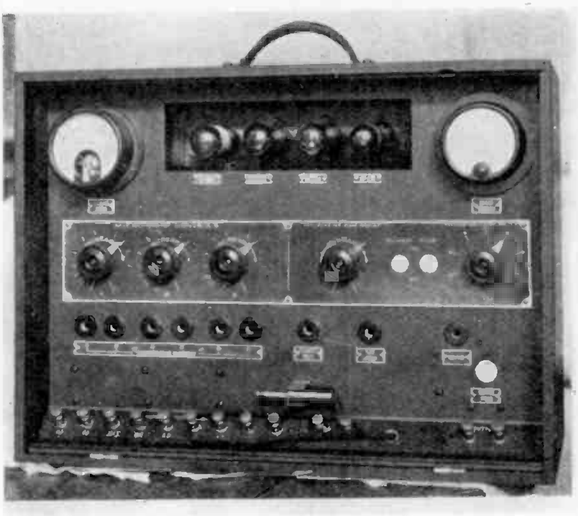

Fig. 16—Portable pickup amplifier, front.

control room and one at the station control room. At the studio control room, the volume indicator measures the level in TU delivered to the line; and at the station, it measures the level delivered to the transmitter. These units give visual indication of the signal level and allow the operators to adjust the "gains" of the amplifiers to the desired amount.

Power for the vacuum tubes, used in the amplifiers, for the signal lights, relays, and other speech input apparatus, is obtained from storage batteries. A potential of twelve volts is used for the tube filaments, relays, and signal circuits, and 400 volts for the tube plate circuits. A three-unit motor-generator set with low- and high-voltage generators, and a battery charging panel are provided for the recharging

Fig. 17—Portable pickup amplifier, rear.

of the batteries. The usual practice is to install two complete 12-volt batteries so that one may be charged while the other is in use. Battery installations are generally of a size sufficient to give twenty-four hours of service without recharging. Fig. 14 shows one type battery charging panel, and Fig. 15 shows its associated motor-generator set.

A portable type of combined amplifier and control unit has been developed for use at "outside" pickup points, such as, baseball and football games, celebrations, etc., also at churches, conventions, and in fact anywhere outside of a regularly equipped studio. One, two, or three carbon microphones are employed, or condenser microphones may be used by adding a battery box. Apparatus of this kind is transported to the place of pickup and connected to lines running to the studio control room or radio station, a short time before the program is scheduled to start. The apparatus is usually removed immediately following the program. See Figs. 16 and 17.

It is obvious that a radio receiver having a perfect fidelity characteristic and receiving from a transmitter with perfect characteristics will not reproduce a program satisfactorily unless this program is properly "picked up," amplified, and controlled by the speech input microphone and its associated equipment. Because of the fact that one radio station is heard by thousands of listeners and also that one microphone may be picking up a program for as many as sixty stations, the importance of correct design of speech input equipment is readily appreciated. In the design of speech input equipment, therefore, the cost is of secondary importance, and the very best of materials are employed. As an additional safeguard against trouble, the main equipment, amplifiers, and monitoring devices generally have their inputs and outputs normalled through jack panels so that in case of failure the defective panel may be electrically disconnected and a spare or duplicate panel put in service by merely inserting the proper patch cords between jacks. The success of the present broadcasting service in the United States is due in a large measure to the high quality of speech input energy delivered to the input terminals of the nation's broadcast transmitters and to the precautions taken to insure against interruptions to programs.

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WIRE LINE SYSTEMS FOR NATIONAL BROADCASTING*

BY

A. B. CLARK

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WHAT we are here considering, as an important factor in promoting national solidarity, is the tying together of a whole nation so that a single broadcast will instantly reach even the most remote points. Radio broadcasting stations (employing the more generally used frequencies) are essentially local distribution centers serving effectively points up to 50 miles (80 km), or, in favorable cases, 100 miles (160 km) or more from the radio transmitter. For the larger nations it is evidently necessary to make division into areas, locating a radio transmitter in each area for its coverage, and then to provide a network of circuits connecting the transmitters in the various areas with the point at which the broadcast originates. At the present time, wire telephone systems are employed almost exclusively for this national distribution of broadcasts. It is the purpose of this paper to discuss the wire networks which are now being provided in the United States by the Bell Telephone System.

In the United States at the present time (January 15, 1929) programs are being regularly distributed over extensive wire networks or "chains," as indicated on the map of Fig. 1. The various chains are usually referred to by colors. As a regular procedure most of these chains operate about six hours each day. Following are the numbers of radio stations served by each chain together with the lengths of telephone circuit involved. (An additional chain which operates only one hour each week is not included.)

	Radio Stations	Telephone Circuit Miles	
Red network	41	10,300	(16,600 km)
Purple network	41	8,450	(13,600 ")
Blue network	12	3,650	(5,900 ")
Green network	8	3,600	(5,800 ")
Orange network	5	1,700	(2,700 ")
Brown network	3	450	(700 ")
Total	110	28,150	(45,300 ")

On occasions when events of particular importance take place, several of the regular chains may be merged together and additional circuits added so as to pick up programs from various parts of the

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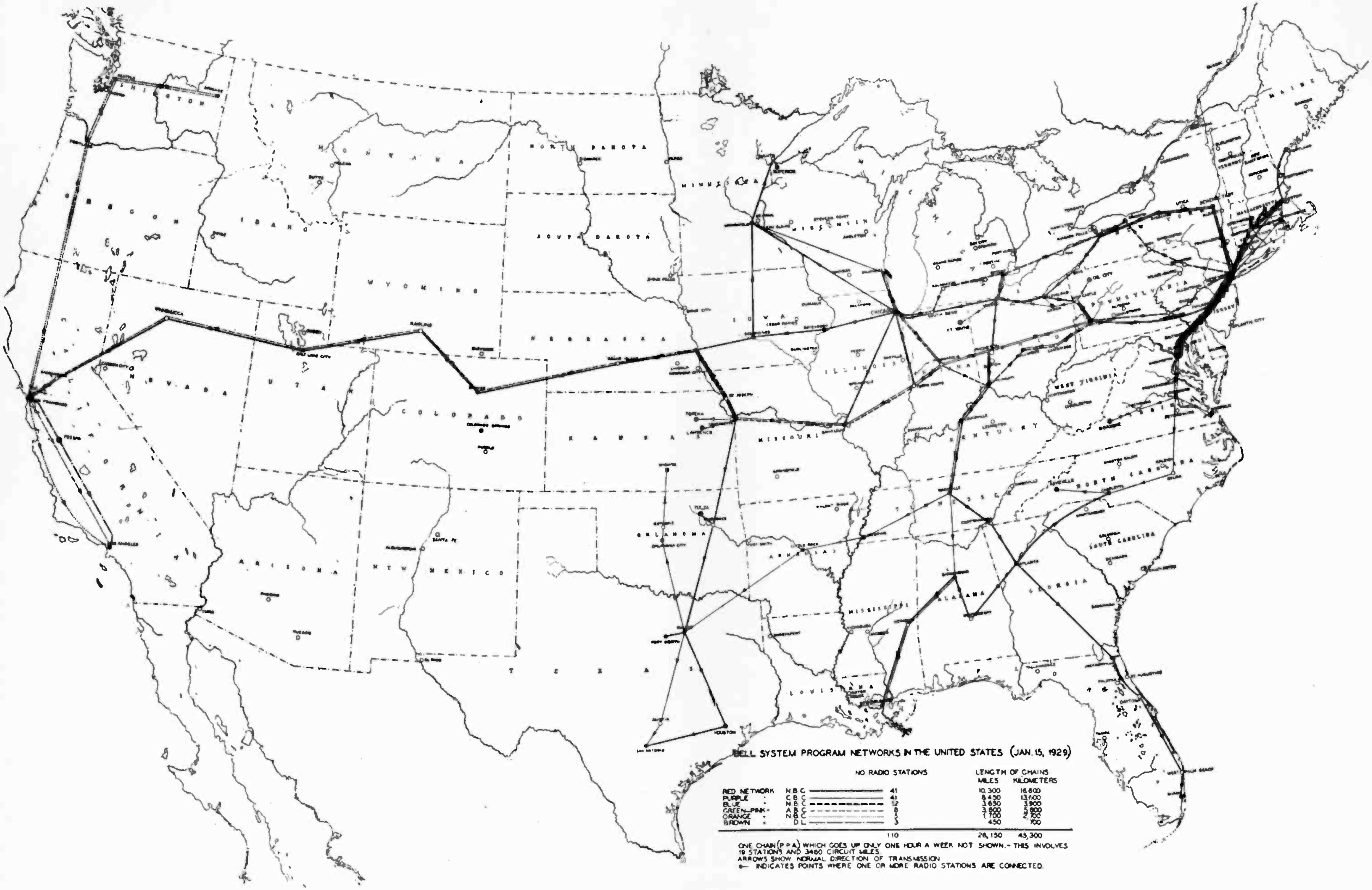

BELL SYSTEM PROGRAM NETWORKS IN THE UNITED STATES (JAN. 15, 1929)
NO RADIO STATIONS
LENGTH OF CHAINS
MILES
KILOMETERS
RED NETWORK N B C 41 10,300 16,600
PURPLE " C B C 41 8,450 13,600
BLUE " N B C 12 3,650 3,900
GREEN–PINK " A B C 8 3,600 5,800
ORANGE " N B C 3 1,700 2,700
BROWN " D L 3 450 700
110 28,150 45,300
ONE CHAIN (P P A) WHICH GOES UP ONLY ONE HOUR A WEEK NOT SHOWN.– THIS INVOLVES 19 STATIONS AND 3480 CIRCUIT MILES
ARROWS SHOW NORMAL DIRECTION OF TRANSMISSION
INDICATES POINTS WHERE ONE OR MORE RADIO STATIONS ARE CONNECTED.

Fig. 1

country. For example, on November 5, 1928, the evening before the United States presidential election, the networks shown in Fig. 2 were in operation, about 85 radio stations being included. At various times during this evening, five separate programs were broadcast from several different points in New York City; Palo Alto, California; Little Rock, Arkansas; and Pittsburgh, Pennsylvania. The United States was thus virtually one great auditorium, with listeners estimated as no less than fifty million.

From the technical standpoint, program transmission circuits are, of course, very different from message telephone circuits. In the first place, message telephone circuits must be arranged so that to and fro conversations can take place practically instantaneously. Program transmission circuits on the contrary are single-direction transmission circuits. They are, therefore, not complicated by problems of electrical echo, singing and the like, which are ever present with long message telephone circuits. However, although free from the problems of two-way working, the design and operation problems of program transmission circuits are by no means easy as compared with those of message telephone circuits. On the contrary, in many respects, these problems are considerably more difficult, the reason being that the requirement as to approach to absolute fidelity of reproduction is much more severe than for message telephone circuits.

A frequency band width of 2,500 cycles furnishes, if properly utilized, a telephone circuit over which speech is transmitted very clearly so that conversations may be easily carried on. This band is not adequate, however, for program transmission because of the different character of the transmitted material. The bulk of present-day broadcast programs consists of musical selections, including a fair amount of high-grade material. To reproduce music, and particularly high-grade music, in a pleasing manner calls for a materially widened band. This wider band also gives a high degree of naturalness to speech which is particularly desirable when loud speakers are used for reception.

At the present time in the United States the frequency band which is transmitted over the long distance program chains extends from about 100 cycles to about 5,000 cycles. It is, of course, possible to transmit an even wider band than this, although the cost of the circuits will, of course, increase as the band is widened. In considering how wide the band should be, the complete system, including pickup apparatus, wire transmission line, radio transmitters, radio transmission paths through the ether, radio receiving apparatus and loud speakers must be considered. It seems probable that as the art progresses a band wider than the above will be found desirable. On the wire line

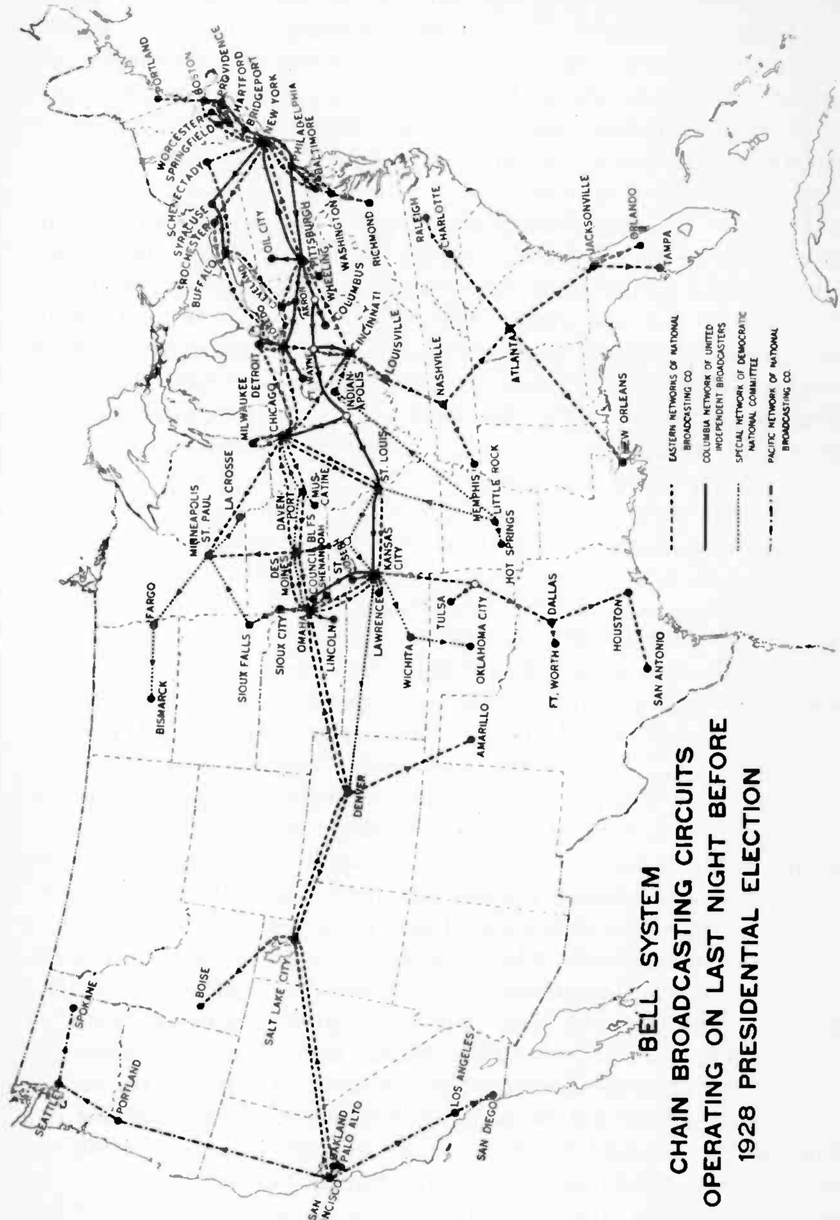

BELL SYSTEM
CHAIN BROADCASTING CIRCUITS
OPERATING ON LAST NIGHT BEFORE
1928 PRESIDENTIAL ELECTION
EASTERN NETWORKS OF NATIONAL BROADCASTING CO.
COLUMBIA NETWORK OF UNITED INDEPENDENT BROADCASTERS
SPECIAL NETWORK OF DEMOCRATIC NATIONAL COMMITTEE
PACIFIC NETWORK OF NATIONAL BROADCASTING CO.
PORTLAND
BOSTON
PROVIDENCE
HARTFORD
BRIDGEPORT
NEW YORK
PHILADELPHIA
BALTIMORE
WORCESTER
SPRINGFIELD
SCHENECTADY
SYRACUSE
ROCHESTER
BUFFALO
OIL CITY
PITTSBURGH
WASHINGTON
RICHMOND
WHEELING
AKRON
COLUMBUS
CINCINNATI
LOUISVILLE
RALEIGH
CHARLOTTE
JACKSONVILLE
ORLANDO
TAMPA
ATLANTA
NASHVILLE
NEW ORLEANS
MILWAUKEE
DETROIT
CHICAGO
INDIANAPOLIS
ST. LOUIS
MEMPHIS
LITTLE ROCK
HOT SPRINGS
MINNEAPOLIS
ST. PAUL
LA CROSSE
DAVENPORT
MUSCATINE
DES MOINES
COUNCIL BLFS
SHENANDOAH
ST. JOSEPH
KANSAS CITY
LAWRENCE
FARGO
BISMARCK
SIOUX FALLS
SIOUX CITY
OMAHA
LINCOLN
WICHITA
TULSA
OKLAHOMA CITY
DALLAS
FT. WORTH
HOUSTON
SAN ANTONIO
AMARILLO
DENVER
BOISE
SALT LAKE CITY
SPOKANE
SEATTLE
PORTLAND
OAKLAND
PALO ALTO
SAN FRANCISCO
LOS ANGELES
SAN DIEGO

Fig. 2

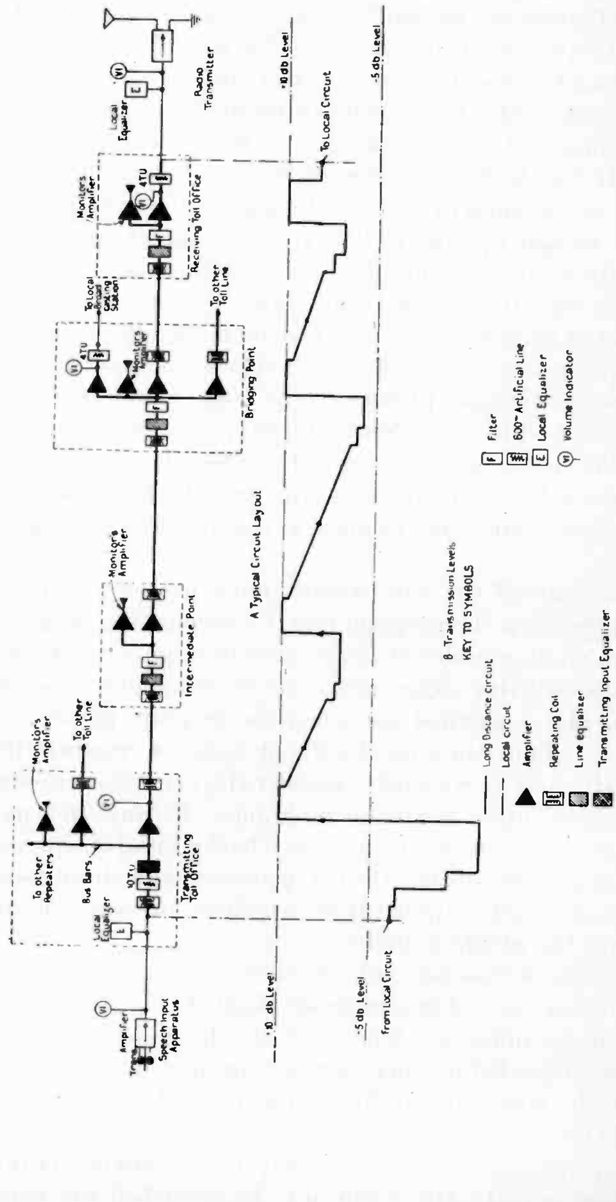
systems, development work is going forward looking toward the possibility that such wider bands may be found desirable in the future. At the lower frequencies, where most people consider that improvement is particularly desirable, consideration is being given to the possible extension of the band down to 50 cycles and possibly lower. Consideration is also being given to the possible addition of two or three thousand cycles to the top of the band.

In addition to this broad band transmission requirement, program transmission circuits must be designed to handle wide ranges of volume, particularly for the transmission of musical programs. Much of the enjoyment in listening to good music appears to come from the ranges of volume, so that in order to deliver such musical programs properly these ranges of volume must be preserved in large part at least. At the present time the volume ranges are "compressed" somewhat by adjustment of amplification under control of an operator at the pickup point. This tends to make easier the radio transmission problem as well as the wire transmission problem. The range of volume which is now delivered, as read by a "volume indicator" (a meter which roughly indicates the peaks), is of the order of 30 db (3.4 nepers), which means that during the fortissimo parts of programs the power which is transmitted is about 1,000 times as great as it is during the pianissimo portions.

The designer of the wire circuits must be concerned lest during those periods when the program power is strong, the program circuits produce an undue amount of disturbance in neighboring circuits which may be transmitting other programs or telephone messages. The designer is also concerned lest when the program power is weak the programs be unduly interfered with by noise or crosstalk from other circuits. He must particularly consider the noise and crosstalk which may be heard during pauses in programs. During such pauses it is very annoying to the listeners to hear a background of noises of various sorts and it is essential that the listeners be unable during such pauses to pick up intelligible speech from telephone message circuits crosstalking into the program circuit.

At the present time generally satisfactory results are being obtained in transmitting the volume range of about 30 db (3.4 nepers). Considerably more must be done both in the radio and in the wire systems, however, before there can be transmitted volume ranges comparable with those put out by symphony orchestras, high-grade artists, and the like.

Having indicated in a general way the requirements of program transmission circuits, there will next be described the wire systems which are now in use in the United States.



Speech Input Apparatus
Amplifier
Local Equalizer
Transmitting Toll Office
To other Repeaters
Bus Bars
Monitors Amplifier
To other Toll Line
Intermediate Point
Bridging Point
To Local Broadcasting Station
To other Toll Line
Receiving Toll Office
Radio Transmitter
A Typical Circuit Lay out
+10 db Level
-5 db Level
From Local Circuit
To Local Circuit
B Transmission Levels
KEY TO SYMBOLS
Long Distance Circuit
Local circuit
Amplifier
Repeating Coil
Line equalizer
Transmitting Input Equalizer
Filter
600~ Artificial Line
Local Equalizer
Volume Indicator

Fig. 3

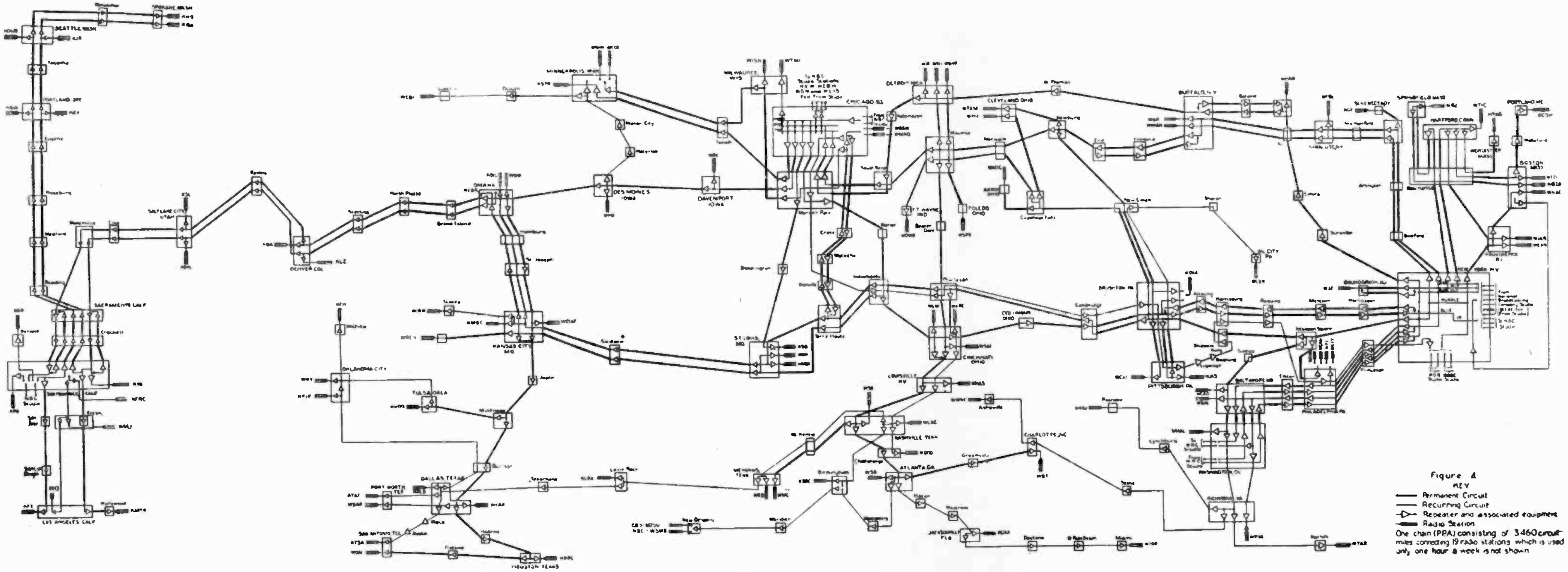


Fig. 4—Bell System network of circuits for connecting radio broadcasting stations. Layout of permanent and recurring program transmission circuits with repeater equipment on the basis of normal direction of transmission. January 15, 1929.

The present-day program transmission circuits in the United States are "on a voice-frequency basis," which means that the waves transmitted over the circuits are essentially copies of the sound waves impinging on the microphones. Most of the circuits now being provided are carried by the familiar open wires, usually copper wires 0.165 in. (4 mm) in diameter spaced about 1 ft. (30 cm) apart on the crossarms. The transmission properties of an open-wire pair without loading are well suited for program transmission purposes since the distortion is comparatively small although it is far from negligible. Spaced at intervals on these circuits, averaging roughly 150 miles (240 km) apart, are one-way repeaters or amplifying devices. Along with these amplifiers are other electrical devices for counteracting the distortion introduced by the open-wire circuits, incidental cables involved, etc. Other one-way repeaters are provided at the terminals of the circuit. Considerable technical refinement is, of course, involved in the design of these amplifiers and of the auxiliary apparatus associated therewith which cannot be gone into here.

In setting up the program transmission circuits, an important part of the work consists in making measurements at different single frequencies within the band which it is desired to transmit over the circuit. Before making such overall measurements, the amplifiers and auxiliary apparatus are so adjusted locally as to compensate for the amount of distortion which theory and experience indicate should be expected. Then, final adjustments are made by certain specially provided adjustable parts in accordance with the overall measurements. Such overall tests and adjustments are, in general, made daily.

In setting up these circuits, another important consideration is that each amplifier carry its proper load or, in telephone parlance, each amplifier deliver to its associated line the proper output level. To insure this, diagrams are prepared in advance, showing the desired transmission levels at each repeater, a typical diagram being shown in Fig. 3. In setting up the circuits, the repeater gains are first set to values which theory and experience indicate should result in conditions as shown in the prescribed transmission level diagram. Testing current is then applied to the sending end of the circuit and sensitive measuring devices are applied at the output of each repeater. If the results of these measurements do not accord with the transmission level diagram, suitable adjustments are then made.

In building up the large chains which tie together a considerable number of radio transmitters, wire distributing centers are provided at strategic points. Fig. 4 shows the circuit layout of the various chains which have been referred to and indicates in a general way how the various chains are interconnected and arranged for switching at certain distributing centers.

In the United States the largest distributing center is, naturally, in New York City, since the bulk of the program material originates at that point. At such a distributing center a special collection of various forms of equipment is provided consisting of one-way amplifiers, loud speakers, multifrequency oscillators, various forms of transmission measuring devices and miscellaneous apparatus. The photo-

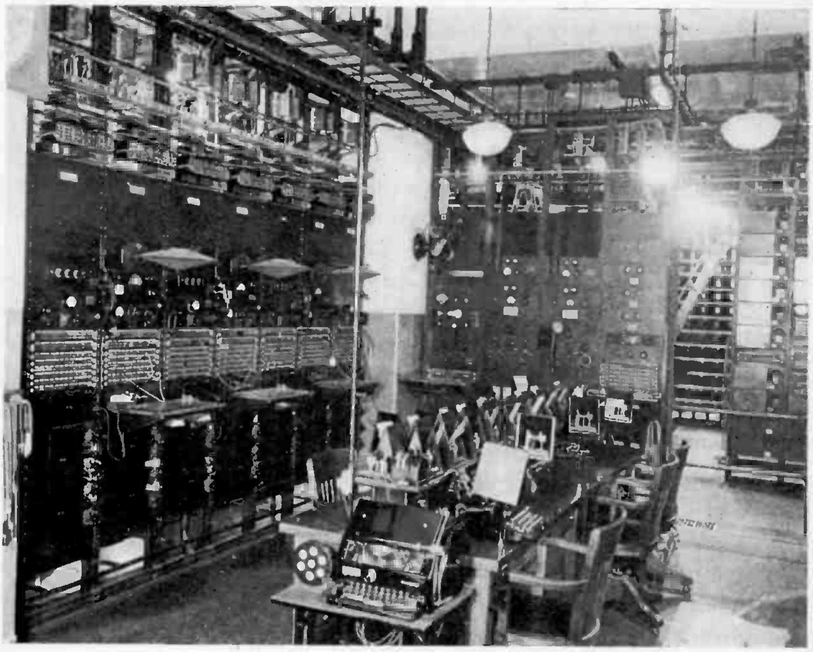


Fig. 5

graph of Fig. 5 shows a portion of the program layout in the New York long distance telephone office as of January 15, 1929. The various bays at the left carry the line apparatus associated with branches of various chains. In the rear are located the transmission measuring apparatus and multifrequency oscillators. In the foreground are the terminals of various telegraph order wires.

In transmitting programs over a wire network, as has been pointed out above, it is important that the volume range be held within proper limits. It is one of the obligations of the one who "picks up" the program to hold his range of volume between proper limits. At the central distributing point those in charge of the wire circuits usually find it desirable to make checks from time to time to insure that the proper range of volume is maintained. This checkup is made by means of a device known as a "volume indicator" similar to the one which the program supplier uses for purposes of regulating his volume range. Other volume indicators are provided at various strategic points in the wire network in order to insure that the proper range of volume is reaching these points. In addition to regularly making these observations by means of volume indicators, loud speaker monitoring observations are continually made at practically all repeater points.

The results of these observations are transmitted back to the control points periodically by means of telegraph order wires so that the control operator knows at all times the condition of transmission at every point in his territory.

With the network chains grown to such vast proportions as indicated in Figs. 1 and 4, it is essential that the system for controlling the networks be such that all points involved be in instant communication with certain designated control points. To accomplish this, the United States has been divided into four areas, each area of which is under the control of a distributing center or control station. The four control stations in the United States at present (January 15, 1929) are, New York covering the eastern section, Chicago the western section, Cincinnati the southern section, and San Francisco the Pacific Coast section. Each of these control points is connected to every repeater point in its area by means of telegraph order wires and in addition is connected to every radio station in the area served by the networks under its control. The various control points are also connected together by means of order wires and arrangements are provided so that New York can be placed in communication with any of the radio stations in the United States which are served by the chains. The total telegraph wire mileage employed for this service is now approximately 43,000 miles (70,000 km).

A large corps of specially trained telephone men is needed to supervise properly the transmission performance of the chains as well as to take care of the switching and general coordination work involved. At present, about 300 men are employed in the United States for this service, these men, of course, being in addition to those who care for the regular wire and equipment maintenance.

Acknowledgment

Acknowledgment is made to H. S. Hamilton for considerable assistance in connection with the preparation of the text and particularly of the drawings, and to G. S. Bibbins and H. C. Read for furnishing most of the statistical data.

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RADIO BROADCASTING REGULATION AND LEGISLATION*

By
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GOVERNMENTAL regulation of radio has been, and still is, a difficult problem. This is true throughout the whole realm of radio, conspicuously so in broadcasting. In many countries the solution is being sought through a government monopoly of broadcast transmission, in the United States through private ownership and operation. In every country there is strict government control, the tendency in most cases being to vest this control in a specially created commission.

The legislative problem arises from certain inherent limitations of radio. These are primarily two: (a) radio waves spread out everywhere, stopping at no boundaries, and capable of great mutual interference; (b) the number of radio communication channels is definitely and severely limited. The implications of these basic principles are far-reaching. The first has led to international regulation, now embodied in the 1927 International Radio Convention.

The second (the limited number of communication channels) is the essential problem with which the governments of the various nations are wrestling. The right to operate radio transmitting stations has become so valuable that the demand for channels in most countries far exceeds the supply. The number of channels is being increased from time to time, as radio technique develops, but at any given time there are only a limited number of communication channels. If stations are permitted to operate in excess of the capacity of these channels extensive interference develops and radio operation becomes unsatisfactory. In the present state of radio technique the number of channels in the whole radio spectrum is as follows: in the low frequencies (15 to 550 kc), there are something less than 1000 channels; in the principal broadcast band of frequencies (550 to 1500 kc), there are 96 channels; and in the high frequencies (from 1500 to 23,000 kc), there are about 1260 channels. Thus we have a total of about 2350 channels available for the radio traffic of the entire world. On some of these frequencies, particularly the very low and the very high, it is not feasible to have more than one station operating at any given time in the whole world. On many of the others a large number of stations

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can operate simultaneously. The facts regarding these frequencies are well enough established to permit us to calculate the number of stations which can be operated without causing excessive interference.

The fact that the number of channels is limited and the number of stations assignable to any one channel is again limited, imposes upon governments the necessity of choice among applicants for the radio channels. This is the underlying reason why radio commissions have come to be created. To provide for choice among those who aspire to construct and use radio stations, the United States Government created not only a commission as its instrument to make the choice, but also a judicial principle to be the basis of choice, viz., the principle of "public interest, convenience, or necessity."

The interpretation and application of this phrase is a novel development in jurisprudence. The phrase is borrowed from legal terminology used in the regulation of public utilities, such as street-car lines and gas companies. Radio broadcasting stations are not public utilities, and yet the test of a public utility must be applied to them for the two basic reasons already given, viz., the potential interference of each radio transmission with every other, and the fact that the number of channels is sharply limited.

The test of "public interest, convenience, or necessity" is being applied in the United States to mean that the rights of the listeners are superior to those of the broadcasting stations. This means that, as far as possible, interference must be avoided. It means that rural listeners remote from any station, as well as city listeners, must be given service. It means that excessive duplication of programs by many stations cannot be permitted, and that high-power stations cannot be located in the midst of cities. Perhaps the most important implication is that the total number of broadcasting stations must be limited to the number necessary to prevent undue interference.

The number of stations which can be in simultaneous operation depends on a number of engineering factors. Chief among these is the width of channel necessary for each. Extensive experience has shown that the minimum separation between adjacent channels, for satisfactory musical reception, is 10 kc. Even this is not quite sufficient for musical reproduction of the highest quality. In the frequency band from 850 to 1500 kc (both inclusive) there are a total of 96 available frequencies. If there is more than one station, using in excess of 1-kw power, on one frequency in an area the size of the United States, interference is likely to result. Now there are 620 stations in the United States, and the difficulty of regulating their operation is at once apparent.

In order to minimize interference among this large number of broadcasting stations it has been necessary to: (a) limit the simultaneous operation of stations by making many of them divide time; (b) assign frequencies carefully selected with regard to geographical separation of stations, to reduce interchannel interference (i.e., disturbance of reception of a station on one frequency by other stations on adjacent frequencies); and (c) limit the power of stations so they would not cause interference to other stations on the same frequency.[1] The most striking of the problems involved in the new allocation was the carrying out of requirement (c) just mentioned. Stations assigned to the same frequency have not, up to the present, been able to maintain their frequencies with sufficient accuracy to prevent the existence of a slight difference or beat frequency, producing what is commonly known as heterodyne interference, or whistles. Unfortunately the heterodyne interference reaches out to enormously greater distances from a station than the program. Consequently the operation of two or more stations on a channel results in an area of destructive interference far in excess of the area in which program service is provided. For instance, a 5-kw station's program can be heard with fair intensity under good conditions at 100 miles while the heterodyne interference from two such stations is heard at 3000 miles. Two stations of 5 kw or more, therefore, cannot be assigned the same frequency in the United States. It is possible, on the average, to put two or more 1-kw stations on the same frequency if they are at least 1800 miles apart, and two or more 1/2-kw stations if they are at least 1200 miles apart. All stations subject to these restrictions have only a small service area, and give no service to remote rural areas. Such distant service is given only by stations having exclusive use of the channels to which they are assigned.

In order to provide rural service 40 channels are each used by one station exclusively. The stations on the exclusive channels not only serve very great areas but deliver a more satisfactory intensity at every point within those areas. Their service is better for all concerned, the greater the power they use. This fact is not commonly understood by others than radio engineers. It is clear when the distinction between the exclusive and the other channels is comprehended. Service on the non-exclusive channels would be utterly ruined if the power limits fixed by the facts of heterodyne interference should be exceeded, and in consequence such stations cannot in general use more than 1 kw. But on the exclusive channels the service is better the higher the power level, and indeed such stations will not be serving

[1] For a detailed description of this allocation from the engineering viewpoint, see "Analysis of Broadcasting Station Allocation," PROC. I. R. E., 16, 1477–1485; November, 1928.

the public most effectively until the level reaches hundreds of kilowatts.

There is some hope that the limitation of power and service of the non-exclusive channels may be overcome. If the frequencies of stations on the same channel are maintained to a certain very high accuracy, the heterodyne or whistle becomes inaudible. The technique of frequency control is fast approaching this goal and success has been attained in isolated instances. The satisfactory service area of such "synchronized" stations is not yet known, but it is believed that it will be substantially greater than when heterodyne interference exists. The significance of this is that the present power limits for stations on shared channels can be raised, better service given, and wider areas served. Synchronization is therefore looked for as the next great advance in broadcasting.

This discussion of broadcasting has been largely with reference to night conditions. Broadcast transmission is entirely different in the daytime. Transmission distances are much less, and somewhat greater power can be allowed the stations. Furthermore, additional stations are licensed for daytime operation only.

The difference between day and night transmission conditions raised one technical problem of considerable moment, viz., determination of the time when day ends and night begins, and thus at what hour daytime stations should close. Investigation revealed that the change from day to night radio conditions extends over a period of something more than an hour and a half, beginning about a half hour before sunset and closing an hour after sunset. The most reasonable time to choose as the transition point is the moment of sunset.

There are many other technical problems involved in the regulation of broadcasting. The limitations of this brief discussion will permit a mere listing of examples, such as chain program limitation; visual broadcasting (television); the requirement of an artificial (dummy) antenna in broadcasting stations for use during warming-up periods; the location of high power stations with respect to populous areas; requirement of highly accurate frequency control; allowable ratio of day to night power; permissible intensity of harmonics; percentage modulation; and fidelity of transmission.

Radio legislation and regulation have the peculiar difficulty that the facts dealt with are extremely complex. They are indeed rapidly shifting. Not only must allowance be constantly made for the flux of changes inherent in a rapidly developing art, but radio waves themselves exhibit extraordinary vagaries. Orderly radio regulation must proceed on a consideration of the distances at which the waves are received. But distances vary enormously between day and night, from season to season, even from night to night, and are different over different kinds of terrain. Knowing this is not to counsel despair. These vagaries have, after all, certain discernible laws becoming more and more calculable as the results of scientific investigations accumulate. It is not necessary to throw up our hands and say that the whole situation is chaotic. In spite of their vagaries, radio phenomena are subject to known engineering principles. Violation of such engineering principles in radio would sooner or later reduce the service of radio to the public.

Summarizing, the regulation of radio broadcasting involves extensive and difficult problems. These arise largely from certain outstanding facts or principles. First, radio waves spread out everywhere and potentially interfere with one another. Second, the available number of communication channels is definitely limited. Another controlling principle, as the art stands today, is that heterodyne interference sharply limits the power that may be permitted any two or more broadcasting stations on the same channel. Finally, radio wave transmission is characterized by extreme vagaries. The facts and implications of each of these principles are subject to constant revision as radio progresses. Such facts constitute the natural limitations of radio regulation and legislation.

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MEASUREMENT OF FREQUENCY*

By

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Summary—Absolute measurement of frequency.—Various methods of absolute measurement of frequency are first described. Particular attention is devoted to the stroboscopic method and the phonic motor method for audio frequencies. A modified method of harmonic comparison is also presented.

Standard frequency oscillators.—The author has designed a clock-controlled oscillator which consists of a tube-driven 25-cycle adjustable tuning fork and a chronometer. The performances of various kinds of tuning fork oscillators are discussed mathematically, and a new type, which has a magnetic device of such nature as to make the electromagnetic controlling force extremely small, is described. The factors affecting the constancy of frequency of quartz oscillators are discussed.

Resonators.—Several types of electrical and mechanical resonator are compared with respect to their usefulness as frequency standards. For expressing the sharpness of resonance, the author recommends the adoption of the quantity Λ defined by the equation $\Lambda = \omega_0/2\delta$, where ω_0 is the angular velocity at resonance and δ the damping constant. Experimental results are presented showing the sharpness of resonance of a number of resonators of different types.

I. Introduction

AT the present time the precise measurement of frequency is becoming more and more important. In this paper, first the absolute measurement of frequency, second the primary standards of frequency, and finally the behavior of working standards are described.

Since frequency is the reciprocal of time, the standard of time and the measurement of time intervals will be the most important factors throughout the present problem. As the primary standard of time, the author has used a Riefler standard clock which has been corrected against the standard clock at the astronomical observatory by means of radio signals. As the working standard of time, a Nardin chronometer has been used. The time intervals are measured by the chronometer and a tape chronograph as shown in Fig. 1. By this device, a measurement extending over six minutes will enable us satisfactorily to obtain an accuracy of time interval of the order of one part in a hundred thousand.

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II. Absolute Measurement of Frequency

1. Stroboscopic Method

Radio frequencies are usually measured by means of harmonic comparison with an audio-frequency standard. Hence first of all the absolute measurement of audio frequency must be considered.

The author recommends the stroboscopic and the phonic motor methods as the most precise means of measuring audio frequency. As already known, the measuring device in the stroboscopic method consists of a sector revolving at a constant speed and a neon glow lamp illuminating it, as shown in Fig. 2. If the frequency of the voltage

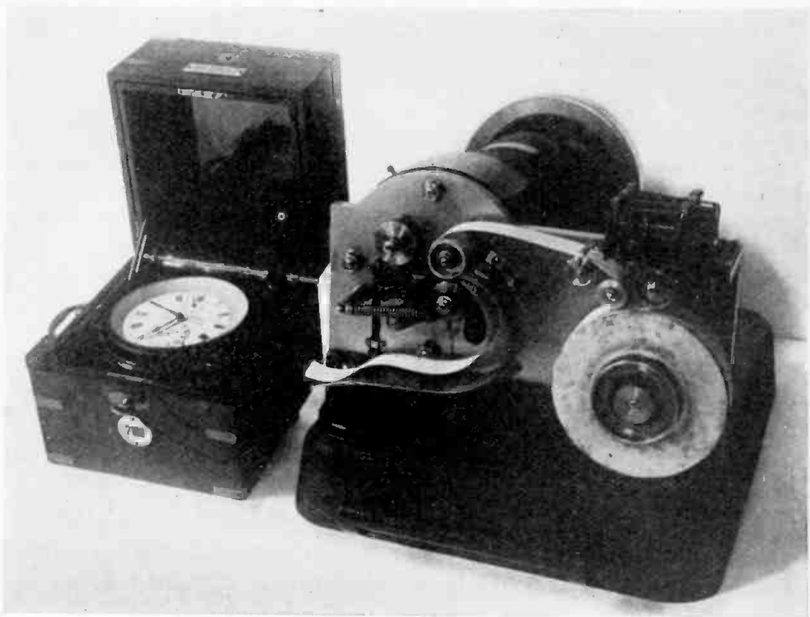

Fig. 1

impressed on the glow lamp is equal to that of the revolution of the pattern in the sector, the pattern looks as if it stood still. When the pattern moves so slowly that the rate of its movement can be counted, the frequency f of the voltage can be written as

$$f = f_m \cdot N \pm n/T \qquad (1)$$

where f_m is the number of revolutions of the disk per second, N the number of patterns on the disk, T the measured time interval required for n transits of the pattern. n/T is negative when the direction of displacement of the pattern coincides with that of the sector.

The most important point in the stroboscopic method is the constancy of speed of the sector disk. There are many devices for constant speed governors. The author has succeeded in developing a highly sensitive speed governor, shown in Fig. 3.

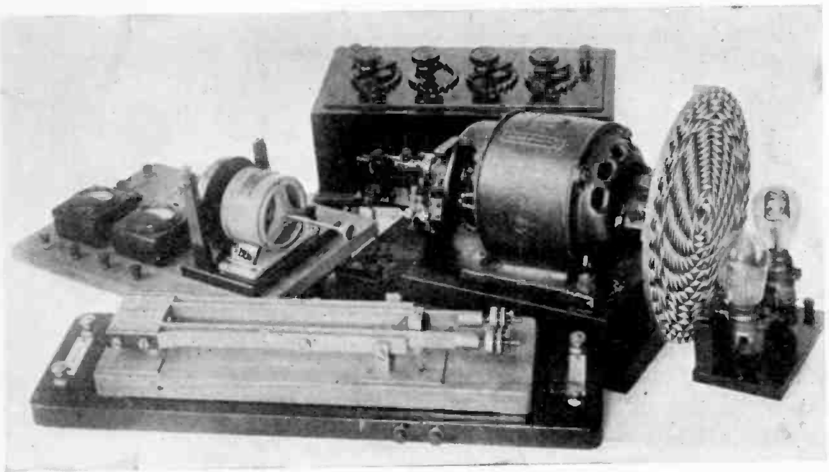

Fig. 2

The author's method is somewhat similar to that of R. H. Hough and F. Wenner[1] in principle, but it presents a remarkable improvement. The principle of this governor consists in the synchronism of a motor with the vibrations of a tuning fork. In the new device, a half-ring commutator is on the shaft of a d-c motor which is separately excited. Two brushes on this commutator are connected to the terminals of a non-inductive adjustable resistance r in the field circuit of the motor through the commutator brushes of a phonic motor, which consist of wires stretched tangentially on the commutator of the phonic motor.

The latter commutator consists of ten segments and its diameter is 10 cm, so that it acts as a flywheel to prevent the hunting of the phonic motor. The phonic motor and the tuning fork of 25 cycles per sec. are of the Tinsley-Wood type. Now if owing to any cause the speed of the motor is slightly decreased, the time interval for short-circuiting the resistance r decreases, and consequently the field current decreases until it is of the proper value to keep the motor from falling below synchronism.

[1] R. H. Hough and F. Wenner, *Phys. Rev.*, **24**, 535, 1907.

Since in this device commutators are used for producing the electrical contacts, the time interval for short-circuiting the resistance is very reliable, and consequently the performance of the governor is sufficiently precise. It is ascertained experimentally that the governor is most sensitive when the time interval for short-circuiting the resistance

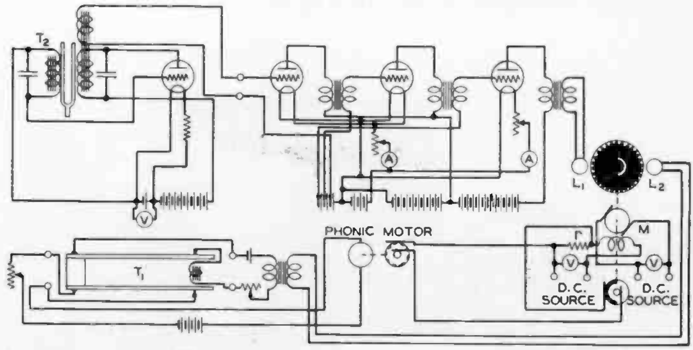

Fig. 3—Apparatus and circuits for stroboscopic comparison of frequencies.*

is 1/4 of the period corresponding to one complete revolution of the motor, as shown in Fig. 4. The resistance r is 285 ohms, and the exciting voltage 90 volts.

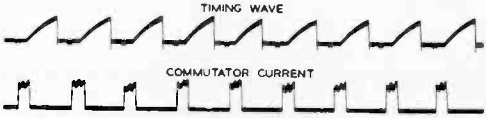

Fig. 4

Fig. 5

* In Fig. 3, T_1 is the special 25-cycle make-and-break fork mentioned in the text, and T_2 the fork with which it is to be compared. T_1 consists of two flat metal springs fastened to an insulating block. The upper contact is the make-and-break in the circuit that drives the fork, while from the lower contact impulses are sent for driving the phonic motor. The make-and-break wheel on the latter is in series with the half-ring commutator on the shaft of the d-c motor M, and together they regulate the field excitation of M in such a way as to hold the speed constant. The stroboscope is on the shaft of M. The neon lamp L_1 is supplied with alternating current amplified from the output of the tuning fork oscillator T_2. The lamp L_2 is lighted at the frequency of T_1. Thus by means of L_2 and the stroboscope disk a check is obtained of the synchronism between T_1 and M while L_1 serves for comparing T_2 with the speed of the disk and hence with T_1.—*Ed.*

The constancy of the tuning fork is an important consideration in this device. It is investigated by comparing two dots on the tape of the chronograph shown in Fig. 1, one of which is made at the rate of one per second by an electric contact on the phonic motor operated by the tuning fork, and the other by the chronometer. The experimental result obtained during a run of 20 minutes, shown in Fig. 5, shows that the constancy of this fork is sufficient. It will be noticed that the wave-form of the voltage on the glow lamp must be steep to obtain a clear pattern.

By this stroboscopic method with the above speed-governor, the author has succeeded in obtaining a precision of one part in a hundred thousand in the absolute measurement of frequency.

In this method, it is an excellent feature that any multiple of 25 cycles, from 50 to 1025 cycles per sec., can be easily measured. The author believes that this governor will prove useful for various applications.

2. Phonic Motor Method

The phonic motor was designed by Latour and Lord Rayleigh. A high-frequency motor operated by a small power tube has been described by D. W. Dye and recently by J. W. Horton and W. A. Marrison.[2] The author has designed a phonic motor which has 50 teeth and two pairs of poles. This motor can be operated by a UX171 tube from 100 to 700 cycles per second. For frequencies over 700 cycles, a synchronous motor made by the General Radio Co. is now being used, until a new high-frequency motor is finished. In the phonic motor method, the hunting of the motor is noticeable. To prevent this hunting, mercury is frequently used, but by the stroboscopic method it is found that mercury is not sufficient for this purpose. In this connection, it may be added that it is most important that the pole arrangement be as regular as possible. However, since perfection is not to be expected, the motor must be run long enough to eliminate the effects of hunting from the experimental result.

By this method, we may expect an accuracy as high as one part in a hundred thousand in frequency.

3. Harmonic Comparison Method

As is well-known, a radio frequency can be measured by harmonic comparison with a standard frequency. There are many methods of accomplishing this, such as the multivibrator and the cathode ray oscillograph.

[2] J. W. Horton and W. A. Marrison, Proc. I. R. E., 16, 137; February, 1928.

The author has developed a method of harmonic comparison, in which the measuring device consists of a multifrequency oscillator, a selector circuit and a frequency bridge. The multifrequency oscillator is somewhat similar to the timing device in Gabor's cathode ray oscillograph.[3] By adjusting the resistance in the plate circuit so as to make the time constant of the plate circuit nearly equal to the reciprocal of the circular frequency applied to the grid of the valve, the desired result can be expected. The oscillating current contains an ample supply of the higher harmonics.

The selector circuit consists of a fixed air condenser, a variable air condenser and a low loss coil, and its sharpness of resonance is sufficiently large.

The resonant sharpness of the frequency bridge is so great as to give a balance within two tenths of a cycle per second from 100 to 1,500 cycles, and the bridge is calibrated by the phonic motor method. In this method, the frequency to be measured can be easily compared with the 50th harmonic of the audio-frequency standard.

High frequencies over 50 kc can be similarly compared with harmonic frequencies of a quartz oscillator, the fundamental frequency of which can be determined by the above method, while in this case the multifrequency oscillator is not needed. In the method mentioned above, we can expect the accuracy of one part in a hundred thousand for all frequencies greater than 20 kc.

III. Standard Frequency Oscillators

1. Introduction

The absolute measurement of frequency is somewhat laborious, so that in order to preserve the results of absolute measurement a standard frequency oscillator is needed. The standard frequency oscillator must fulfil the following conditions:

1. Frequency must not depend on external circumstances,
2. Permanence of frequency.

The oscillators satisfying the above conditions are the following:

1. Clock-controlled oscillator,
2. Tuning-fork oscillator,
3. Quartz oscillator.

First, we will consider the performance of a homogeneous mechanical vibrator.

There are to be considered the longitudinal, lateral (or flexural), and torsional modes of elastic vibration. If we consider a thin bar

[3] D. Gabor, "Forschungshefte d. Studiengesellschaft für Hochspannungsanlagen, September, 1927.

with a rectangular cross section, and if the thickness, length and breadth are x, y and z, respectively, then the natural frequency of longitudinal vibration can be expressed by

$$f_{lx}=mv_l/2x, \quad f_{ly}=mv_l/2y, \quad f_{lz}=mv_l/2z \tag{2}$$

where m is any integer and v_l denotes the propagation velocity $\sqrt{E/\rho}$, while E is the modulus of elasticity, and ρ the density.

For the flexural vibration of a Curie cut plate in the yz plane, we have

$$f_b=\frac{k^2v_l}{4\pi\sqrt{3}}\cdot\frac{z}{y^2} \tag{3}$$

where $k=(m+1/2)\pi$, $v_l=\sqrt{E/\rho}$, and m is a constant.

For the torsional vibration, about the y-axis,[4] provided that r is less than 1/3, where $r=x/z$, we have approximately

$$f_t=\frac{mv_t}{2y}\cdot\frac{2r}{\sqrt{1+r^2}}\cdot\sqrt{1-0.63r} \tag{4}$$

where v_t is $\sqrt{T/\rho}$ and T the torsional rigidity. The propagation velocity depends on the physical properties of the material. The approximate values for steel and quartz are shown in Table I.

TABLE I

Material	v_l (cm/sec)	v_t (cm/sec)
Steel	$4,2\text{–}5,2.10^5$	$3,2.10^5$
Quartz	$5,4.10^5$	$3,5.10^5$

The tuning fork is a clamped-free bar, and according to Lord Rayleigh we have

$$f_b=845900\cdot z/y^2. \tag{5}$$

The vibration of a monochord is not an elastic wave, still its natural frequency is similarly obtained:

$$f_c=v_c/2y \tag{6}$$

and

$$v_c=\sqrt{W/\rho}$$

where W is the tension, y the length and ρ the mass of the monochord per cm.

The above equations may not be sufficiently accurate for practical cases, because actually the vibrations are somewhat complicated and very difficult to solve mathematically.

[4] Giebe and Scheibe, *Zeitschr. f. Phys.*, **46**, p. 638, 1928.

2. Clock-Controlled Oscillator

A. Dey and C. V. Raman[5] have already shown that the vibrations of a mechanical vibrator, whose frequency is f/m, where m is any integer, can be maintained by an alternating current of which the frequency is f cycles. The present oscillator is somewhat similar to the above oscillator in principle.

The present oscillator consists of a chronometer and tube-maintained tuning fork as shown in Figs. 6 and 7.

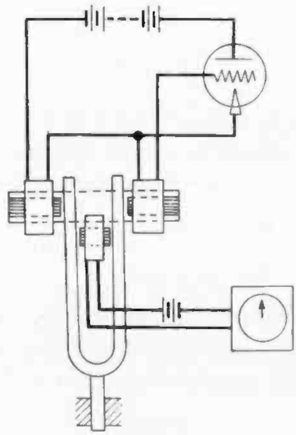

Fig. 6

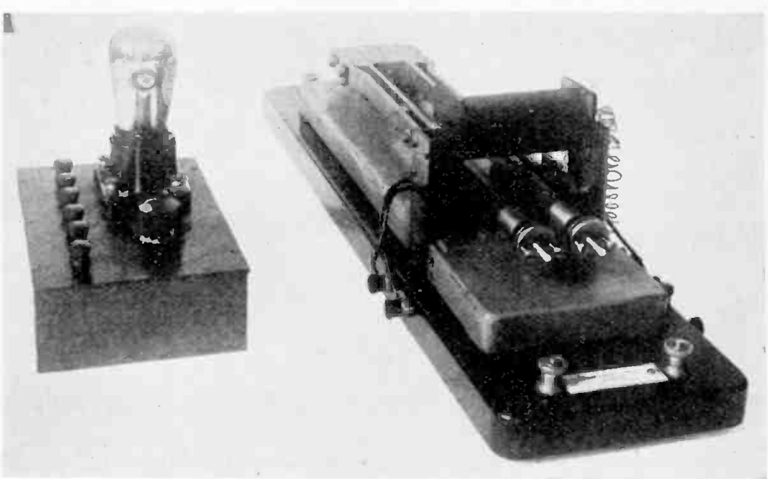

Fig. 7

[5] A. Dey and C. V. Raman, *Proc.* Roy. Soc., 95, 533, 1919.

In the tube-maintained tuning fork, the working resonant sharpness can be extremely large, so that forced oscillations of the fork may be produced by the harmonic current, which is usually very small, over a rather wide range of natural frequency of the fork.

In Fig. 8 an adjustable tuning fork having a normal frequency of 25 cycles per second is used; f_t denotes the frequency of oscillation for various adjustments when controlled by the chronometer, and f_f the frequency without the chronometer. According to this figure, we see that the automatic synchronization can be held over a considerable range.

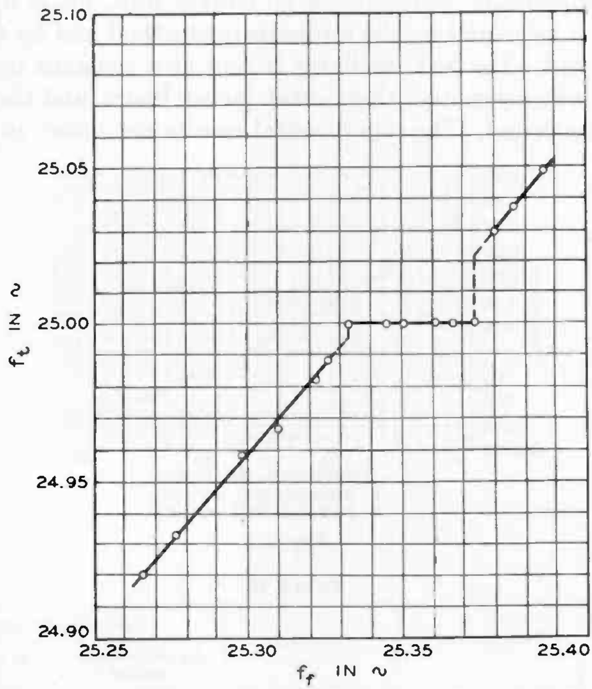

Fig. 8

In this device, it is true that the synchronization must always be produced artificially, but there is the advantage that synchronization can be easily obtained, and it is not disturbed by the surrounding temperature and other factors.

3. Tuning Fork Oscillator

The principle of the tuning fork oscillator was discovered by W. H. Eccles. The performance has been studied by S. Butterworth and T. G. Hodgkinson theoretically, and by D. W. Dye experimentally.[6]

The author considers the important factors affecting the oscillating frequency to be (a) the surrounding temperature, (b) magnetization of the fork, and (c) the clamping device of the fork. These factors will be treated as follows.

(a) *Temperature coefficient.* The temperature coefficient of an ordinary steel fork is about 1×10^{-4}; but if it be made of elinvar (Ni, 35 per cent; Cr, 12 per cent; Fe, 53 per cent), this coefficient becomes as small as -1×10^{-5}.

The temperature coefficient of an elinvar fork, made by the Sullivan Co., is measured by the stroboscopic method and by the phonic motor method. The fork oscillator is kept at a constant temperature in a bath with a sensitive thermostat for six hours, and then the frequency is measured. The experimental results are shown in Table II.

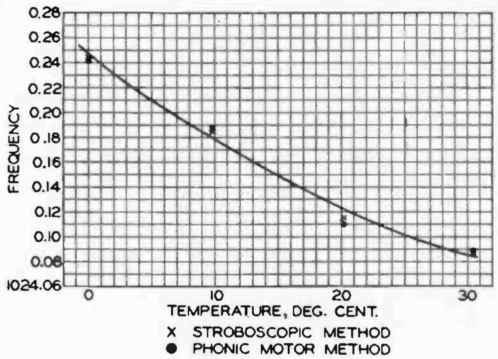

Fig. 9

TABLE II

Correction of Riefler clock	Temperature	Humidity	Measured Frequency	
			by stroboscopic method	by phonic motor method
+0.49	30.4 deg. C	66 per cent	1023.08_7	1024.08_9
+0.53	20.2	72	1024.11_8	1024.11_0
+0.49	9.9	51	1024.18_6	1024.18_0
+0.52	0.0	30	1024.24_8	1024.24_0

The two values are in sufficiently close agreement with each other, and the accuracy of measurement can be about one part in a hundred thousand. The performance curve of the first of these forks is shown in Fig. 9. A similar curve was obtained with the other fork. From these results, we have

[6] S. Butterworth, *Proc.* Phys. Soc. (London), **32**, 345, 1920; T. G. Hodgkinson, *Proc.* Phys. Soc. (London), **38**, 24, 1925; D. W. Dye, *Proc.* Roy. Soc., **103**, 209, 1923.

$$f=1024.24_8\{1-7.6\times10^{-6}T+7.8\times10^{-8}T^2\} \tag{7}$$

and

$$f=960.26_9\{1-12.8\times10^{-6}T+6.5\times10^{-8}T^2\}$$

Therefore, we know that the temperature coefficient of the elinvar fork has always a negative sign, and that it is nearly 1×10^{-5}.

(b) *Magnetization of fork.* We first consider the theory of the fork oscillator, which is of the untuned type.

The motion of the fork can be expressed by the following equation:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{y}}\right)+\frac{\partial F}{\partial \dot{y}}+\frac{\partial V}{\partial y}=\frac{\partial T_e}{\partial y}, \tag{8}$$

where T denotes the kinetic energy, F the dissipation energy, V the potential energy, T_e the electrokinetic energy, and y the displacement of the fork.

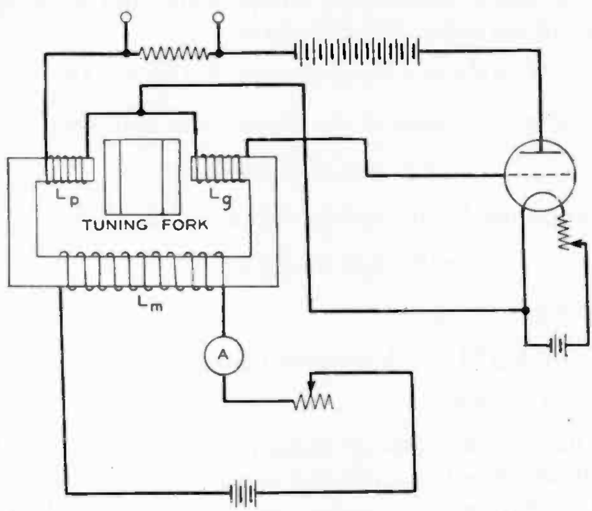

Fig. 10

Now we will suppose that the fork has one degree of freedom, and that the mechanical restoring force of the fork is not proportional[7] to the displacement y. We then have

$$T=\tfrac{1}{2}\alpha\dot{y}^2, \quad F=\tfrac{1}{2}\beta\dot{y}^2, \quad V=\tfrac{1}{2}(\gamma-\tau y^2)y^2.$$

Therefore we have

$$\{\alpha D^2+\beta D+(\gamma-2\tau y^2)\}y=\frac{\partial T_e}{\partial y}.$$

[7] Rayleigh, "Theory of Sound," Vol. 1, p. 77.

As shown in Fig. 10, let L_p, L_g, L_m be the self inductances of plate coil, grid coil, and magnetizing coil, respectively.

Now we suppose that L_p, L_g, M_{pg} are independent of y and that

$$L_m = l_0 + l_1 y + l_2 y^2 \tag{9}$$

$$M_{pm} = M_{gm} = m_0 + m_1 y + m_2 y^2.$$

Let I_0 be the magnetizing current, I the induced alternating current in the magnetizing coil, then

$$\frac{\partial T_e}{\partial y} = \tfrac{1}{2}(l_1 + 2l_2 y) I_0^2 + (l_1 + 2l_2 y) I I_0 + (m_1 + 2m_2 y) I_0 I_p.$$

Considering the saturation of the tube, we have

$$I_p = G_v E_g (1 - g E_g^2)$$

where I_p, E_g denote alternating components, and G_v is the mutual conductance of the tube. Then we have

$$I_p = G_v (m_1 + 2m_2 y)(1 - g m_1^2 I_0^2 (Dy)^2) I_0 Dy$$

Let G_m be the conductance of the magnetizing coil, then

$$I = -G_m (l_1 + 2l_2 y) I_0 Dy$$

Therefore, the equation of motion can be written

$$\{\alpha D^2 + \beta_e D + \gamma_e\} y = \tfrac{1}{2} l_1 I_0^2 \tag{10}$$

where $\beta_e = \beta + \beta_m - \beta_v$.

$$\beta_m = G_m (l_1 + 2l_2 y)^2 I_0^2, \quad \beta_v = G_v (m_1 + 2m_2 y)^2 (1 - g m_1^2 I_0^2 (Dy)^2) I_0^2,$$

$$\gamma_e = \gamma - l_2 I_0^2 - 2\tau y^2.$$

The above differential equation cannot be completely solved, because β_e, γ_e are functions of y. We will consider that actually the mean values of β_e, γ_e during one complete vibration act on the fork, assuming $y = Y \cos \omega t$. We can then obtain the following approximate solution:

$$\omega \doteqdot \omega_0 \left\{ 1 - \frac{l_2 I_0^2}{2\gamma} - \frac{\tau}{2\gamma} Y^2 \right\} \tag{11}$$

$$Y \doteqdot \frac{\sqrt{2}}{\omega_0 m_1 I_0 \sqrt{g}} \left\{ 1 - \frac{\beta}{G_v m_1^2 I_0^2} - \frac{G_m}{G_v} \left(\frac{l_1}{m_1} \right)^2 \right\}^{1/2} \tag{12}$$

supposing l_2/m_1, m_2/m_1 to be very small. ω_0 denotes 2π times the natural frequency of the fork, viz. $\sqrt{\gamma/\alpha}$. From the above theory, we conclude that

(1) The oscillating frequency depends on the magnetizing current; namely the frequency increases with decrease of magnetization of fork, because the electromagnetic controlling force, in addition to the mechanical restoring force, acts on the fork.
(2) The amplitude of vibration is small when the natural frequency of the fork is large.
(3) The presence of the magnetizing coil causes large damping.

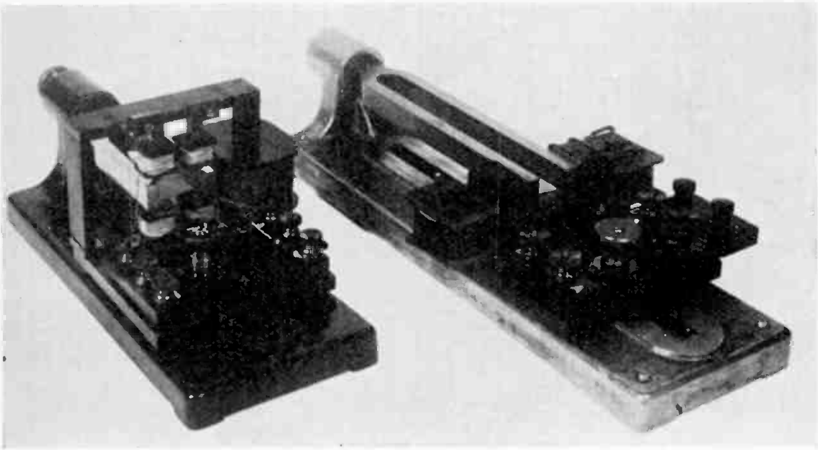

Fig. 11

The first point is most noticeable. According to the author's theory, the electromagnetic controlling force can be eliminated by making the coefficient l_2 equal to zero. In order to realize this, the author has contrived a new form of fork oscillator as shown on the left hand side of Fig. 11 while that on the right hand side is one of ordinary type.

In this new oscillator, the four poles are arranged against the fork and the poles are shaped in such a manner as to make the above coefficient l_e become zero. The relation between magnetizing current and amplitude of fork or frequency was investigated experimentally. In this experiment, a tuning fork of 1000 cycles is used and it is installed in a bath with a thermostat, whereby the temperature is always kept constant. The amplitude of the fork is measured by a cathetometer, and the frequency of oscillation by the phonic motor, chronometer and chronograph already mentioned. These experimental results are shown in Fig. 12. Fig. 12A is for the ordinary type of fork, with tube circuit untuned, while Fig. 12B is similar but with tube circuit tuned to fork frequency. Figs. 12C and 12D were obtained with the author's new device, the tube circuits being untuned in Fig. 12C, and tuned in Fig. 12D. In the ordinary device, there is a considerable variation of frequency due to the change of exciting current, while in the new device, this variation is extremely small.

The author believes that this new device will be valuable as a standard frequency oscillator, because, even though the permanent

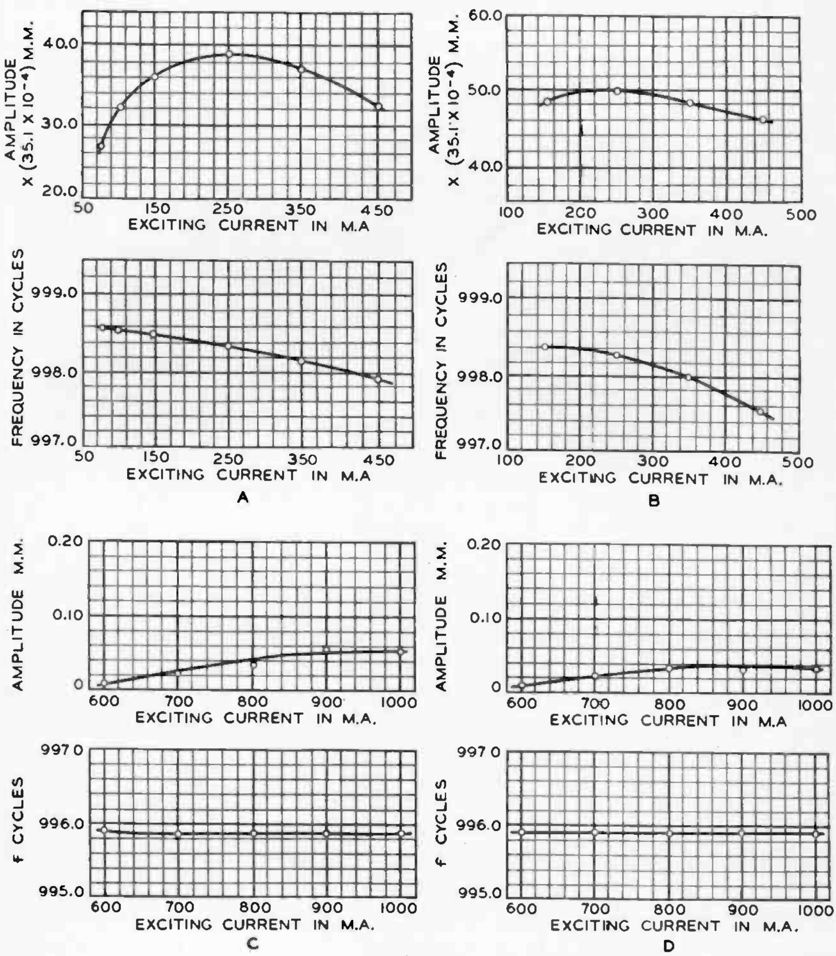

Fig. 12

magnet in the oscillator may become partially demagnetized after long running, the frequency is not affected.

Oscillators may be classified into tuned and untuned types. The author suggests that the former type is suitable for high-frequency forks, the latter for low. The monochord oscillator designed by the author may also be available as a standard frequency oscillator, but its reliability is not so great as that of the chronometer, fork and quartz.

(c) *Clamping device of fork.* Any insecurity in the clamping of the fork will introduce a considerable change in frequency. However, this may easily be removed by sufficiently clamping the fork to the base. Besides this factor, there are several others, such as weight of base,

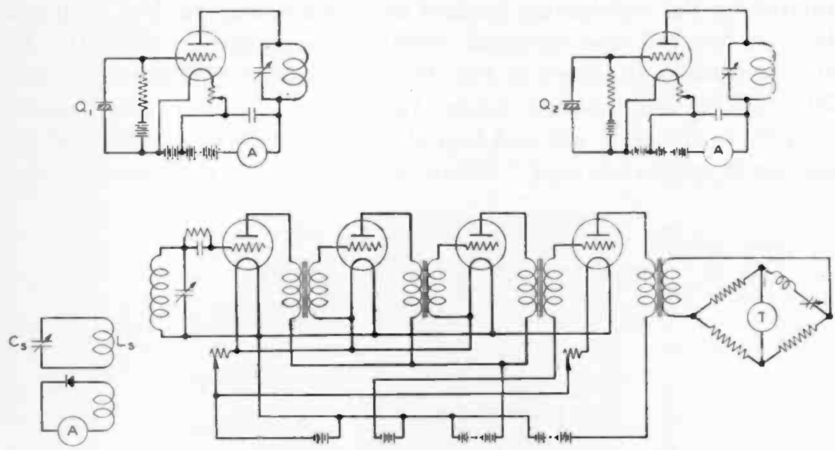

Fig. 13—Circuits for comparison of two piezo oscillators.

circuit conditions, etc., but these factors will not introduce any noticeable influence on the frequency. The standard frequency oscillator must be always kept in a definite state, under, as constant conditions as possible.

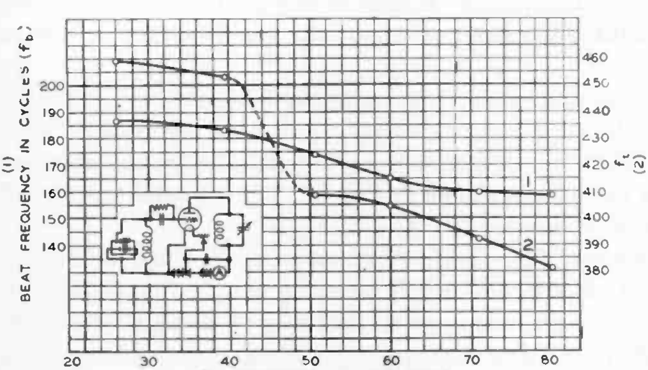

Fig. 14—Excitation of flexural and torsional vibrations in piezo oscillator. Dependence of frequency on temperature. Curve 1, flexural; curve 2, torsional.

4. Quartz Oscillator

There are two modes of cutting a crystal in common use, in one of which the dimension along the normal x is small compared with y, while in the other y is small compared with x, where x is the length along the electric axis, z along the optical axis and y along the third axis.

A piezo oscillator employing the longitudinal vibration is easily excited by the well-known method as shown in Fig. 13, but to obtain lateral (flexural) and torsional vibrations is somewhat difficult. By the connection as shown in Fig. 14, both flexural and torsional oscillations have been tested, where the grid coil is somewhat loosely coupled to the plate coil and four electrodes covering a portion of the surface of quartz are used.[8] When the frequency of the tube oscillator

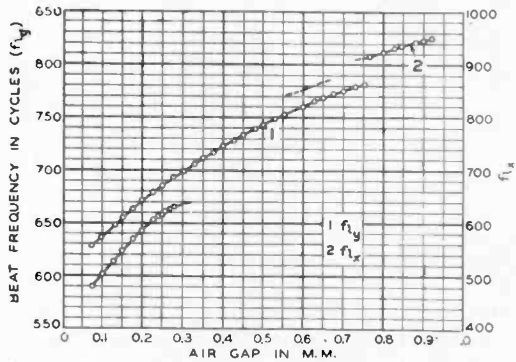

Fig. 15—Dependence of frequency upon air-gap, Curie cut crystal.

approaches the natural frequency of the quartz, there is in the torsional case a remarkable change in the reading of the ammeter in the plate circuit, by means of which the synchronization can be clearly recognized.

The important factors affecting the frequency are (1) the temperature, (2) the air gap in the mounting, and (3) the electric circuit.

The effects of temperature and of the air gap are obtained by the beatnote method as shown in Fig. 17. The temperature coefficient is found to lie between 4.10^{-5} and 1.10^{-5}.

As shown in Fig. 15, the frequency for the Curie cut increases with increase of air gap, and it will be noted that f_{lx} (longitudinal vibration parallel to x-axis) cannot be obtained at some particular length of air gap. This peculiarity disappears on using a mesh electrode instead of the plane electrode.

[8] The flexural vibrations were of the type described by Harrison, Proc. I. R. E., 16, 1455; November, 1928. The torsional vibrations were as described by Giebe and Scheibe *Zeitschr, f. Phys.* 46 p. 638, 1928.

It is found that the electric circuit does not exert so great an influence as the above-mentioned effects.

IV. Resonators

1. Theory of Damping of Resonators

Various types of resonator can serve as efficient working standards of frequency.

A resonator must fulfil the following conditions:

(a) the frequency must depend as little as possible on external conditions, such as the temperature.

(b) the resonant sharpness must be as large as possible.

Resonators may be divided into two classes, one being the electrical type and the other the mechanical type. The frequency bridge and the wavemeter belong to the former, while the sonometer type resonator and the quartz resonator belong to the latter. Now the resonant sharpness Λ can be defined by the following equation:

$$\Lambda = \omega_0 / 2\delta \qquad (13)$$

where ω_0 is $2\pi f_0$, f_0 the resonant frequency, and δ the damping factor. Now let Δ, S, R be logarithmic decrement, selectivity, and resonance range, respectively, then we have

$$\Delta = \pi / \Lambda \qquad (14)\text{a}$$

$$S = \sqrt{1 + 4.10^4 \Lambda} \qquad (14)\text{b}$$

$$R = \frac{\sqrt{3}}{2} \frac{100}{\omega} \% \qquad (14)\text{c}$$

The last equation holds when Λ is greater than 100. The numerical relations between these different measures of sharpness of resonance are shown in Table III.

TABLE III

Λ	1	50	100	300	600	1000	3000	6000	10000
Δ	314	6.3×10^{-2}	3.1×10^{-2}	11×10^{-3}	5.2×10^{-3}	3.1×10^{-3}	11.10^{-4}	5.2×10^{-4}	3.1×10^{-4}
S	200	1400	2000	3500	4900	6300	11000	15000	20000
R %	–	–	0.87	0.29	0.15	0.087	0.029	0.015	0.009

It will be clearly understood from the above figures how convenient Λ is to express the sharpness of resonance.

We will next consider the resonant sharpness of the resonator.

2. The Electrical Resonator

The electrical type of resonator may be classified into the wavemeter type and the bridge type.

Campbell's frequency bridge and the ordinary wavemeter illustrate these two types.

Let I be the current in an L-C-R circuit, and I_0 that at resonance, then we have

$$I=\frac{I_0}{1+j\Lambda\left(x-\dfrac{1}{x}\right)}. \tag{15}$$

$$I_0=E/R,\quad x=\omega/\omega_0,\quad \Lambda=1/\omega_0CR=\omega_0L\ R.$$

If the resistance R is that of the inductance coil, Λ is equal to $\tau\omega_0$, where τ denotes the time-constant of the coil. Therefore, the time constant of the coil must be as large as possible, in order to get the greatest sharpness, but since there is a limit to the attainable time constant of a coil, it follows that this resonator, that is, the wavemeter, will be available only for radio frequency. From the above equation, we have

$$\Lambda=\frac{\sqrt{\left(\dfrac{I_0}{I}\right)^2-1}}{x-\dfrac{1}{x}}. \tag{16}$$

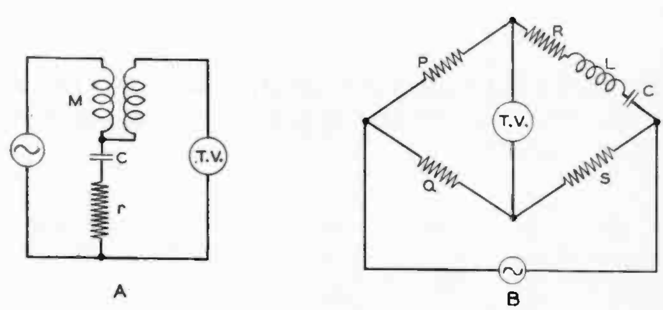

Fig. 16

By this equation, we can obtain the resonant sharpness. In Campbell's bridge as shown in Fig. 16A, let E be the potential difference in the detector circuit and E_0 that at resonance; then supposing that the current at the primary side I is constant, we have

$$E = E_0 \left\{ 1 + j\Lambda\left(x - \frac{1}{x}\right) \right\} \tag{17}$$

where $E_0 = rI$ and $\Lambda = \omega_0 M/r$.

The resistance r represents the effects of "impurity" of the mutual inductance M (lack of quadrature between primary current and secondary e.m.f.), and dielectric loss in the condenser. If low loss apparatus is used, the sharpness will be very large at audio frequency. From the above equation, it follows that

$$\Lambda = \frac{\sqrt{\left(\frac{E}{E_0}\right)^2 - 1}}{x - \frac{1}{x}}. \tag{18}$$

By this equation, we can find the resonant sharpness using a tube voltmeter.

With the bridge type resonator as shown in Fig. 16B, supposing that the applied voltage E_0 is always kept constant, we have

$$L = \frac{E}{E_0}\left(1 + \frac{S}{Q}\right) = \frac{j\Lambda\left(x - \frac{1}{x}\right)}{1 + j\Lambda\left(x - \frac{1}{x}\right)} \tag{19}$$

where the symbol L is introduced as an abbreviation, E is the potential difference in the detector circuit measured by a tube voltmeter T. V., and

$$\Lambda = \Lambda_0 \frac{R}{P + R}.$$

Λ_0 denotes the intrinsic resonant sharpness of the resonance arm. From this equation, it follows that

$$\Lambda = \frac{L}{\sqrt{1 - L^2}} \Big/ \left(x - \frac{1}{x}\right), \tag{20}$$

so that Λ can be found experimentally.

3. The Mechanical Resonator

There are two kinds to consider, the electromagnetic and the electrostatic type. The fork type frequency meter and the magnetic sonometer type resonator belong to the former, while the static sonometer type resonator and the quartz resonator belong to the latter.

In the case of the electromagnetic type resonator, the equation of motion can be written

$$(\alpha D^2+\beta D+\gamma)y=\psi I. \tag{21}$$

The intrinsic sharpness, Λ_0, is given by

$$\Lambda_0=\sqrt{\alpha\gamma}/\beta. \tag{22}$$

This resonator can be represented by an equivalent electric circuit as shown in Fig. 17A, where

$$C_v=\alpha/\psi^2, \quad L_v=\psi^2/\gamma. \qquad R_v=\psi^2/\beta.$$

It will be noticed that the working resonant sharpness, which involved

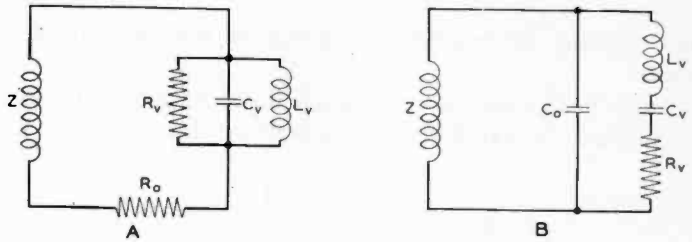

Fig. 17

the entire circuit, is different from the intrinsic sharpness. For the electrostatic type of mechanical resonator, the equation of motion can be written

$$\{\alpha D^2+\beta D+\gamma\}y=\phi E. \tag{23}$$

The intrinsic sharpness is also given by the equation (22).

This resonator can be represented by an equivalent electric circuit as shown in Fig. 17B, where

$$C_v=\phi^2/\gamma \quad L_v=\alpha/\phi^2 \quad R_v=\beta/\phi^2.$$

The working sharpness of the quartz resonator (Figs. 18 and 19) can be written

$$L=\frac{I}{I_0}=\frac{1}{1+j\Lambda\left(x-\frac{1}{x}\right)} \tag{24}$$

and

$$\Lambda = \Lambda_0 \frac{R}{R+R_v}. \tag{25}$$

The shunt capacity C_0 is here assumed to be extremely small.

4. Experimental Results

There are two methods of measuring resonant sharpness. One is the optical method, in which the decay of motion of the vibrator is automatically recorded, and the other is the resonance-curve method using a tube voltmeter or a thermoammeter.

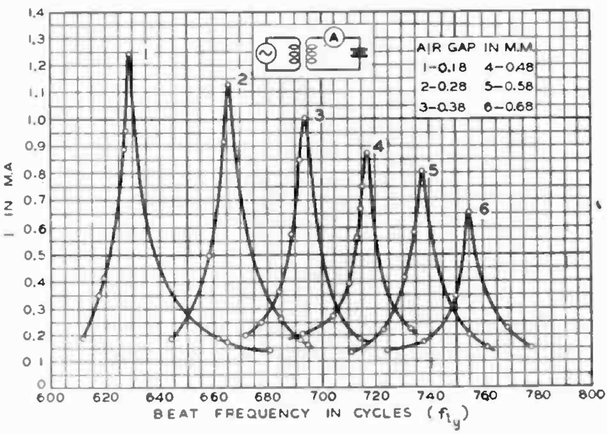

Fig. 18

The author used chiefly the latter method in these experiments. A new type tube voltmeter as shown in Fig. 20 was employed. The author's voltmeter has the following merits: (1) the calibration de-

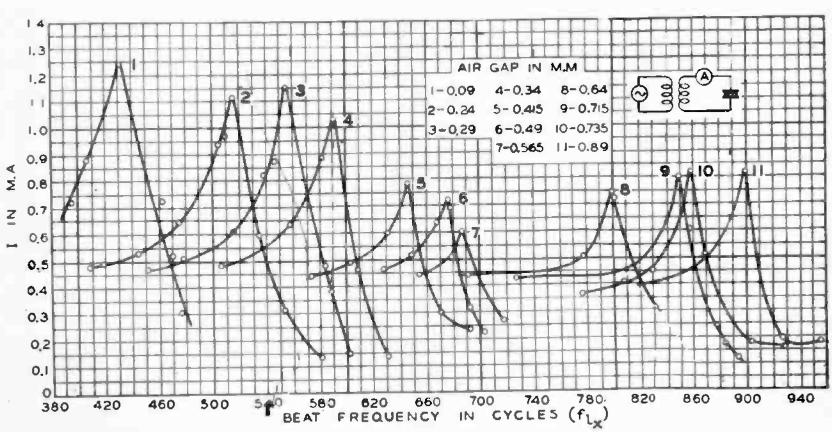

Fig. 19

pends only slightly on the frequency, (2) the input power is extremely small, and (3) the calibration is not affected by the outside circuit.

We can accurately measure a voltage as small as from 0.1 to 1 volt by this voltmeter. The thermoammeter used in these experiments

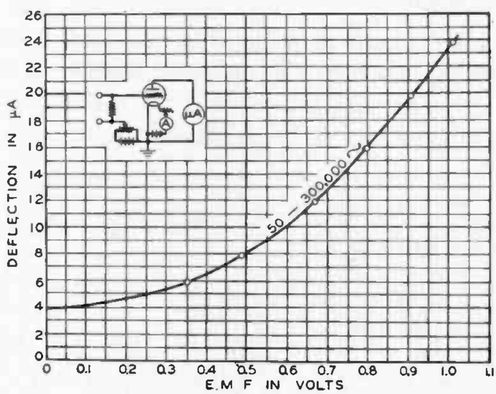

Fig. 20

consists of a Western Electric thermovacuum junction and a Weston millivoltmeter. The sonometer type resonator is very useful as a working standard of frequency.

TABLE IV

Kinds of Resonators		Resonant Frequency	Λ
Hartmann Kempf Frequency Meter		22.5 32.0 46.5 52.5	1100 900 900 610
Tuning Fork		260 490 760	2800 7300 3300
A Freq. Meter Made in Japan		920	6.3
Campbell Frequency Meter		850 640	6.3 2.6
Campbell's Bridge		950 570	11 75
L C Bridge		970 550	17 11
Wavemeter		127000 570000	54 69
G. R. Co. Wavemeter		140000	19
Sonometer	Magnetic	310 730 1010	360–660 630–1400 1000–1600
	Static	990	1600–2000
Piezo Resonator		128000 570000	18000–22000 22000–34000

Many resonance curves have been obtained by the method above mentioned, and the values of resonant sharpness are assembled in Table IV.

The resonant sharpness of the fork type frequency meter and of the tuning fork is measured by the optical method. It will be noted that the resonant sharpness is extremely small with some frequency bridges, and is greatest with the quartz resonator. There are some aperiodic types of frequency bridge, and in such types the calibration curve will be linear, but it will be a drawback that the sharpness of resonance is so small. According to the results shown in Figs. 18 and 19 we see that the resonant sharpness of the quartz resonator decreases regularly with increase of air-gap for the frequency of f_{ly}, while for the frequency f_{lz} the decrease is not regular. It will also be observed that resonance for the frequency of f_{lz} cannot be obtained at some particular length of air-gap and that near this peculiar state the resonant sharpness is very small.

This peculiar phenomenon is considered to arise from the damping in the region of air between the quartz and the electrode.

In conclusion, the author wishes to render thanks to R. Kojima and K. Inagaki, for their very skilful assistance in carrying out the precise measurements.

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FURTHER OBSERVATIONS OF RADIO TRANSMISSION AND THE HEIGHTS OF THE KENNELLY-HEAVISIDE LAYER*

By

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Summary—*The results of further observations on radio transmission phenomena associated with the reflections of radio pulse and spark signals are outlined and a brief theoretical consideration of the form of index of refraction variation best adapted to explain the observed phenomena given. The discussion considers the relation of this index of refraction variation to that discussed in a previous paper and that recently considered by Breit. The results of long-wave field strength observations are also presented. Evidence for a considerable diurnal layer movement is found from the short-wave observations of layer height.*

In a previous paper[1] measurements of the height of the Kennelly-Heaviside Layer as determined from observations made on October 7 and 8, 1928, were presented and the relations between "real" and "virtual" heights as obtained from such observations were discussed.

It is the purpose of this paper to outline and compare the results of similar observations conducted at the Moore School since this paper was submitted for publication and also to present certain results of low-frequency field strength observations (on 18.35 kc) and echo effects on 390 kc.

1. Recent Kennelly-Heaviside Layer Height Determinations on 4435 kc.

(*a*) *Test of Feb. 3 and 4.*

Through the courtesy of the Department of Terrestrial Magnetism and Naval Research Laboratory another 24-hour test was carried out on Feb. 3 and 4 on 4435 and 8870 kc. As in the case of the test of October 7 and 8, the higher frequency was not oscillographable at Philadelphia. Abnormal transmission phenomena were, moreover, observable during this test on 4435 kc to a more marked degree than during the October test. These phenomena indicate what is believed to be somewhat abnormal conditions associated with magnetic storm disturbances prevalent at periods near to but not coincident with this

* Dewey decimal classification: R113.4. Original manuscript received by the Institute, August 21, 1929. Presented before meeting of Philadelphia section, May 24, 1929.

[1] Kenrick and Jen, "Measurements of the Height of the Kennelly-Heaviside Layer," Proc. I. R. E., 17, 711; April, 1929.

period of observation. As in the case of the previous test, the signal intensity mounted during the sunset period and continued strong for a few hours during the early evening; meanwhile, the layer mounted to a height of 350 km and signals remained strong but were subject

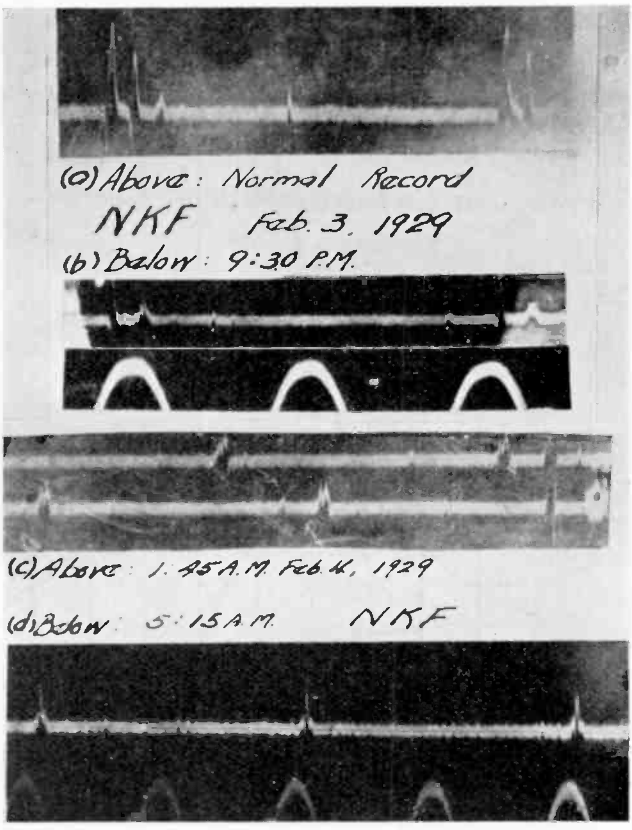

Fig. 1—Oscillographic records of NKF taken on Feb. 3 and 4, 1929.
(a) regular transmission
(b) blurred peaks
(c) increased blurring and fading
(d) single peaks with slight blurring

to increasing fading. During the late evening and night periods, however, the fading grew progressively worse, while the average signal strength progressively decreased until signals were hardly oscillographable. The oscillographic records during this period showed broadening and blurring of the pulses. These effects accentuated until multiple peaks were no longer observable with such intensity as to render accurate height estimates possible. The results of such estimates as could be made from faint peaks occasionally observed, however, indicate large virtual heights during the middle night period (ac-

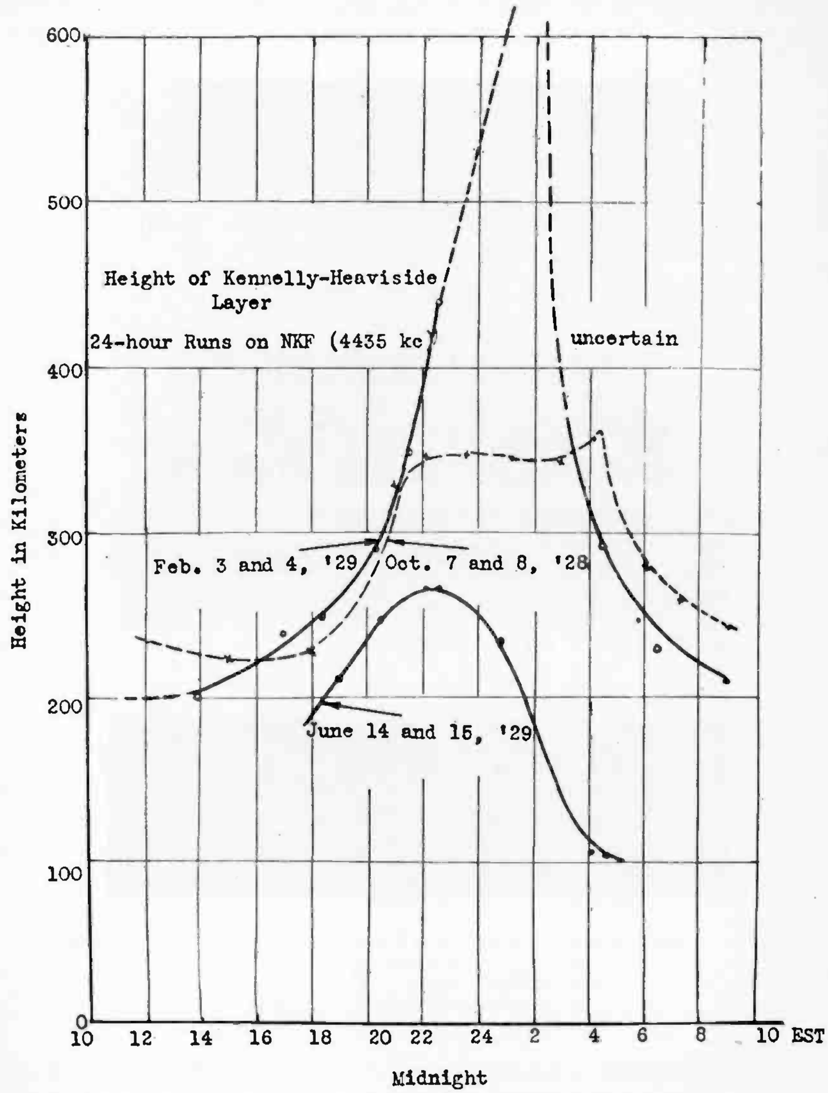

Fig. 2—Comparison of virtual-height data on NKF transmissions as observed at Philadelphia.

companied with very weak and broadened peaks). These uncertain virtual height determinations are indicated by the dotted parts of the Feb. 3–4 curve in Fig. 2.

Perhaps the most remarkable phenomenon associated with this transmission was observed from 7:30 to 9:00 A.M. (after the sunrise period). In Fig. 3 records taken over this period are shown. It will be noted that the 7:30 A.M. and the 7:55 A.M. records show a second (abnormal) group retarded by nearly but not quite half the group frequency. The 9:15 A.M. record shows sharp and almost single pulses with definite normal group frequency. The existence of long retar-

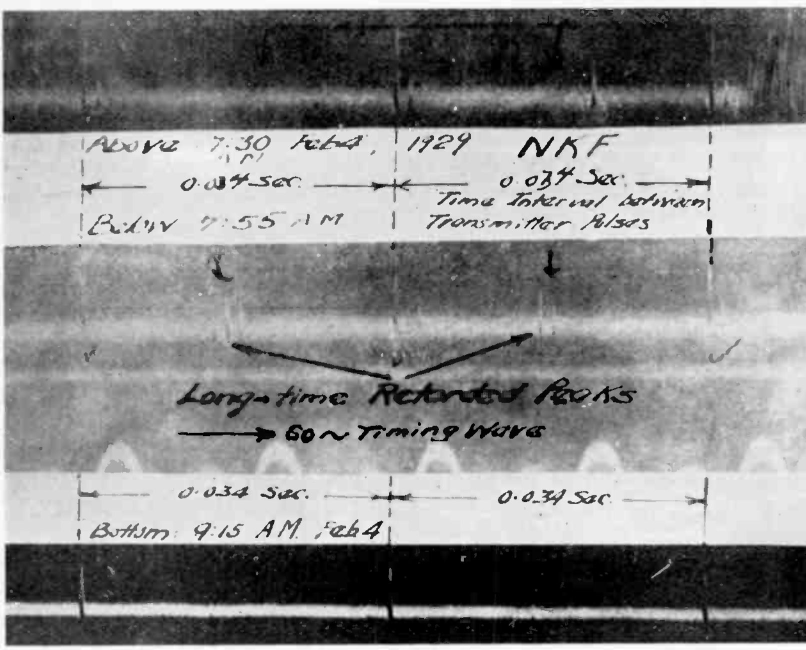

Fig. 3—Long-time retarded peaks of NKF observed at the University of Pennsylvania on Feb. 4, 1929.

dations of the form $5000+10000n$ km ($n=0,1,2,3,$—) on the relatively low frequency 4435 kc has not to the writers' knowledge been previously observed, although they are of common occurrence on the higher frequencies.[2] The existence of the secondary groups nearly half way between the normal groups suggests a possible doubling of emitted group frequency at the transmitter, but such an explanation was rendered improbable by the failure of the records taken at the Dept. of Terrestrial Magnetism to exhibit such a phenomenon during this period and by the failure of the secondary pulses to be exactly

[2] Taylor and Young, "Studies of Echo Signals," PROC. I. R. E., 17, 1491; September, 1929.

centered between the other groups within the tolerance ordinarily observed for the normal pulse groups. Further (less marked) evidence for this phenomenon was also observed on other records taken during the 24-hour interval. The 10000n ambiguity is introduced by the normal group frequency together with uncertainty that the secondary group is due to the preceding normal pulse.

(*b*) *Test of June 14–15.*

A similar 24-hour test was again conducted on June 14 and 15. The test was scheduled to begin at 10:00 A.M., E.S.T., June 14, but no audible signals either on 500-cycle modulation or pulses from the

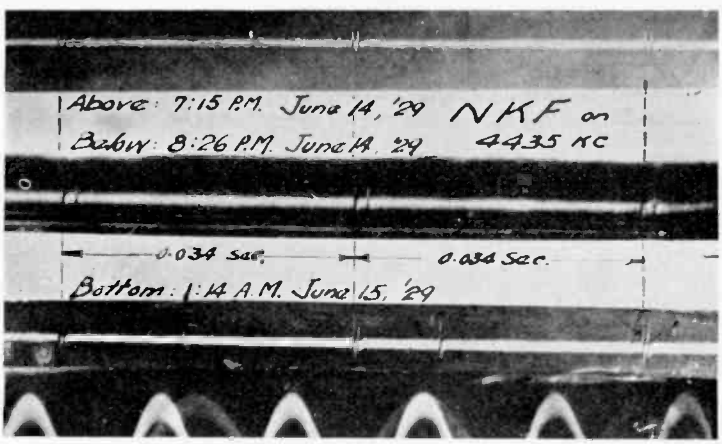

Fig. 4—Oscillograms on NKF transmission taken on June 14 and 15, 1929, showing very low heights.

multivibrator were received at Philadelphia before 4:00 P.M. After 4:00 P.M. NKF was heard faintly at first, then signals gradually built up to good intensity. The fact that this change took place without any alteration on the setup gives further evidence of high summer daytime attenuation on 4435 kc.

Referring to Fig. 4, oscillograms taken around 7:00 P.M. show clear-cut peaks. The height of the layer, as determined at this period, is about 200 km (see Fig. 2). An hour later the spacing between the reflected peaks is apparently broadened, showing a larger height. The layer kept increasing in height to about 250 km a little before midnight. After midnight, however, the layer appears to drop down gradually and reaches a level below 100 km at the end of about 4 hours, as is exemplified by the very small spacing between the reflections given by the bottom trace of Fig. 4. In fact the record taken around 4:30 A.M.

June 15 shows almost single peaks. Moreover, the intensity was noticeably faint at this time and became fainter as time went on. Around 7:00 A.M. the signals from NKF were presumably suffering again from as large attenuation as to be quite inaudible at Philadelphia.

Aside from the abnormality of the strangely low layer height after midnight, it will be noticed from Fig. 2 that the entire curve of the height of the layer for this test is lower than on the two preceding tests. This effect is presumably due to summer conditions. It will be noted that the period of this test was nearly coincident with that of longest days and correspondingly high electron density in the upper atmosphere.

2. Observations of Long-Wave Field Strengths.

Considerable evidence has been deduced by numerous competent observers of long-wave field strengths to support the hypothesis that many observed variations are due to phase opposition and reinforcement phenomena.[3]

The observed variations are, however, so complicated as to render an explanation by this hypothesis alone hardly satisfactory. It is evident that a satisfactory explanation of the variations of field intensities for the long waves cannot be realized if we restrict our attention solely to the effects of reflections. Many investigators in the past have already realized the variability of the intensity of radio waves due to absorption, which results from collisions between the electrons and molecules in the upper atmosphere. In fact, the theory of variable attenuation due to changes in ionization offers a beautiful qualitative explanation for the sunrise and sunset phenomena. In general, however, it is difficult to single out the relative importance of the various factors responsible for the change of field intensities. The best we can do, for the present at least, is to find correlations between observations of transmission phenomena on varied frequencies and over varied transmission paths.

Dr. Austin at Bureau of Standards, Washington, D.C., and Mr. Pickard at Newton Centre, Mass., have taken simultaneous recordings of the field intensities of the radio station WCI at Tuckerton, N. J., for a considerable period. The variations of the field intensities at both places have been found to follow in general the same curves.[4]

[3] Hollingworth, *Jour.* I.E.E., **64,** 579–595; 1926.
Austin, "Experiments in Recording Radio Signal Intensity," PROC. I. R. E., **17,** 1192; July, 1929.

[4] Mr. Pickard kindly informed the authors that this condition was true of 1928, and so far 1929 records show considerable difference between Washington, D. C., and Newton Centre. He also pointed out that perhaps the different Layer height and density this year account for this change.

With a view to taking simultaneous observations with a different distance from the transmitter, similar records have been made at Phila-

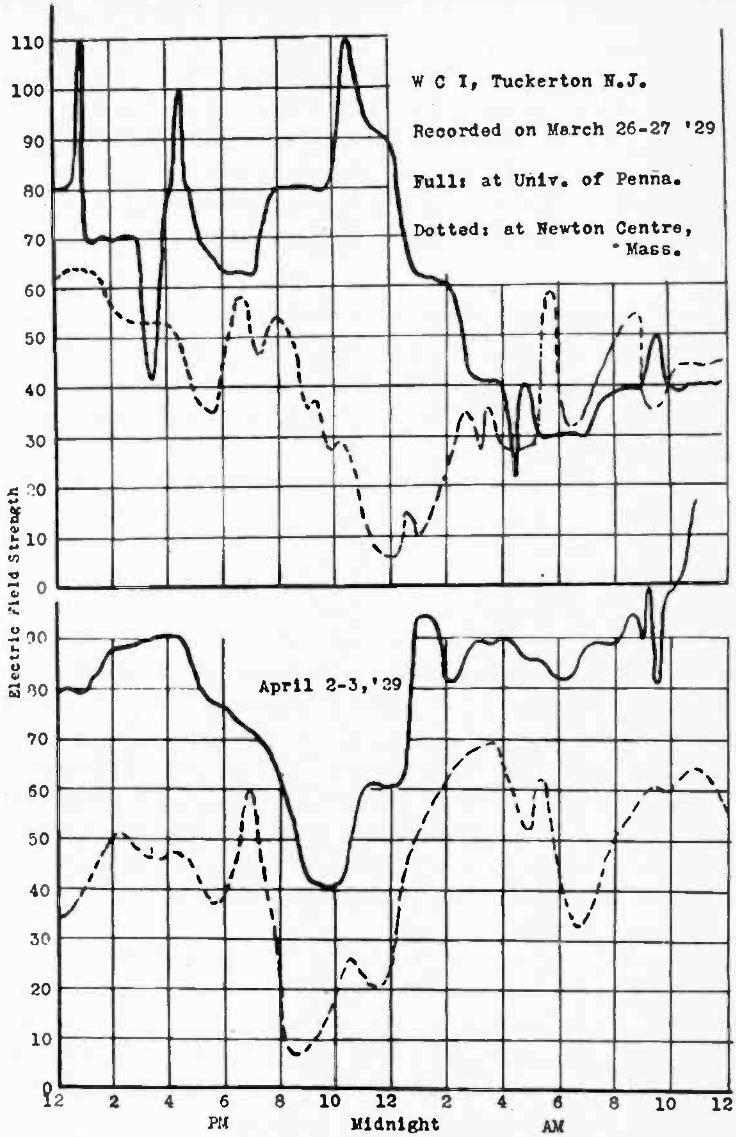

Fig. 5—A daily record showing the variation of the field strength of WCI.

delphia for a period of three months. While observations of the field strength of WCI at Philadelphia have not been continued for a long enough period to make general conclusions safe, certain phenomena associated with the relatively brief period of simultaneous observations available are perhaps worthy of note at this time.

Referring to Fig. 5 it is seen that the upper plot shows that the field intensities as recorded at Newton Centre, Mass., and Philadelphia

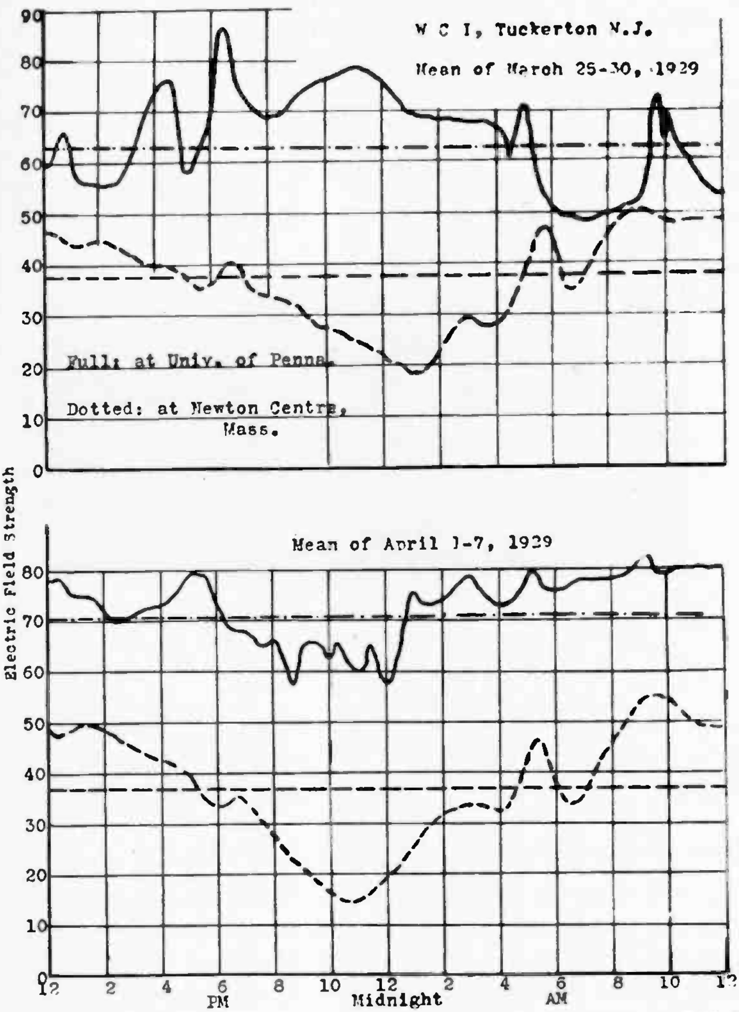

Fig. 6—A weekly mean of the variation of the field strength of WCI.

are just reversed. An extremely low intensity at Newton Centre around midnight corresponds roughly to the very high intensity recorded at Philadelphia. An examination of the daily records during that week shows that there is a gradual shift from the upper plot to the lower plot of Fig. 5. The complete change was made roughly within one week. The lower record shows evidently that the variations of field intensities at two places are just in phase.

Fig. 6 shows the same phenomenon when the averages of the field intensities of the corresponding two weeks are taken. It is seen that although the small variations have been considerably smoothed out the general effect is still clearly illustrated. The existence of such a cyclic change is further evidenced by the reappearance of the opposite patterns for the variations of the field intensities at both places during the third week.

While the period of observation is not long enough to render a general conclusion justified, the above observation of a cyclic change

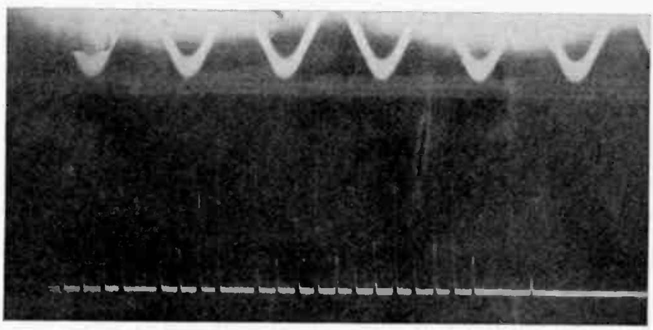

Fig. 7—A typical oscillogram on WNW transmissions as received at the University of Pennsylvania showing single peaks—(variable size due to non-synchronous gap).

of field intensity suggests a possible correlation with some major changes in the upper atmosphere. It is our hope to confirm the result by further experimentation before making definite conclusions.

3. Observations of Echo Signal Phenomena on 390 kc.

On December 16, 1928, interesting phenomena were observed in a series of simultaneous oscillograms taken at Washington and Philadelphia on transmission from the spark station WNW located at South Wharves, Philadelphia. This station employs synchronous and non-synchronous rotary gaps producing spark discharges of the form shown in Fig. 7.

Simultaneous observations taken at the Moore School of Electrical Engineering during the course of the tests described and involving over 100 oscillograms failed to disclose departures from the form shown in

Fig. 7, except for minor peaks of less than 10 per cent the amplitude of the main peaks; these minor peaks are attributable to the reflected waves of importance in the Washington records but inconsiderable compared to the large low-frequency ground wave at distances of a few miles (i.e. at the Moore School).

During sunrise and sunset periods, however, oscillograms taken at the Department of Terrestrial Magnetism and Bureau of Standards disclose marked doubling of peaks. This phenomenon (by its consistency, progressiveness, and failure to appear in Philadelphia oscillograms taken over the same period) does not appear to be due to any irregularities in the transmitter but rather to a genuine transmission phenomenon.

The phenomena exhibited are of particular interest in exhibiting not only the existence of multiple transmission paths on 390 kc, as

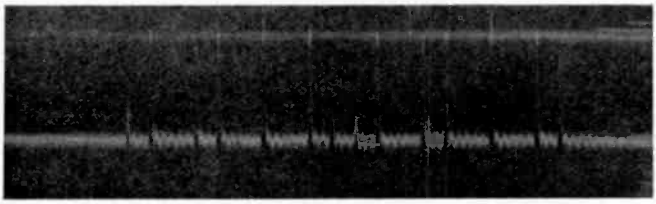

Fig. 8—Spark discharges from WNW being followed, on certain occasions, by minor peaks as received at the University of Pennsylvania.

would indeed be suspected, but also the importance of absorption at this frequency. It will be noted that by far the most important multiple path phenomena were evidenced during the dawn period, and daytime and evening records failed to show important secondary peaks. The major peak is at this frequency and distance supposedly due to the ground wave.

Virtual height determinations may be carried out from these oscillograms by methods similar to those used with the 4435-kc records and indicate heights of the order of 100 km in accord with the results of Hollingworth and other investigators determining heights by other methods. Considerable evidence is also to be found of a cyclical change in height. Determinations of height from these records are, however, considered somewhat unreliable due to the shortness of the time intervals which must be measured on the records and the failure of the multiple peaks to resolve completely. This renders measurements subject to error because of shifting of the apparent maxima of the peaks as a result of inertial effects and possible phase interferences between waves arriving by various paths (provided the wave trains thus arriving really overlap and the apparent lack of resolution is not due to oscillographic inertia as seems quite possible from theoretical estimates of the duration of the spark discharges based on rational assumption of circuit decrement).

Fig. 9—WNW transmission as received at the Department of Terrestrial Magnetism, Washington, D. C.

4. Approximation Curves for n as a Function of Maximum Electric Density and Distribution.

In a previous paper[5] the relations of the virtual heights obtained from pulse records to the maximum height attained by the ray during

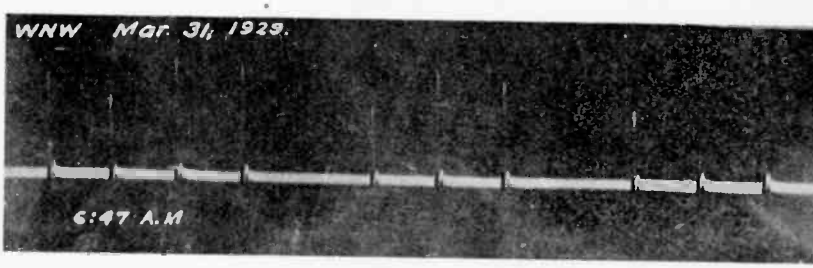

Fig. 10—WNW transmission as received at Bureau of Standards, Washington, D. C.

[5] Kenrick and Jen, loc. cit.

its trajectory (termed the "true height") were discussed for several types of assumed variation of refractive index with height. One of these assumed types of distributions is compared with the experimentally estimated curve for 4435 kc in Fig. 11.

It will be noted that these curves are concave downward and intersect the Y axis nearly parallel to the n axis. An examination of the form of the curves for electron density against height reveals that this is a normal condition for frequencies well below the limiting frequency corresponding to that for a skip distance approaching zero.

As the maximum electron density approaches that necessary to turn back a ray at normal incidence, however, the n curve assumes

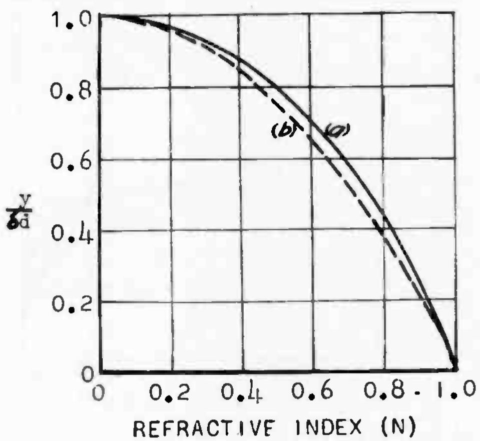

Fig. 11—(a) Experimentally estimated curve at 4435 kc; (b) parabolic curve for the variation of refractive index against height ($n^2=1-ry$).

a form having a point of inflection such as shown in curve a (see Fig. 12).

Further decreases of electron density cause the curve to pass through tangency and finally to assume a shape such as shown in curve b corresponding to a finite skip distance. These curves are not well approximated for small values of n by the form of equations assumed in the previous paper. We will term the frequency corresponding to the tangent curve the "critical frequency" (obviously variable with the electron density.) Inasmuch as the evidence of the February test indicates phenomena similar to those we would expect near the "critical frequency," a brief resurvey of the problem seems desirable.

5. Approximation Equations for n near the Critical Frequency.

In a recent paper[6] Breit has discussed the problem of long time retardations corresponding to the echo phenomena of Störmer and van der Pol[7] and shown that an exponential distribution of refractive index of the form $n=\epsilon^{-y/a}$ would lead, with the proper choice of constants, to phenomena such as those observed.

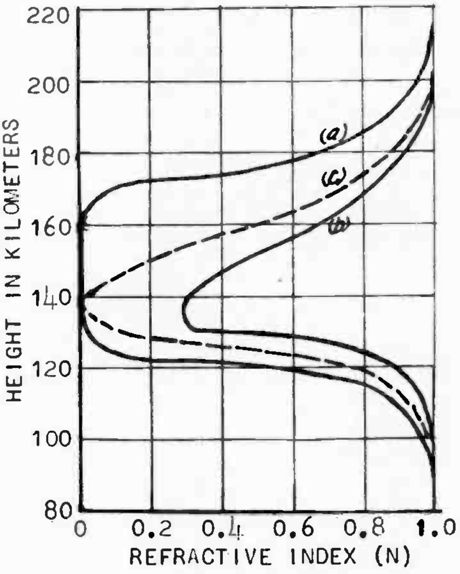

Fig. 12—Variation of refractive index with height
(a) estimated curve at 4435 kc
(b) estimated curve at 8870 kc
(c) estimated curve at 7800 kc (critical frequency)

In Fig. 13 the fits to the n curve of the type c of Fig. 12 by the use of the exponential types of equation and the type leading to a parabolic path are shown.

It will be noted that the exponential type is well adapted to approximate the critical frequency curve for small values of n, while the curves previously considered are satisfactory for larger values of n. In interpreting the phenomena described herein the writers have found a hybrid form in which the exponential type is used for small values of n and the types previously employed for larger values

[6] Breit, "Group-Velocity and Long Retardations of Radio Echoes," Proc. I. R. E., 17, 1508; September, 1929.
[7] *Nature*, 122, 878–879, 1928.

to be successful in describing at least qualitatively the major phenomena observed. In a subsequent section, certain characteristics of pulse echo groups produced by these types of distributions will be

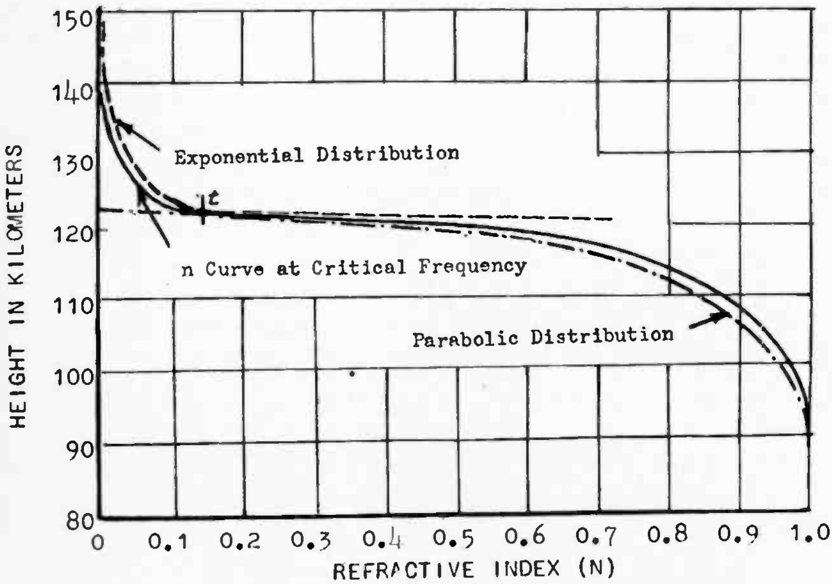

Fig. 13—A comparison between the hybrid distribution for refractive index and the estimated refractive index curve at critical frequency.

discussed and the characteristics of the hybrid distribution then outlined.

6. Virtual Height Determinations in the Absence of a Ground Wave.

Observations made on NKF transmission on 4435 kc and higher frequencies at Philadelphia have not shown evidence of a ground wave, a situation quite in accord with what would be expected from theoretical considerations. Again in accord with theory for this frequency, the Dept. of Terrestrial Magnetism observes both ground waves and sky waves at a distance of 10 km from the transmitter. However, if observations are to be made at frequencies much above the critical (such, for instance, as 8870 kc where the ground wave does not cover up the skip distance) a consideration of what inferences may be drawn as to virtual heights from observations involving sky waves alone seems appropriate. This study is conveniently divided according to the types of dielectric constant distribution encountered.

(a) *Distributions Similar to* $n^2 = 1 - ry$

In cases such as investigated in the previous paper (which may be thought of as more or less normal distributions for frequencies below the critical frequency) it was shown that the ratio of true to virtual height was nearly if not quite constant, and that the virtual height was hence nearly if not quite independent of the angle of incidence of the ray. Under these conditions, if the first two pulses received are assumed to be the first and second reflections the virtual height may be readily evaluated by simple geometry. In fact, for a base line as short as Philadelphia to Washington and virtual heights of the order of 250 km, little error is introduced by taking the observed time interval as twice for a ray to traverse a distance equal to the virtual height (i.e., neglecting the base). The relations involved are clarified by a study of the quantitative results for an illustrative typical case for the $n^2 = 1 - ry$ distribution (see Table I). From Table I it is clear that the

TABLE I
PARABOLIC PATH
$d = 140$ km $(\delta d_1) = 70$ km $\rho = 200$ km $(h/h') \doteq 0.75$

Interval	Time in Sec.	Virtual Height Neglecting Base in km	Virtual Height Considering Base in km	True Height in km
$T_g - T_0 =$	6.67×10^{-4}			
$T_1 - T_g =$	13.2×10^{-4}	197	$h_1' = 280$	$h_1 = 210$
$T_2 - T_1 =$	19.7×10^{-4}	295	$h_2' = 293$	$h_2 = 217$
$T_3 - T_2 =$	19.8×10^{-4}	297	$h_3' = 296$	$h_3 = 218$
$T_4 - T_3 =$	20×10^{-4}	300	$h_4' = 297$	$h_4 = 219$

intervals between successive pulses are nearly equal to each other (ground wave absent) and to the time for a wave to travel a distance $2h'$ with the velocity of light.

(b) *Exponential Distribution*

In Table II similar computations have been tabulated for the case of the exponential distribution of n. A lower and more sharply defined boundary was necessarily assumed in this case in order to show several

TABLE II
BREIT'S $\epsilon^{-y/a}$ DISTRIBUTION
$d_0 = 140$ km $h^1 =$ variable $a = 10$ $\rho = 200$ km

Interval	Time in Sec.	Virtual Height Neglecting Base in km	Virtual Height Considering Base in km	True Height in km	$\frac{h}{h'}$
$T_0 - T_g$	6.67×10^{-4}				
$T_1 - T_g$	5.5×10^{-4}	83	154	146	0.95
$T_2 - T_1$	13.0×10^{-4}	195	190	154	0.81
$T_3 - T_2$	23.7×10^{-4}	370	245	160	0.65
$T_4 - T_3$	43.5×10^{-4}	650	345	166	0.48

reflections. It will be recalled that Breit has shown that for this distribution the X coordinate corresponding to the maximum Y ordinate for a ray departing with an angle ϕ_0 in a medium where $n=\epsilon^{-y/a}$ is[8]

$$x=a(\pi/2-\phi_0) \tag{1}$$

Where n = dielectric constant ϕ_0 = angle of departure.

This function varies but little with ϕ_0 and hence as pointed out by Breit, for a comparable with the distance of transmission ρ, but one value of ϕ_0 is in general possible, although if $2a=\rho$ and $a=d_0$ (the height at which the value of n starts to vary) focussing action will result. For small values of a compared with ρ, however, several reflections may still be possible, but in this case widely variable spacings and virtual heights will be obtained depending on what reflection or path difference is measured.

In general, then, we would expect to find focussing action broad peaks and variable spacing between peaks accompanying distributions of this type. When these phenomena are present, therefore, great caution should be exercised if inferences as to true heights or unique values of virtual heights are to be deduced by measurements of time intervals between received pulses.

(c) *Hybrid Distributions*

Reference to Fig. 13 suggests that a considerably improved fit to the curve we believe to correspond to the critical frequency could be obtained if an equation of the type discussed in paragraph (a) were used for large values of n and an equation of the type of paragraph (b) modified to the form $n=c\epsilon^{-y/a}$ for small values of n, thus providing a point of inflection. The range in a medium approximated by this law for n is readily computable for the sine of the angle of incidence at the point of change is given by the Snell law, i.e.

$$n_t \sin \phi_t = \sin \phi_0 \tag{2}$$

When n_t = dielectric constant at transition point

ϕ_0 = initial angle
ϕ_t = angle at point of transition.

It will be noted that for oblique rays, i.e., $\sin \phi_0 = n_t$ the trajectory of the ray is still normally parabolic (for the $n=\sqrt{1-ry}$ case).

Appropriate modification of the limits of integration in Breit's equations (by use of equation $V-1_a$ of the previous paper) gives

[8] In this paper we are preserving the notation of our previous paper (somewhat different from Dr. Breit's).

the values of x and y of the maximum point in the ray path referred to the coordinates of the initial point on the trajectory where n starts to vary, i.e.

$$X = a\left[\frac{\pi}{2} - \sin^{-1}\left(\frac{\sin \phi_0}{n_t}\right)\right] + \frac{2 \sin \phi_0}{r}\left[\cos \phi_0 - \sqrt{\cos^2\phi_0 - (1 - n_t^2)}\,\right]$$

or (for small ϕ's)

$$X = a\left(\frac{\pi}{2} - \frac{\phi_0}{n_t}\right) + \frac{2 \sin \phi_0}{r}\left[\cos \phi_0 - \sqrt{\cos^2 \phi_0 - (1 - n_t^2)}\,\right] \tag{3}$$

$$Y = \frac{1 - n_t^2}{r} + a \log\left(\frac{n_t}{\sin \phi_0}\right) \qquad n_t > \sin \phi_0 \tag{4}$$

If preferred, for small values of ϕ_t and ϕ_0 1, we may write

$$X \doteq a\left(\frac{\pi}{2} - \phi_t\right) + \frac{2 \sin \phi_0}{r}\left[\cos \phi_0 - \sqrt{\cos^2 \phi_0 - \left[1 - \left(\frac{\phi_0}{\phi_t}\right)^2\right]}\,\right] \tag{5}$$

$$Y \doteq \frac{1 - \left(\frac{\phi_0}{\phi_t}\right)^2}{r} + a \log(\phi_t^{-1}). \tag{6}$$

It will be noted that for comparable values of a and r, the second terms of the right-hand members of equations (4) and (5) are nearly negligible. A rapid transition hence takes place for values of $\phi \backsimeq \phi_t$ and for smaller values of ϕ the focussing action described by Breit takes place.

The virtual height for the s'th reflected ray may be readily computed by application of equations (2) to (6). Thus, for the s'th order reflection and a transmission distance ρ, the virtual height for the s'th reflection is (by Breit and Tuve's theorem)

$$h' = \frac{\rho}{s} \tan \phi_s. \tag{7}$$

Where ϕ_s is given (for values of $\phi_s < \phi_t$) by the solution of the transcendental equation

$$\left(\frac{\rho}{s} - d_0 \tan \phi_s\right) = a\left(\frac{\pi}{2} - \phi_s\right) + \frac{2 \sin \phi_0}{r}\left[\cos \phi_0 - \sqrt{\cos^2 \phi_0 - \left[1 - \left(\frac{\phi_0}{\phi_t}\right)^2\right]}\,\right] \tag{8}$$

Where d_0 = height above earth at which n starts to vary
ϕ_s = angle of departure from earth of s'th order reflection.

The value of ϕ_s is best derived from transcendental equation (8) by successive approximations. When ϕ_s is greater than $\sin \phi_t$ the first term of the right-hand member should be omitted. When $\sin \phi_t = 1$ equations (7) and (8) may be used to deduce the results given in Table II while the results of Table I are deducible by letting $\sin \phi_t = 0$ (and neglecting the first term of the right-hand member).

The characteristics of the hybrid distributions are, moreover, well adapted to describe the type of phenomena observed during the February test.

Thus, it will be noted that the early night period of the Feb. 3–4 test showed high virtual heights and broadened peaks such as would be given by equations (7) and (8) for a small and $\phi_1 > \phi_t > \phi_2$, i.e., when the critical angle was between the angles corresponding to the first and second reflected paths.

Perhaps more difficult of explanation are the long retardations of the late sunrise period although these are consistent with the hypotheses of an angle $\phi_t < \phi_4$ for part of the path and a value of a approximately $200/\pi$ for part of the path. Under these conditions the first few rays would be normally reflected, giving pulses of normal group frequency while higher order rays after a single normal reflection near Washington would attain a point where $\phi_0 < \phi_t$ on a subsequent entry into the layer. Two successive rays of this type would give rise to a second group of two closely spaced highly retarded rays.

The use of a law for n as a function of heights possessing a compound curvature and an exponential tangency to the axis of y, such as just described, thus appears to possess considerable advantages in the discussion of phenomena such as those considered here. It is at the same time in good accord with the forms of distributions anticipated from other considerations. We see that most of the phenomena described by an exponential distribution may be equally well accounted for by a small region of exponential tangency near the Y axis while normal more oblique reflections phenomena are not impaired. This appears also to be a point worthy of consideration in the case of van der Pol echoes where the long retardation is measured between signals coming through a more or less normal path and a path of high retardation. The presence of both paths is of course essential to the measurement of the retardations.

A study of distributions of this form indicates frequencies near the critical to be the most fertile field for the study of long retardations and similar abnormal transmission phenomena while, as would be suspected, the border line of the skip distance appears the most fertile field in the short-wave region.

Conclusions

The results of these further Kennelly-Heaviside layer pulse studies indicate that a decided diurnal variation is probably present on 4435 kc. On the whole, the fall test reported in the previous paper was the most satisfactory in furnishing consistent results at Philadelphia and Washington.

The February 3 and 4 test represents a winter run corresponding to a period of short days and low electron densities. The phenomena associated with this run indicate 4435 kc to be close to if not above the "critical" frequency for zero skip distance at periods during the night and dawn at this season and furnish interesting evidence of long time retardations and blurred pulse groups.

The test of June 14–15 indicates a summer condition of low layer height, high electron density and absorption, and probably rather variable ratios of virtual to true heights. The curve shown giving the results of the observations at Philadelphia for this period illustrates these phenomena but also somewhat erratic heights doubtless associated with changes in h/h', etc. This curve represents a good mean of Philadelphia observations but should not be considered of too great intrinsic significance, for Washington observers report erratic and even lower heights (in some cases as low as 70 km) during this test.

The phenomena described on the lower frequency spark signals and the fading records for long waves should all eventually contribute to the large store of data which must be amassed before anything like a complete picture describing the observed phenomena can be evolved.

The highly variable results of the above tests serve to indicate further the desirability of extended consistent observations on variable frequencies and under varied conditions.

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THE CALCULATION OF THE INDUCTANCE OF SINGLE-LAYER COILS AND SPIRALS WOUND WITH WIRE OF LARGE CROSS SECTION*

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1. Introduction

Summary—*Formulas are given for both wires of round cross section and wires of rectangular cross section. These are obtained by an extension of the Rosa Method.*

Tables are given from which the geometric mean distances of rectangles which enter in the formulas may be readily obtained.

THE use of geometric mean distances for the calculation of inductance was first proposed by Maxwell,[1] who obtained the expressions for the geometric mean distances in certain important cases. Formulas for rectangles were developed by Gray,[2] and these were extended to the special cases of parallel and oblique squares by Rosa,[3] who made use of these formulas in the calculation of the correction for insulating space in circular coils of rectangular cross section.

The method of geometric mean distance was also employed by Rosa[4] to obtain the difference between the inductance of a single layer coil of round wire and that of a cylindrical current sheet of the same number of turns, mean radius, and pitch of winding. For this important practical case he gave tables of constants to aid in numerical computations.

The writer has shown[5] by the use of the exact formula of Snow for the inductance of a helix of wire, that the higher order terms, neglected in the simple geometric mean distance method of Rosa, are negligible in practical cases, and that the method is of general use in other important forms of coil.

In the present paper are given tables of the geometric mean distances of equal parallel rectangles, together with working formulas for the calculation of the inductance of windings of round or rectangu-

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[1] Maxwell, Elect. and Mag. II, sects. 691 and 692.

[2] Gray, Absolute Measurements, vol. II, part 1, pp. 288–306.

[3] Rosa, Bull. Bur. of Standards 3, p. 1; 1907.

[4] Rosa, Bull. Bur. of Standards 2, p. 161; 1906. Sci. Paper B. S. no. 169 p. 122, formula (80), Tables VII and VIII, pp. 197–9.

[5] Grover, B. S. Jour. of Research.

lar wire of relatively large cross section. It is hoped to treat the derivation of these formulas and to describe the methods used in calculating the tables in a future paper.

2. Definitions

The geometric mean distance of two areas is that distance whose logarithm is the average of the logarithms of the distances of all the points of one area from all the points of the other. In what follows, if R represents the geometric mean distance, and d the distance between the centers of the areas, we may write

$$R = kd$$
$$\log R = \log d + \log k. \tag{1}$$

Likewise, the geometrical mean distance of a single area is that distance whose logarithm is equal to the average of the logarithms of the distances of all the points of the cross section from each other. The conception of geometric mean distance is of importance because the mutual inductance of two conductors is found by summing the expression for the mutual inductance of two filaments over the section of the conductors, and since the expression for the mutual inductance involves the logarithm of the distance of the filaments, the geometric mean distance is obtained in the averaging process. Thus a table of geometric mean distances has a use for inductance calculations analogous to that of a table of integrals for mathematical work in general.

3. Nomenclature

Let

b and c be the sides of a rectangular area

ρ = the radius of cross section of a round wire

a = mean radius of a coil or current sheet

n = the number of turns

g = the pitch of a winding

d = the distance between the centers of the cross sections of two turns

r_w = geometric mean distance of the points of the cross section of a wire

r_s = g.m.d. of the cross section of a turn of a current sheet

R_w = g.m.d. of the cross sections of two turns of wire

R_s = g.m.d. of the cross sections of two turns of the current sheet

All dimensions are in centimeters, except where they occur in ratios, in which case it is only necessary that they both be expressed in the same unit. All logarithms, unless otherwise stated, are natural.

Inductances are expressed in millimicrohenries, (μmh), in the formulas; 1 millimicrohenry $=10^{-9}$ henry. Only steady or low-frequency values of inductance are here considered.

4. Geometric Mean Distances

Geometric Mean Distance of a Rectangle

Equation (1) becomes

$$\begin{aligned} \log r &= \log (b+c) - 1.5 + \log \epsilon \\ r &= k(b+c), \quad \log k = -1.5 + \log \epsilon. \end{aligned} \tag{2}$$

Values of k and $\log \epsilon$ may be obtained from Table I as a function of the ratio b/c (or c/b), whichever is less than unity. Special cases are the straight line for which $\log r = \log b - 3/2$, $r = 0.22313\ b$, and the square for which $\log r = \log b - 0.80508$, $r = 0.44705\ b$.

Geometric Mean Distance of a Circle

(This is given for completeness)

$$\begin{aligned} \log r &= \log \rho - \tfrac{1}{4} \\ r &= 0.7788\rho. \end{aligned} \tag{3}$$

Geometric Mean Distance of Two Equal Parallel Rectangles

For convenience of tabulation two cases are considered.

Case 1. Rectangles with their longer sides in the same straight line. (See Fig. 1.) Values of $\log k$ in equation (1) are given for this case in

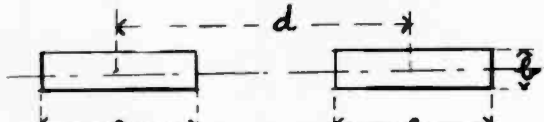

Fig. 1

Table II for the two parameters $\gamma = c/d$ and $\delta = b/c$, both of which have values which range from zero to unity. Special cases are straight lines lying in the same straight line with each other $\delta = 0$, and squares $\delta = 1$.

For rectangles in contact $\gamma = 1$. The values of $\log k$ for squares are positive; the other tabulated values are negative.

Case 2. Rectangles with their longer dimensions perpendicular to the line joining their centers. (See Fig. 2.)

Here it is convenient to employ as parameters $\Delta = c/b = 1/\delta$ and $\beta = b/d$, (or $1/\beta$, whichever is less than unity). An important case is

TABLE I

VALUES OF CONSTANTS FOR THE GEOMETRIC MEAN DISTANCE OF A RECTANGLE

b/c or c/b	k	log ϵ
0.	0.22313	0.
0.025	0.22333	0.00089
0.05	0.22346	0.00146
0.10	0.22360	0.00210
0.15	0.22366	0.00239
0.20	0.22369	0.00249
0.25	0.22369	0.00249
0.30	0.22368	0.00244
0.35	0.22366	0.00236
0.40	0.22364	0.00228
0.45	0.22362	0.00219
0.50	0.22360	0.00211
0.55	0.22358	0.00203
0.60	0.22357	0.00197
0.65	0.22356	0.00192
0.70	0.22355	0.00187
0.75	0.22354	0.00184
0.80	0.22353	0.00181
0.85	0.22353	0.00179
0.90	0.22353	0.00178
0.95	0.223525	0.00177
1.00	0.223525	0.00177

where Δ is nearly zero, and for those cases log k changes slowly for small values of Δ. For $\Delta = 0$, the parameter γ used in Table II is zero whatever the dimension b, so that the parameter β is more convenient

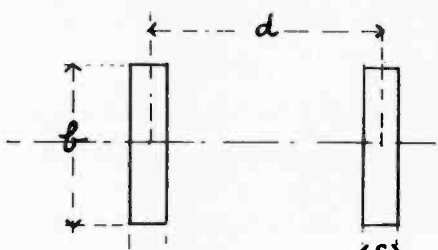

Fig. 2

for this case than γ. Special cases are $\Delta = 1$, squares; $\Delta = 0$, parallel straight lines; and $1/\beta = \Delta$, rectangles in contact. Values of log k for case 2 are given in Table III. All values are positive.

FORMULAS OBTAINED BY ROSA'S METHOD

Inductance of Single-Layer Coil of Round Wire.

For a coil of round wire of radius ρ, wound with n turns of mean radius a, with a pitch of g, the inductance is given by

$$L = L_s - 4\pi na(A + B) \tag{4}$$

in which L_s is the inductance of a cylindrical current sheet of n turns of mean radius a, having the same pitch g, so that its axial length is ng. This may be calculated by known formulas.[6] For an accuracy of a part in a thousand the tables of the writer[7] will be found convenient. The

[6] Grover, B. S. Jour. of Research, paper 16, October, 1928.
[7] Grover, PROC. I. R. E., 12, 193; April, 1924, p. 193; vol. 11.

TABLE II

VALUES OF THE GEOMETRIC MEAN DISTANCE OF EQUAL PARALLEL RECTANGLES WITH THEIR LONGER SIDES IN THE SAME STRAIGHT LINE

The values of log k in the table are all negative, except in those in the last column, $\delta=1$, (squares).

$\gamma=c/\alpha$	$\delta=0$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	$\delta=1$.
0	0	0	0	0	0	0	0	0	0	0	0
	−	−	−	−	−	−	−	−	−	−	+
0.05	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0001	0.0000	0.0000
0.10	0.0008	0.0008	0.0008	0.0008	0.0007	0.0006	0.0005	0.0004	0.0003	0.0002	0.0000
0.15	0.0019	0.0019	0.0018	0.0017	0.0016	0.0014	0.0012	0.0010	0.0006	0.0003	0.0000
0.20	0.0034	0.0033	0.0032	0.0030	0.0028	0.0025	0.0021	0.0017	0.0012	0.0006	0.0000
0.25	0.0053	0.0052	0.0051	0.0048	0.0044	0.0039	0.0034	0.0027	0.0019	0.0010	0.0000
0.30	0.0076	0.0076	0.0073	0.0069	0.0064	0.0057	0.0048	0.0038	0.0027	0.0014	0.0001
0.35	0.0105	0.0104	0.0100	0.0095	0.0087	0.0078	0.0066	0.0052	0.0036	0.0018	0.0001
0.40	0.0138	0.0136	0.0132	0.0125	0.0115	0.0102	0.0086	0.0068	0.0047	0.0024	0.0002
0.45	0.0176	0.0174	0.0169	0.0159	0.0146	0.0130	0.0110	0.0086	0.0059	0.0029	0.0003
0.50	0.0220	0.0217	0.0210	0.0198	0.0182	0.0161	0.0136	0.0106	0.0073	0.0036	0.0005
0.55	0.0269	0.0266	0.0257	0.0243	0.0222	0.0197	0.0164	0.0128	0.0087	0.0042	0.0007
0.60	0.0325	0.0321	0.0310	0.0292	0.0267	0.0235	0.0196	0.0152	0.0103	0.0048	0.0010
0.65	0.0388	0.0383	0.0369	0.0347	0.0316	0.0277	0.0231	0.0178	0.0120	0.0055	0.0014
0.70	0.0458	0.0452	0.0435	0.0408	0.0370	0.0324	0.0269	0.0207	0.0137	0.0062	0.0019
0.75	0.0536	0.0529	0.0509	0.0476	0.0431	0.0375	0.0310	0.0237	0.0156	0.0070	0.0023
0.80	0.0625	0.0616	0.0591	0.0551	0.0497	0.0431	0.0354	0.0269	0.0176	0.0075	0.0031
0.85	0.0725	0.0714	0.0683	0.0634	0.0569	0.0491	0.0401	0.0302	0.0195	0.0081	0.0037
0.90	0.0839	0.0825	0.0786	0.0726	0.0648	0.0555	0.0451	0.0337	0.0216	0.0087	0.0046
0.95	0.0973	0.0954	0.0903	0.0828	0.0734	0.0625	0.0504	0.0374	0.0236	0.0092	0.0056
1.00	0.1137	0.1106	0.1037	0.0942	0.0828	0.0700	0.0561	0.0413	0.0258	0.0098	0.006

TABLE III

VALUES OF THE GEOMETRIC MEAN DISTANCES OF EQUAL PARALLEL RECTANGLES WITH THEIR LONGER SIDES PERPENDICULAR TO THE LINE JOINING CENTERS

The table gives values of log k as a function of $B=b/d$ or $1/\beta=d/b$, whichever is less than unity, and for $\Delta=c/b$. 5 In all cases log k is positive.

β	$\Delta=0$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0	0	0	0	0	0	0	0	0	0	0
0.1	0.0008	0.0008	0.0008	0.0008	0.0007	0.0006	0.0005	0.0004	0.0003	0.0002	0.0000
0.2	0.0033	0.0033	0.0032	0.0030	0.0028	0.0025	0.0021	0.0017	0.0012	0.0007	0.0000
0.3	0.0074	0.0073	0.0071	0.0067	0.0062	0.0056	0.0048	0.0038	0.0027	0.0015	0.0001
0.4	0.0129	0.0128	0.0124	0.0118	0.0109	0.0098	0.0084	0.0068	0.0050	0.0027	0.0003
0.5	0.0199	0.0197	0.0191	0.0182	0.0169	0.0152	0.0131	0.0106	0.0077	0.0043	0.0005
0.6	0.0281	0.0278	0.0271	0.0258	0.0240	0.0216	0.0185	0.0152	0.0111	0.0064	0.0011
0.7	0.0374	0.0371	0.0361	0.0344	0.0320	0.0290	0.0251	0.0206	0.0155	0.0090	0.0019
0.8	0.0477	0.0473	0.0461	0.0440	0.0411	0.0373	0.0321	0.0268	0.0200	0.0129	0.0031
0.9	0.0589	0.0584	0.0569	0.0544	0.0506	0.0464	0.0404	0.0338	0.0254	0.0158	0.0046
1.0	0.0708	0.0702	0.0685	0.0655	0.0614	0.0560	0.0492	0.0406	0.0313	0.0189	0.0065
0.9	0.0847	0.0841	0.0821	0.0787	0.0738	0.0675	0.0596	0.0501	0.0382	0.0250	
0.8	0.1031	0.1023	0.0999	0.0959	0.0903	0.0829	0.0745	0.0622	0.0485		
0.7	0.1277	0.1268	0.1240	0.1192	0.1125	0.1037	0.0925	0.0788			
0.6	0.1618	0.1607	0.1573	0.1507	0.1436	0.1329	0.1194				
0.5	0.2107	0.2094	0.2053	0.1984	0.1886	0.1754					
0.4	0.2843	0.2826	0.2776	0.2691	0.2567						
0.3	0.4024	0.4003	0.3942	0.3831							
0.2	0.6132	0.6105	0.6021								
0.11	1.0787	1.1075									
$1/\beta$	$\Delta=0$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0

constants A and B were calculated by Rosa[4] and tabulated. The constant B is a function of the number of turns and is reproduced here as Table IV. In this, small errors in the original table have been corrected by the use of an improved method of calculation. Rosa's table of A is not given here. Its calculation by the relation $A=5/4-\log g/\rho$ is readily accomplished using the Table VI for computing natural logarithms from common.

TABLE IV

THE CONSTANT B IN FORMULA (6) FOR COILS OF ROUND WIRE

n	B	n	B	n	B
1	0.	31	0.3087	110	0.3278
2	0.1137	32	0.3095	120	0.3285
3	0.1663	33	0.3102	130	0.3291
4	0.1973	34	0.3109	140	0.3296
5	0.2180	35	0.3115	150	0.3301
6	0.2329	36	0.3121	160	0.3305
7	0.2443	37	0.3127	170	0.3309
8	0.2532	38	0.3132	180	0.3312
9	0.2604	39	0.3137	190	0.3315
10	0.2664	40	0.3142	200	0.3318
11	0.2715	41	0.3147	220	0.3323
12	0.2758	42	0.3152	240	0.3327
13	0.2795	43	0.3156	260	0.3330
14	0.2828	44	0.3160	280	0.3333
15	0.2857	45	0.3164	300	0.3336
16	0.2883	46	0.3168	350	0.3341
17	0.2906	47	0.3172	400	0.3346
18	0.2927	48	0.3175	450	0.3349
19	0.2946	49	0.3179	500	0.3351
20	0.2964	50	0.3182	550	0.3354
21	0.2980	55	0.3197	600	0.3356
22	0.2994	60	0.3210	650	0.3357
23	0.3008	65	0.3221	700	0.3358
24	0.3020	70	0.3230	750	0.3360
25	0.3032	80	0.3246	800	0.3361
26	0.3043	85	0.3253	850	0.3362
27	0.3053	90	0.3259	900	0.3362
28	0.3062	95	0.3264	1000	0.3364
29	0.3071	100	0.3269	∞	0.3379
30	0.3079				

Inductance of a Flat Spiral of Round Wire

The spiral is assumed to consist of n turns of round wire of cross sectional radius ρ, wound with a pitch g. The inductance is calculated by the previous formula, (4), except that here a represents the radius of the mean turn of the spiral and for L_s is put the inductance L_s' of a disk current-sheet. The corrections A and B are the same as in the previous case, and their values may be obtained as has already been indicated.

The inductance of the equivalent current sheet L_s may be obtained in most practical cases by means of the formula[8]

$$L_s' = 4\pi a n^2\left[\left(\log\frac{8a}{ng} - \frac{1}{2}\right) + \frac{n^2 g^2}{96a^2}\left(\log\frac{8a}{ng} + \frac{43}{12}\right) + \cdots\right]. \qquad (5)$$

However, in the case of spirals wound nearly to the center, this formula is not sufficiently convergent, and Spielrein's formula[9] should be employed.

[8] Rayleigh and Niven, *Proc.* Roy. Soc., 32, pp. 104–141; 1881. B. S. Sci. Paper 169, p. 117, formula (70).

[9] Spielrein, *Arch. für Electrotech.* 3, p. 187; 1915. B. S. Sci. Paper 320, p. 555; 1918. Butterworth, *Proc.* Lond. Phys. Soc., 32, part 1, p. 31; 1919.

Single-Layer Coil of Rectangular Cross Section

The cross section of the wire is assumed to have dimensions b and c, the former being radial. Two different formulas may be used. In the first

$$L = L_s - 4\pi na(A_1 + B_1) \tag{6}$$

L_s being the inductance of the equivalent cylindrical current sheet, calculated as for the single-layer coil of round wire.

$$-A_1 = \log \frac{g}{b+c} - \log \epsilon \tag{7}$$

$$\begin{aligned} B_1 = B + 2\Bigg[&\frac{n-1}{n}\log k + \frac{1}{12}(\beta^2 - \gamma^2)\left\{(S_2 - 1) - \frac{(\log n/2 + 1.270)}{n}\right\} \\ &- \frac{1}{60}\left(\beta^4 + \gamma^4 - \frac{5}{2}\beta^2\gamma^2\right)\left\{(S_4 - 1) - \frac{(S_3 - 1)}{n}\right\} \\ &+ \frac{1}{168}\left(\beta^6 - \gamma^6 + \frac{5}{3}\beta^2\gamma^4 - \frac{14}{5}\beta^4\gamma^2\right)\left\{(S_6 - 1) - \frac{(S_5 - 1)}{n}\right\}\Bigg] \end{aligned} \tag{8}$$

in which $\beta = b/g$, $\gamma = c/g$, $\delta = b/c$, and $\Delta = c/b$. The value of $\log k$ is taken from Table II or III, B from Table IV, and $\log \epsilon$ from Table I. The remaining constants are

$$S_2 - 1 = 0.6449 \qquad S_4 - 1 = 0.0823$$
$$S_3 - 1 = 0.2021 \qquad S_5 - 1 = 0.0369$$
$$S_6 - 1 = 0.0173$$

When the dimension b of the cross section, which is perpendicular to the line joining the centers of the turns, is large, it is convenient also to calculate the inductance by the expression

$$L = L_s'' + 4\pi na(A_2 + B_2) \tag{9}$$

(note that the correction for cross section is positive here). In this formula L_s'' is the inductance of a current sheet of n turns having a mean radius a, the current being uniformly distributed over a rectangular cross section whose radial dimension is b, and whose axial dimension is ng. The calculation of L_s'' may be conveniently made by the formulas and tables of the Bureau of Standards Scientific Paper 455.

The correction constant A_2 is given by the formula

$$A_2 = \log \frac{b+g}{b+c} + (\log \epsilon_3 - \log \epsilon_w) \tag{10}$$

in which $\log \epsilon_s$ is the value of $\log \epsilon$ taken from Table I for the ratio b/g or g/b, and $\log \epsilon_w$ is the value for the ratio b/c or c/b.

The remaining correction term is

$$B_2 = 2\left[\frac{n-1}{n}(\log k_s - \log k_w) - \frac{1}{12}(1-\gamma^2)\left\{(S_2 - 1) - \frac{(\log n/2 + 1.270)}{n}\right\} + \frac{1}{24}\left\{\beta^2(1-\gamma^2) - \frac{2}{5}(1-\gamma^4)\right\}\left\{(S_4 - 1) - \frac{(S_3 - 1)}{n}\right\} + \frac{1}{36}\left\{\beta^2(1-\gamma^4) - \beta^4(1-\gamma^2) - \frac{3}{14}(1-\gamma^6)\right\}\left\{(S_6 - 1) - \frac{(S_5 - 1)}{n}\right\}\right] \quad (11)$$

$\log k_s$ and $\log k_w$ are to be taken from Table III for the parameters $1/\beta = g/b$ and $\Delta = g/b$ for the former and g/b and c/b for the latter. As before $\gamma = c/g$, and the S constants are those given above.

Inductance of a Flat Spiral of Rectangular Wire

In this case the dimension b of the rectangular cross section is axial and c is radial. Formulas (6) and (9) are immediately available, with the understanding that L_s' is the inductance of a disk current sheet of mean radius a and radial width ng, while L_s'' is the inductance of the current sheet of mean radius a whose rectangular cross section has a dimension b in the axial direction and ng in the radial. This case is illustrated in example 1 below.

Inductance of Polygonal Single-Layer Coils and Spirals

Putting p for the length of the side of the polygon, (in the case of the spiral, the side of the mean turn), N for the number of sides of the polygon, the formulas for the equivalent current sheets are

$$L_p = 2Nn^2p\left[\log\frac{p}{ng} + \left(\frac{3}{2} - r\right) + \frac{s}{3}\frac{ng}{p} + \frac{t}{6}\frac{n^2g^2}{p^2}\right] \quad (12)$$

for the single-layer coil, and

$$L_p' = 2Nn^2p\left[\log\frac{p}{ng} + \left(\frac{3}{2} - r\right) + \frac{s'}{3}\frac{ng}{p} + \frac{T}{6}\frac{n^2g^2}{p^2}\right] \quad (13)$$

for the spiral.

The constants involved in these formulas are given in the following table:

TABLE V

	r	s	s'	t	T
Triangle	1.4055	2.2092	1.2396	−11/12	23/12
Square	0.77401	1	0.5328	−0.0429	3/4
Hexagon	0.15152	0.3954	0.2033	+0.1160	0.2947
Octagon	−0.21198	0.2146	0.1090	+0.1052	0.1662

The corrected formulas for cross section for a winding of round wire are

$$L = L_p - 2Npn\left[A + B + \frac{s}{3}\,\frac{g}{p} + \frac{t}{6}\,n\frac{g^2}{p^2}\right] \tag{14}$$

for the single-layer coil, and

$$L = L_p' - 2Npn\left[A + B + \frac{s'}{3}\,\frac{g}{p} + \frac{T}{6}\,n\frac{g^2}{p^2}\right] \tag{15}$$

for the spiral. The quantities A and B are the same as for circular coils and spirals of round wire. These are multiplied here by a factor which is twice the total length of wire, just as was the case with circular coils and spirals.

For wire of rectangular cross section the only change necessary is to replace A and B by the quantities A_1 and B_1 in formulas (14) and (15).

Long polygonal solenoids are best calculated by finding the inductance of the equivalent circular solenoid.[10]

Examples

Example 1. A flat spiral has ten turns of wire 0.2 cm in diameter, wound with a pitch of 1 cm. The mean radius of the innermost turn is 20.5 cm, and that of the outermost is 29.5 cm. Thus the mean radius is 25 cm. Also $g=1$, $n=10$, $\rho=0.1$. The inductance of a disk current sheet of ten turns of mean radius of 25 cm and radial width $ng=10$ cm is 78.75 μh. In formula (4) $A=5/4-\log 10=-1.0526$, and from Table IV, for $n=10$, $B=0.2664$. Thus, $(A+B)=-0.7862$, and the correction is $786.2\pi=2.47$ μh. Thus the total inductance of the spiral is $78.75+2.47=81.22$ μh.

If the same spiral were wound with wire of rectangular cross section 1 cm by 0.1 cm, with the smaller dimension radial, then in (6) $L_s'=78.75$ μh as before, $b=1.0$, $c=0.1$, $\Delta=0.1$, $\beta=1$, $\gamma=c/g=0.1$. From Table I for $c/b=0.1$, $\log \epsilon=0.0021$, and from Table IV, $B=0.2664$. Log k is taken from Table III for $\beta=1$ and $\Delta=0.1$, and is found to be 0.0702. Since $\log g/b+c=-\log 1.1=-0.0953$ it is found from formulas (7) and (8) that

$$A_1 = 0.0953 + 0.0021 = 0.0974$$

$$B_1 = 0.2664 + 2\Big[0.9(0.0702) + \frac{1}{12}0.99(0.6449-0.2879) - \frac{1}{60}0.975(0.0823-0.0202) + \frac{1}{168}0.972(0.0173-0.0037)\Big]$$

$$= 0.2664 + 2[0.06318 + 0.02945 - 0.00102 + 0.00008] = 0.4497.$$

[10] Grover, B. S. Sci. Paper 468, p. 753, and Table 1, p. 781; 1923.

Thus $(A_1+B_1)=0.5471$, and the correction is $-1.72\ \mu$h. The inductance of the spiral is $78.75-1.72=77.03\mu$h.

If formula (9) be employed to solve the same problem, we have to find first the inductance of a circular current sheet of mean radius 25 cm, with a rectangular cross section whose axial dimension is 1 cm, and whose radial is $ng=10$ cm. The value is $L_s''=75.70\mu$h. From Table I, using the ratio $b/g=1$, $\log \epsilon_s=0.00177$, and for $c/b=0.1$, $\log \epsilon_w=0.0021$. $\log (b+g/b+c)=\log (2/1.1)=0.5978$, so that from formula (10) $A_2=0.5975$.

Table III gives for $\beta=1$, $\Delta=1$, $\log k_s=0.0065$, and with $\beta=1$, $\Delta=0.1$, $\log k_w=0.0702$. Also $\gamma=0.1$. Thus from formula (11)

$$B_2=2\Big[0.9(0.0065-0.0702) - \frac{0.99}{12}(0.6449-0.2879) + \frac{1}{24}\Big\{0.99-\frac{2}{5}0.9999\Big\}\{0.0823-0.0202\} + \frac{1}{36}\Big\{0.9999-0.99-\frac{3}{14}\Big\}\{0.0173-0.0037\}\Big]$$

$$=2[-0.05733-0.02945+0.00153-0.00010]=-0.1707$$

$(A_2+B_2)=0.4268$. The correction is therefore 1.34μh, and the inductance of the spiral comes out $75.70+1.34=77.04\mu$h, which checks the other method very closely.

Appendix

TABLE VI

For Converting Common Logarithms into Natural Logarithms

Common	Natural	Common	Natural	Common	Natural	Common	Natural
0	0.0000	25.0	57.565	50.0	115.129	75.0	172.694
1.0	2.3026	26.0	59.867	51.0	117.432	76.0	174.996
2.0	4.6052	27.0	62.170	52.0	119.734	77.0	177.299
3.0	6.9078	28.0	64.472	53.0	122.037	78.0	179.602
4.0	9.2103	29.0	66.775	54.0	124.340	79.0	181.904
5.0	11.513	30.0	69.078	55.0	126.642	80.0	184.207
6.0	13.816	31.0	71.380	56.0	128.945	81.0	186.509
7.0	16.118	32.0	73.683	57.0	131.247	82.0	188.812
8.0	18.421	33.0	75.985	58.0	133.550	83.0	191.115
9.0	20.723	34.0	78.288	59.0	135.853	84.0	193.417
10.0	23.026	35.0	80.590	60.0	138.155	85.0	195.720
11.0	25.328	36.0	82.893	61.0	140.458	86.0	198.022
12.0	27.631	37.0	85.196	62.0	142.760	87.0	200.325
13.0	29.934	38.0	87.498	63.0	145.063	88.0	202.627
14.0	32.236	39.0	89.801	64.0	147.365	89.0	204.930
15.0	34.539	40.0	92.103	65.0	149.668	90.0	207.233
16.0	36.841	41.0	94.406	66.0	151.971	91.0	209.535
17.0	39.144	42.0	96.709	67.0	154.273	92.0	211.838
18.0	41.447	43.0	99.011	68.0	156.576	93.0	214.140
19.0	43.749	44.0	101.311	69.0	158.878	94.0	216.443
20.0	46.052	45.0	103.616	70.0	161.181	95.0	218.746
21.0	48.354	46.0	105.919	71.0	163.484	96.0	221.048
22.0	50.657	47.0	108.221	72.0	165.786	97.0	223.351
23.0	52.959	48.0	110.524	73.0	168.089	98.0	225.653
24.0	55.262	49.0	112.827	74.0	170.391	99.0	227.956
25.0	57.565	50.0	115.129	75.0	172.694	100.0	230.259

Example 2. To illustrate the use of Table VI, suppose that the natural logarithm of 0.08549 is required. The common logarithm is 2.93192. This may be written as 0.93192 − 2.

Table VI is a multiplication table constructed for the factor 2.302585 . . . ., the ratio between natural and common logarithms, so that if we denote this ratio by M, then from the table

$$
\begin{array}{rl}
0.93\ M = & 2.14140 \\
0.0019\ M = & .00044 \\
0.00002 M = & .00005 \\
\hline
 & 2.14189 \\
-2M = & -4.6052 \\
\hline
 & -2.4633 = \text{required natural logarithm.}
\end{array}
$$

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OPERATING CHARACTERISTICS IN PHOTOELECTRIC TUBES*

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Summary—This paper gives a discussion of the characteristics of photoelectric tubes which are important in the engineering applications of such tubes. Definitions of photometric terms are given together with the introduction of a few special terms essential to photoelectric tube work. Curves are given showing both the static and dynamic characteristics of a typical tube. A simple mathematical analysis is given of the elementary photoelectric tube circuit. An appendix of photometric formula and conversion factors is provided.

Introduction

There has been a great deal published on the physics of the photoelectric tube, but very little on its engineering aspects. The photoelectric tube now has such wide application that it is becoming of increasing importance to have a system of engineering terminology and to consider its characteristics in detail. The object of this paper is to discuss some of the photoelectric terms and tube characteristics which are of use in connection with the engineering applications of the tubes.

A knowledge of the photometric terms in most general use is essential to an understanding of photoelectric tube operation. For that reason the following list of definitions is given for reference.

Illuminating Engineering Nomenclature and Photometric Standards[1]

Luminous flux is the rate of passage of radiant energy evaluated by reference to the luminous sensation produced by it.

Lumen. The unit of luminous flux is the lumen. It is equal to the flux emitted in a unit solid angle by a uniform point source of one international candle.[2]

Luminous intensity of a point source in any direction is the luminous flux per unit solid angle emitted by that source in that direction.

* Dewey decimal classification: 535.3. Original manuscript received by the Institute, July 18, 1929.

[1] *Trans.* I. E. S., July, 1925.

[2] For the calculation of the light flux on a given area the following formula is found convenient:

$$l = C \times (\text{Area})/(\text{distance})^2.$$

l—light flux in lumens. C—the candle power of the source in the direction considered. Area and distance are in corresponding units.

Candle power is luminous intensity expressed in candles.

Illumination at a point of a surface is the density of the luminous flux incident at that point or the quotient of the incident flux by the area of the surface when the latter is uniformly illuminated.

Foot Candle. Taking the foot as the unit of length, the unit of illumination is the lumen per square foot. It is known as the foot candle.

Photoelectric Tube Characteristics

From the viewpoint of performance and characteristics there are two distinct types of photoelectric tubes: the vacuum tube and the gas-filled tube. The first, as the name implies, is highly evacuated,

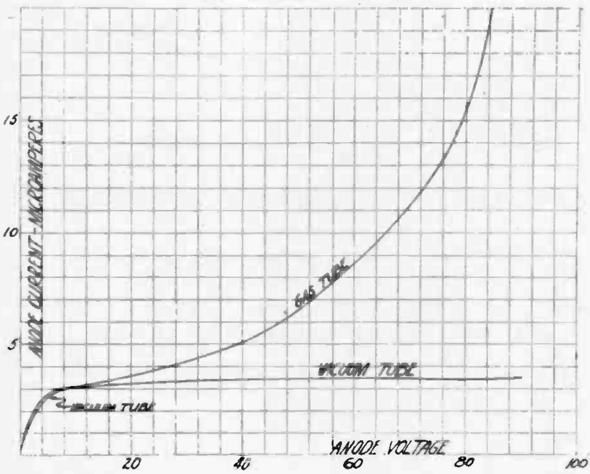

Fig. 1—Anode voltage-anode current characteristic of photoelectric tubes.

while the second contains an inert gas at pressures in the order of 20 to 150 microns. The anode voltage-anode current characteristic of a typical vacuum photoelectric tube with a constant value of light flux incident on the cathode is shown in Fig. 1. This characteristic is similar to thermionic emission when limited by filament temperature. When an inert gas at low pressures is present the characteristic changes to that of the gas tube shown in Fig. 1.

If the anode voltage is held constant and the light flux varied, the current is very nearly proportional to the amount of light. A typical family of curves of this type is shown in Fig. 2.

Although the photoelectric emission of electrons from the cathode responds to light variations of radio frequency, the amplification due to the gas does not follow such high-frequency variations. Fig. 3

shows the variation of the a-c output with frequency of the alternating light input for a typical gas-filled photoelectric tube. The lower curve shows the response of a vacuum photoelectric tube under similar conditions.

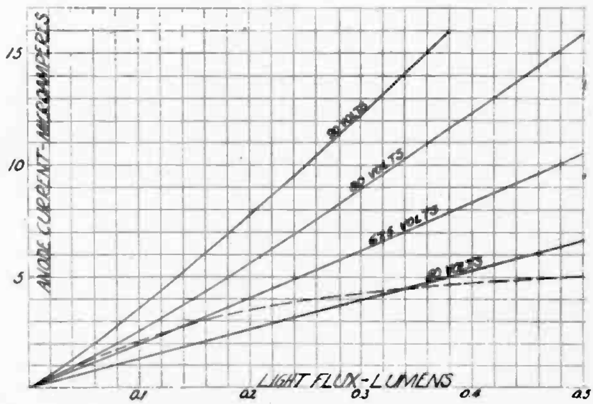

Fig. 2—Light flux-anode current characteristic of gas-filled photoelectric tubes.

Photoelectric Terms

Sensitivity. The slope of the light flux-anode current curve at a given point is the sensitivity of the tube at that point. That is, $S = di_a/dl$. This characteristic of the photoelectric tube is more clearly

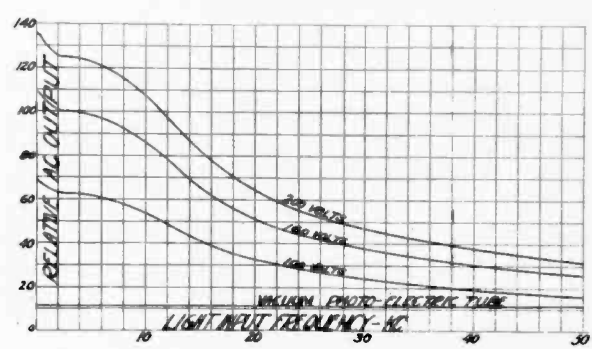

Fig. 3—Dynamic sensitivity of gas-filled photoelectric tubes with 100 per cent modulation of light flux.

understood if the light flux is compared to the grid voltage on the triode and the sensitivity to the mutual conductance. It must be noted, however, that the relation of each to change in anode voltage is not similar.

Conductance Per Lumen. The slope of the anode voltage-anode current curve divided by the light flux is the conductance per lumen at the point considered. This may be expressed as

$$G = \frac{1}{l} \frac{di_a}{de_a}.$$

This factor determines the maximum voltage output for a given condition of fidelity. This characteristic may be compared to the plate conductance of the triode. It must be borne in mind, however, that the conductance is a direct function of the light flux in the photoelectric tube case.

Applications

Before any calculation of circuit constants can be made, it is necessary to consider the applications to which the photoelectric tube is

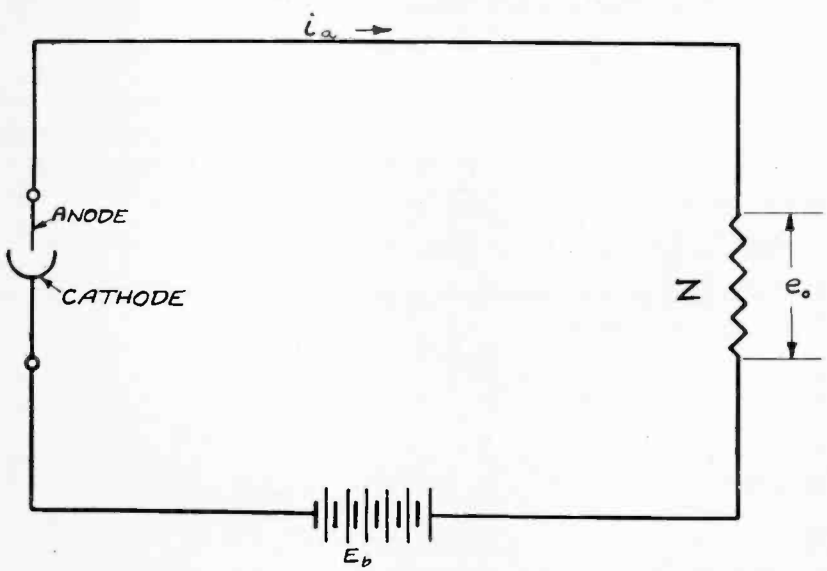

Fig. 4—Elementary circuit for photoelectric tube operation.

to be placed. The majority of the applications fall into one of three classes.

The first is d-c relay operation. In this class the tube is used to actuate a relay to either an "on" or "off" position.

The second is d-c linear operation. The photometry of lamps or the recording of daylight intensity is representative of this group.

The third group may be called a-c linear operation. That is, the response must be linear and uniform throughout a definite frequency range. Television and talking motion pictures are examples of such requirements.

Each of the above classes of operation requires an independent set of operating conditions.

Circuit Theory

In order to determine the best operating conditions, it is necessary to analyze the elementary circuit of the photoelectric tube in detail. The fundamental circuit considered is that shown in Fig. 4.

The following notation will be used in the development of the circuit equation:

- l —instantaneous value of light flux on the cathode
- i_a —anode current
- S —sensitivity
- G —conductance per lumen
- Z —load circuit impedance
- e_o—output voltage

From the figure it is seen that anode current is composed of two components. Let i_{a1} be the component which flows due to the constant battery voltage E_b, and i_{a2} be the component due to the change in anode voltage. Thus,

$$i_a = i_{a1} + i_{a2}.$$

By reference to the definitions of sensitivity and conductance per lumen it is seen that

$$i_{a1} = Sl$$

$$i_{a2} = (lG)e_0$$

then $$i_a = Sl + lGe_0.$$

However, $$e_0 = -i_a Z$$

so $$i_a = Sl - lGi_a Z.$$

Simplifying $$i_a = \frac{Sl}{1 + lGZ}$$

then $$e_o = \frac{SlZ}{1 + lGZ}.$$

By comparison with the triode plate current equation,

$$i_p = \frac{e_g G_m}{1 + G_p R_0}$$

it is seen that the fundamental difference is that while the triode equation is linear with respect to grid voltage, the photoelectric tube equation is hyperbolic with respect to the similar controlling factor, light flux. The dotted line in Fig. 2 shows the variation of anode current with light flux when a 5-megohm load resistance is used.

It is the curvature of this equation that limits the output voltage to a definite value for a given quality of reproduction. The magnitude of the harmonics introduced may be calculated from the current equation,

$$i_a = \frac{Sl}{1+lGZ}$$

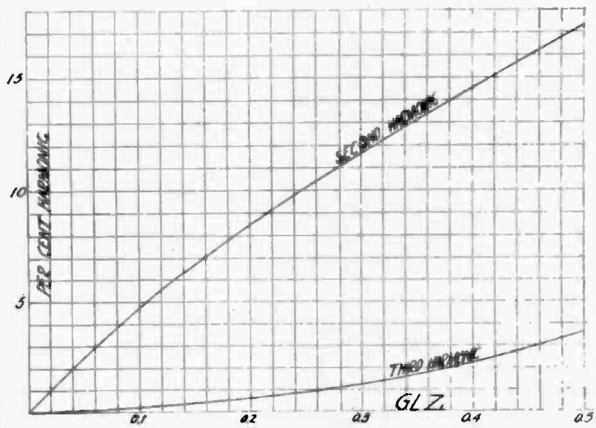

Fig. 5—Harmonics introduced into the output as a function of the product of conductance per lumen, light flux, and load impedance.

by substituting L (sin $\omega t+1$) for l. This assumes 100 per cent modulation of the light flux, but little error is introduced by the steady component.

Substituting and simplifying

$$i_a = \frac{S}{GZ}\left(1 - \frac{1}{GZL(1+\sin\omega t)+1}\right).$$

Expanding into a Fourier series

$$i_a = \frac{S}{GZ}\begin{pmatrix} A_0 + A_1 \sin\omega t + A_2 \sin 2\omega t \cdots \\ + B_1 \cos\omega t + B_2 \cos 2\omega t \cdots \end{pmatrix}.$$

It is now possible to determine the ratio of the harmonic currents to the fundamental, and the magnitude of the fundamental freqnency.

These are found to be a function of the product of G, Z, and L. The per cent harmonics are plotted in Fig. 5, while the output voltage is obtained from Fig. 6.

Due to the large value of load circuit impedance necessary to secure maximum output voltage, the capacity shunting the load circuit should always be considered. This capacity often limits the load impedance to a small value when it is required to cover a large frequency band.

In general, the major consideration in the design of photoelectric tube circuits is the fact that the photoelectric tube is fundamentally

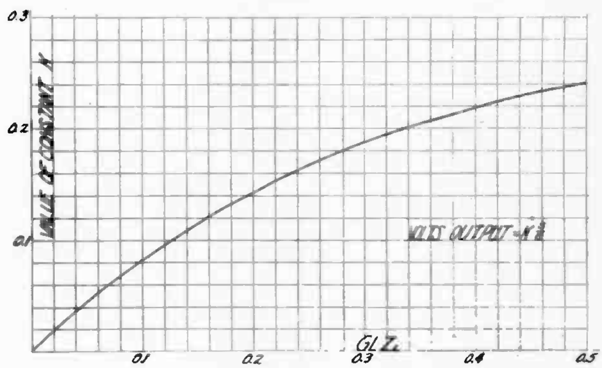

Fig. 6—Output voltage of fundamental frequency as a function of conductance per lumen, light flux, and load impedance.

an exceedingly high impedance device. For that reason the load impedance can never approach the condition for maximum power output, but should always be as large as conditions of fidelity and capacity will allow.

Appendix

The following list of formulas and conversion factors is given for convenience in future reference.[3]

Photometric quantity	Name of unit	Symbol and defining equation	Abbreviation for name of unit
1. Radiant flux	Erg per sec. Watt	Φ	
2. Luminous flux	Lumen	F	l.

[3] *Trans.* I. E. S., July 1925

3. Luminous intensity (candlepower)	Candle	$I=\frac{dF}{d\omega}$	c.
4. Illumination	Lux, phot; foot-candle	$E=\frac{dF}{dS}$ (incidence)	ph., fc.
5. Quantity of light	Lumen-hour	$Q=\int F dt$	l-hr.
6. Brightness	Candle per unit area; Lambert; millilambert; Foot-lambert	$B=\frac{dI}{dS \cos \theta}$	L; mL.; ft.L.
7. Visibility		$K=\frac{F\lambda}{\phi\lambda}$	

8. Reflection factor p
9. Absorption factor a
10. Transmission factor τ
11. Mean spherical candlepower scp.
12. Mean lower hemispherical candlepower lcp.
13. Mean upper hemispherical candlepower ucp.
14. Mean zonal candlepower zcp.
15. Mean horizontal candlepower mhc.
16. A source of unit spherical candlepower emits 12.57 lumens.
17. 1 lumen is emitted by a source whose spherical candlepower is 0.07958.
18. 1 lux = 1 lumen incident per square meter = 0.0001 phot = 0.1 milliphot.
19. 1 phot = 1 lumen incident per square centimeter = 10,000 lux = 1,000 milliphots = 1,000,000 microphots.
20. 1 milliphot = 0.001 phot = 0.929 foot-candle.
21. 1 foot-candle = 1 lumen incident per square foot = 1.076 milliphots = 10.76 lux.
22. 1 lambert = 0.3183 candle per square centimeter = 2.054 candles per square inch = 929 foot-lamberts.
23. 1 millilambert = 0.001 lambert = 0.929 foot-lambert.
24. 1 foot-lambert = 1.076 millilamberts = 0.00221 candles per square inch = 0.000343 candles per square centimeter.
25. 1 candle per square centimeter = 3.1416 lamberts = 2919 foot-lamberts.
26. 1 candle per square inch = 0.487 lambert = 487 millilamberts = 452 foot-lamberts.

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THE PENETRATION OF ROCK BY ELECTROMAGNETIC WAVES AND AUDIO FREQUENCIES*

By

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Summary—*This paper aims to throw some light upon the much discussed topic of radio penetration and the path of radio waves. Conclusive experimental evidence at the Mammoth Cave of Kentucky, free from all metallic conductors, confirms the hypothesis that radio waves penetrated through the ground and did not follow air openings or conductors. There is further evidence that audio-frequency magnetic fields are not greatly damped through an overburden to 300 ft. of sandstone and limestone having a resistivity of about 50,000 ohms per cm³.*

During the month of June, research work has been carried out at the Mammoth Cave, Kentucky, under the joint auspices of the United States Bureau of Mines and the Geological Survey of Canada. The disputed question of the extent to which wireless waves will penetrate into the earth has a high scientific interest, and it bears directly on some practical modern methods of geophysical prospecting for underground conductors such as the sulphides of lead, iron, and copper.

Previous investigations have been made at the experimental mine of the Bureau of Mines at Bruceton, Pa., in the Caribou mine, Colorado, and in the Mount Royal Tunnel, Montreal.[4] Notices and letters on this subject have also appeared from time to time in the columns of *Nature*. The results of all this work have been of a dubious character because of the presence of iron pipes and rails, and of copper conductors connected with electric lighting. There were three schools of thought; some claimed that the radiations came through the entrance, others that the waves passed through the rock, while the remainder considered that the effects were transmitted along wires, pipes, and rails. Probably all three paths are available, but certainly the Mount Royal experiments proved beyond question that the short waves of length 40 m (7,500 kc), failed to enter the tunnel by any of these means for more than a few hundred feet. Longer waves, broadcasting upwards, were heard and measured throughout the entire three and a half miles of tunnel.

* Dewey decimal classification: R113.5. Original manuscript received by the Institute, July 6, 1929. Published by permission of U. S. Bureau of Mines and the Canadian Geological Survey.

[4] An account of the experiments may be found in Technical Paper 434, pp. 37–40, Bureau of Mines, Department of Commerce, Washington, D. C., and in Proc. I. R. E., **17**, 347: Feb., 1929.

To settle the question, Mammoth Cave, Kentucky, was selected for experiments, and it proved a fortunate choice. This cave has not been electrified for illumination, and the managers were good enough to remove telephone wires. There are no conductors whatever in the cave except here and there short lengths of iron handrails. The exits are filled by and sealed with the waters of Echo River and the River Styx, which flow into Green River. A few years ago a new entrance was found and some electric wiring introduced; this is four miles away overland and eight miles away by cave. A careful survey was made both under and above ground so that corresponding points could be located and levels known. Most of the work was carried out above River Hall, with 300 ft. of overburden,—about 200 ft. of Mammoth Cave limestone capped by 100 ft. of Cypress sandstone. The resistivities of these rocks *in situ* were ascertained by electrical prospecting to be of the order of 10,000 to 20,000 ohms per cm^3.

Broadcasting Wavelength

The words and music from Louisville, Nashville, and Cincinnati were received on a No. 26 portable Radiola superheterodyne six-tube set, and their bearings were taken with the small loop which is part of the apparatus. These signals were traced into the cave from the entrance and were lost at 500 ft. from the mouth, where the overburden is 150 ft. Yet under the Mammoth Dome, 1,000 ft. in the cave, capped by an ascertained thickness of 75 ft., mostly sandstone, the signals were clear enough, and these were traced along a rather narrow tunnel for 300 ft., when the thickness was 150 ft.

On a later occasion Messrs. Joyce, Barlow, and Kidd took a 300-ft. aerial and gave three turns of it round the loop, so as to form a close coupling, and led the other end to the ground. In this manner there was at night good audible broadcasting in River Hall 300 ft. below the ground, and more than 1,000 ft. from the entrance at a point approached by the famous tortuous passage well named the Corkscrew. On the next night, signals and speech were also audible at Echo River, which is reputed to be 350 ft. underground. The conclusion is irresistible: waves from distant stations can be detected under 300 ft. of sandstone and limestone—waves which do not come through the entrance, and which do not pass along conductors.

Long-Wave Stations

Morse signals from about six stations with bearings approximately N. 65 W. (Long Island and others) were heard on a loop with a model RE low-frequency receiving equipment, consisting of an antenna coupling unit, a radio-frequency amplifier, a low-frequency receiver, and a tuned audio amplifier. These signals were clear enough to hear, but their intensities were hard to measure, partly owing to static. The wave fronts appeared to be mainly vertical, and the waves must therefore have been travelling through rock rather than down from above. The reception was again at River Hall, 300 ft. below the surface plateau near the camping ground of the Mammoth Cave Hotel. The bearings of these signals obtained above and below ground were nearly identical. This picture of a wave, with its front mainly vertical, travelling through the rock (just as through the air), is rather novel. We could pick up these unidentified stations with three turns of wire on a 4-ft. square frame, and we obtained bearings therewith.

Horizontal Wave Fronts

A circular horizontal transmitting loop, 100 ft. in diameter, was placed on the ground, and the insulated wire could be tapped so as to give one to ten turns as required. A rectangular receiving coil of three turns (40×10 sq. ft.) was placed on the floor of the cave at River Hall (300 ft. down). Currents of known magnitude of about half an ampere were introduced into a single turn of the loop, using a gasoline engine generator to excite an oscillator. The high-frequency loop current was modulated by applying a 500-cycle a-c potential on the oscillator plates. The frequency was varied by steps of 10, from 20 to 110 kc. The received voltage on the coil was measured in microvolts, and averaged about four, suggesting a flux of 10^{-9} lines per sq. cm in the cave, due to half an ampere in the loop above ground. It was a most remarkable fact that the 20- and 30-kc frequencies boomed out loudly as compared with the 40- and 100-kc frequencies. Measurements made above ground on the same frequencies showed no such emphasis, and there is a strong suggestion that these frequencies (20 to 30 kc) pass with markedly less absorption through the rock. This question must stand over for a fuller investigation. The selectivity did not appear to be a function of the receiving instrument.

Audio Frequencies

When 500-cycle frequency alternating current was impressed on the full ten turns of the 100-ft. diameter circular loop, powerful signals were received with headphones both with and without a three-stage amplifier, using a 400-turns 3×2 sq. ft. rectangular coil, at depths of 100 and of 300 ft. Of particular interest is the fact that detection was readily made without amplifier in the Mammoth Dome, 900 ft. on an inclined line from the horizontal loop. We conclude that the electromagnetic effects of a 500-cycle frequency passed through 900 ft. of continuous rock. It is intended to publish a full report on these experiments in due course.

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A VACUUM-TUBE VOLTAGE REGULATOR FOR LARGE POWER UNITS*

By

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Summary—*A new voltage regulator is described, suitable for large power units of standard construction. This regulator uses vacuum tubes as the controlling element, in place of vibrating contacts that have hitherto been employed. The voltage variation is less than 0.1 per cent when the load is gradually changed from no load to a little above full load. When this regulator is applied to d-c unit, some a-c source is necessary to supply the B-eliminator which is an essential part of it. The voltage of this a-c source, however, need be only fairly constant; it may safely vary by ±3 volts (in the case of a 110-v source) without causing more than ±0.1 per cent variation in the d-c line under regulation. When an a-c unit is to be regulated, on the other hand, the same unit may supply the B-eliminator.*

Accurate regulation of voltage is one of the serious problems encountered in connection with the generation and distribution of electrical power. In research laboratories this problem may may be of prime importance, since even a small variation of voltage may seriously interfere with certain types of work.

There are two main types of regulators now on the market. One of these, the induction regulator, is applicable only to a-c units; the other type consists essentially of a control magnet which, operated by the line voltage, actuates a pair of contacts that in turn control the field of the main unit in some way. This may be accomplished by short-circuiting a resistance in series with the main field or, in case of large machines, by short-circuiting the field of an auxiliary motor, the armature of which is in the main field circuit. Vibrating contacts as control elements have obvious disadvantages. A slight amount of wear or a little dirt may hamper the regulation seriously or may even start an accumulative deterioration. Moreover, the contacts introduce a time lag in addition to that which is inherently present in the main field and in the field of the auxiliary motor, thus delaying the response.

Such a regulator, with a counter e.m.f. auxiliary motor, has been in use in these laboratories for some time. The regulation obtained with it was not, however, sufficiently close for various types of precision work. Furthermore, it was not reliable. At times the line voltage would suddenly drop three or four volts and then oscillate about a lower mean value. The cause of this trouble was later found to be a sudden reversal of the auxiliary motor. With proper adjustments of

* Dewey decimal classification: R358. Original manuscript received by the Institute, April 24, 1929.

speed the possibility of reversing was minimized. These troubles led to the development of a new regulator, which utilizes vacuum tubes as control elements. The description of this regulator forms the subject matter of this paper.

Various suggestions have been made regarding the application of thermionic tubes to voltage regulation problems. Van der Bijl[1] has suggested two very simple arrangements which are adaptable only to specially designed generators and tubes. During the World War a small generator was developed in conjunction with a special tube for airplane radio work, where a small amount of power was to be delivered at a constant voltage under highly variable speed.[2,3] Recently Stoller and Power have made use of a vacuum-tube amplifier in a precision voltage regulator for small amounts of a-c power.[4] Thus various schemes have already been worked out for special applications. The regulator described here is believed to be the first vacuum-tube regulator that can be applied to any standard d-c machine. With a slight modification it can also be used for a-c machines, as will be pointed out later. Probably the main reason why vacuum tubes have not yet been used for this purpose is that the requirements have never been exacting enough to warrant the expense and maintenance of the apparatus involved. The difficulties of maintenance have been minimized by the employment of a B-eliminator in the new regulator. The operation is very simple, since the control has been centralized in a single rheostat. With the exception of the exciter generator, which requires a special field winding, all the parts used are standard and can be readily procured.

Description

Fig. 1 is a schematic representation of the regulator. It consists of a one-stage high-μ d-c amplifier (UX240) which amplifies the fluctuation of the line and feeds into a power tube (UX210) through a coupling resistance, R_3. The output of the power tube is passed through the field of the exciter generator which supplies the main generator field. The only batteries used are in the input of the first tube, employed to balance out most of the line voltage (in this case 110 volts). Since the grid of this tube has a negative bias, no current passes through these batteries, and their life is at least the normal

[1] "The Thermionic Vacuum Tube and Its Applications," pages 371–373.

[2] E. B. Craft and E. H. Colpitts, "Radio Telephony," *Trans.* A. I. E. E., **38**, part 1, page 330, 1919.

[3] Robt. W. King, "Thermionic Vacuum Tubes and Their Applications," *Bell Sys. Tech. Jour.*, **2**, No. 4, p. 96–98, Oct. 1928.

[4] H. M. Stoller and J. R. Power, "A Precision Regulator For Alternating Voltage," *Jour.* A. I. E. E., **XLVIII**, No. 2, p. 110, February, 1929.

shelf-life. The regulator is controlled by rheostat R_1 in the input circuit, mounted on the main switchboard. Balancing voltage, for adjusting the power tube grid bias, and all B-power are supplied by the eliminator, which is not shown in the diagram. Filaments are lighted by alternating current supplied by independent transformers.

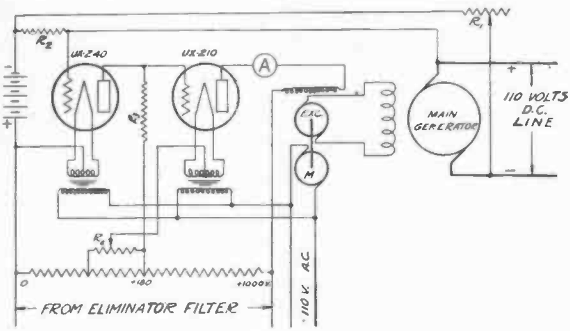

Fig. 1

The field of the exciter generator is designed so that its resistance matches the plate resistance of the power tube and at the same time it operates well below the knee of the saturation curve for the exciter, in order to get the maximum possible change in the output for a given variation of the line voltage.

In Fig. 2 is shown the actual photograph of the instrument with the exciter motor-generator set. The exciter may be run by the same

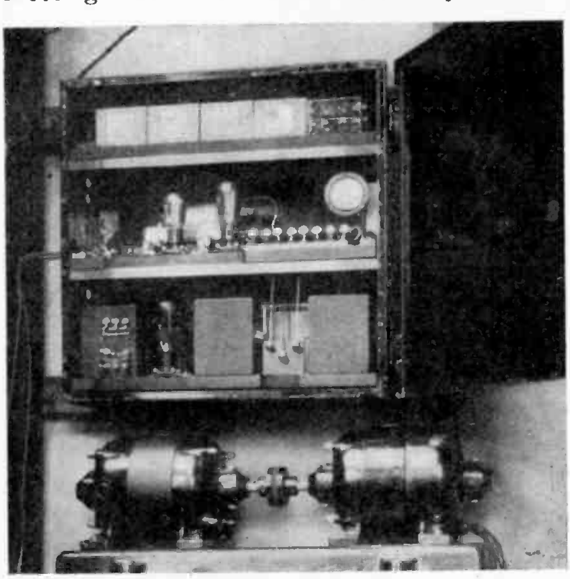

Fig. 2

prime mover as the main generator. It was found more convenient under local conditions to drive it by a separate motor which gets its power from the same line as the B-eliminator through a common transformer connected in parallel with the motor that drives the main generator.

The cycle of operation is as follows. A small decrease of line voltage produces a corresponding increase of negative grid bias on the 240 amplifier tube, thereby lessening its plate current. This reduction of the plate current which flows through the coupling resistance R_3, decreases the drop across it and consequently decreases the negative bias of the 210-power tube. The plate current of the latter tube thus increases and boosts the exciter voltage and in turn the line voltage. This process is reversed throughout when the line voltage tends to rise.

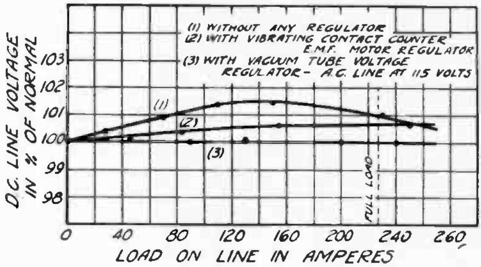

Fig. 3

Performance

The results of various tests are shown in Figs. 3, 4, and 5. Without any regulator the generator does not give a constant voltage at a given load. It drifts continuously. Curve 1 of Fig. 3, therefore, merely shows an estimated mean value of the line voltage without any regulator. Curve 2 shows the performance of a vibrating contact counter-e.m.f. motor type regulator. Curve 3 of the same figure shows that the new regulator maintains the line voltage constant at all loads tested, within the reading error of the voltmeter, which is ± 0.1 per cent. In Fig. 4 is shown the regulation as a function of the a-c voltage applied to the eliminator which supplies the amplifier and the power tube. Curve (1) of this figure shows that a 30 per cent variation in a-c voltage makes less than 1 per cent change in d-c voltage. Hence we may safely say that the regulator will function quite satisfactorily on an average a-c line.

Under the direction of Professor Bedell, a transformer has recently been developed in this laboratory that delivers a constant load at a constant voltage over a large range of primary voltage. Such a transformer, designed for this purpose, maintains 115 volts at the secondary terminals when loaded with the eliminator. The primary voltage was changed gradually from 100 to 130 volts without making any readable change in the line voltage, as shown by curve 2 of Fig. 4.

Fig. 5 shows continuous records of line voltage taken under normal operating conditions on a Leeds and Northrup recorder. Each ordinate division corresponds to about 1.2 per cent variation from the mean value of the line voltage. While these records were being taken, the load varied at random, as would be expected in a physical laboratory.

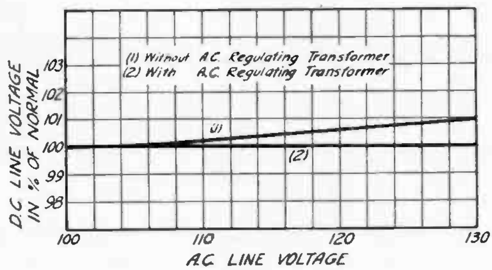

Fig. 4

When record 5 (Fig. 5) was under way, it was observed that, in addition to the general variation, the load changed ± 5 amperes continuously at intervals of about one minute. In examining these records, it must be borne in mind that, due to the inductance of the main field, a sudden change in load causes a corresponding jump in the voltage, which returns to normal in the course of a fraction of a second. These variations are too fast for the recorder to follow and only once in a while does one of these dips show up in the records. The time lag caused by the inductance of the main field also sets a limit to the rapidity with which any regulator can compensate for voltage fluctuations. For this reason, regulation for small rapid fluctuations is no better with this regulator than with the vibrating contact type.

The various records shown in Fig. 5 were taken under the following conditions:

No. 1 is the record of line voltage when no regulator was in operation.

No. 2 was taken with the vibrating contact counter-e.m.f. motor type regulator. Voltage, though kept well within reasonable range during this period, fluctuated quite rapidly.

Nos. 3 and 4 are the records taken with the new regulator while the eliminator was directly connected to the a-c line. The marked difference between these two records is caused by the fact that when No. 3 was being taken there was a large air compressor on the a-c line.

This compressor motor causes a-c line voltage fluctuations which are quite rapid and correspond to the cycle of the compressor. Possibly some sort of transients are set up in the eliminator that cause such behavior of the regulator. In record No. 4, however, these variations are not present.

No. 5 is the record of line voltage taken when the eliminator was supplied through the new regulating transformer mentioned above.

The comparison between records Nos. 4 and 5 will readily show that practically no improvement is made by regulating the a-c line

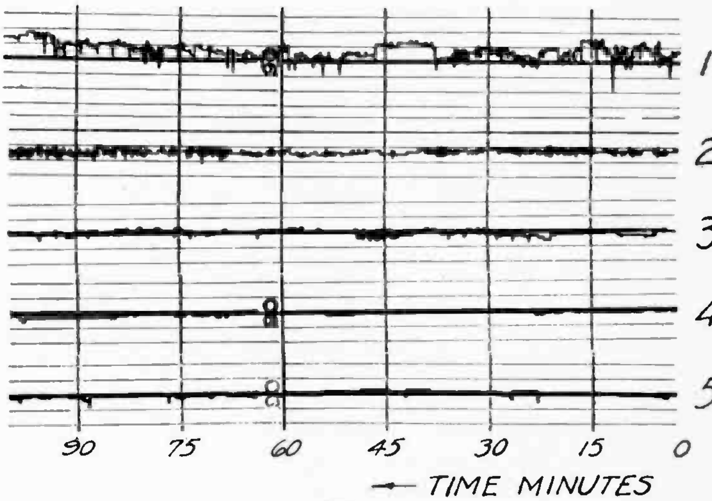

Fig. 5

voltage through the regulating transformer. As observed from the records, the variation of line voltage from the mean is of the order of 1/4 volt with the new regulator as compared to about 1/2 volt with the older equipment. One advantage of the new regulator, however, is that the variations are not as fast and are quite independent of the load. Thus long periods of constancy are obtained. We have not yet definitely determined why the slow variations seen in the records are more pronounced than those observed when the data for the curves of Figs. 3 and 4 were taken. They seem to be caused either by longitudinal drift of the generator armature in its bearings, or by the application of a large load on one of the 55-volt branches of the line, which brings into operation only one half of the series field.

Simultaneous records of load and voltage were not taken, since only one recorder was at hand. The curves of Figs. 3 and 4, however, clearly show that the new regulator maintains the voltage constant irrespective of the load.

It may be well to mention here that for the sake of experiment an extra stage of amplification was added ahead of the power tube. This introduced hunting and caused the line voltage to oscillate about a mean value at a definite period.

Possible Modifications

This regulator can easily be adapted to line drop compensation and stabilizer installations in which both lighting and elevator loads are present.

A slight modification is necessary in order to apply it to a-c units. By means of a suitable transformer (viz. bell-ringer) the line voltage may be stepped down and rectified by an extra tube placed ahead of the amplifier. The two may then be coupled through a suitable resistance in a somewhat similar manner to that in which the amplifier is coupled to the power tube (Fig. 1). It is obvious that in this case a separate source of power for the B-eliminator is unnecessary. The regulation may therefore be slightly improved, since it is independent of voltage variations of a separate a-c line.

Acknowledgment

The authors are indebted to the Heckscher Research Council of Cornell University, who partially supported this work (grant No. 155). They also wish to thank Prof. Frederick Bedell and Mr. J. G. Kuhn, whose valuable suggestions and interest greatly aided this work.

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BOOK REVIEW

Vibration Problems in Engineering. By S. Timoshenko. Published by D. Van Nostrand, 340 pp.

In this book the fundamentals of the theory of vibrations are developed, and their application to the solution of technical problems is illustrated by various examples.

The contents of the book are as follows: the first chapter is devoted to the discussion of harmonic vibrations of systems with one degree of freedom. The general theory of free and forced vibration is discussed, and the application of this theory to balancing machines and vibration recording instruments is shown.

Chapter two contains the theory of the non-harmonic vibration of systems with one degree of freedom. The approximate methods for investigating the free and forced vibrations of such systems are discussed.

In chapter three, systems with several degrees of freedom are considered. The general theory of vibration of such systems is developed and its application in the solution of such engineering problems as: the vibration of vehicles, the torsional vibration of shafts, whirling speeds of shafts on several supports, and vibration absorbers.

Chapter four contains the theory of vibration of elastic bodies. The problems considered are: the longitudinal, torsional, and lateral vibrations of prismatical bars of variable cross section; the theory of vibration of circular rings, membranes, plates, and turbine disks.

Brief descriptions of the most important vibration recording instruments which are of use in the experimental investigation of vibration are given in the appendix.

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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.

R100. Radio Principles

R007.1 Dellinger, J. H. Engineering aspects of the work of the Federal Radio Commission. Proc. I. R. E., 17, pp. 1326–1333; August, 1929.

(The engineering problems of the Federal Radio Commission are presented.)

R007.1 Whittemore, L. E. Some principles of broadcast frequency allocation. Proc. I. R. E., 17, pp. 1343–1353; August, 1929.

(The assignment of available broadcast channels to stations is considered with a view of giving the best possible service to the country as a whole.)

R007.2 Batcheller, A. An outline of the Radio Inspection Service. Proc. I. R. E., 17, pp. 1365–1376; August, 1929.

(A history of the Radio Inspection Service of the Department of Commerce is given together with an outline of the scope and general nature of its work.)

R113 Krüger, K., and Plendl, H. The propagation of low power short waves in the 1000-kilometer range. Proc. I. R. E., 17, pp. 1296–1312; August, 1929.

(A description is given of experiments carried out between two ground stations and between an airplane and a ground station to determine the possibility of obtaining reliable short-wave (25 to 55 meters) communication over a distance of 500 km or more with relatively low power (2 watts, continuous wave). An airplane installation operating into a dipole antenna (fixed) is described, and results of a large number of observations at ground receiving stations of the signals received from the airplane in flight are presented.)

R113 Breisig, F. Ueber die Ausbreitung elektrischer Wellen um eine leitende Kugel. (The propagation of electric waves around a conducting sphere). *Elektrische-Nachrichten Technik*, 6, pp. 268–271; July, 1929.

(The derivation of a formula for finding the field intensity of an electromagnetic radiation at any point on the surface of a conducting sphere is given.)

R113 Eckersley, T. L. An investigation of short waves. *Jnl.* I. E. E., (London), 67, pp. 992–1032; August, 1929.

(An account is given of investigation made during the past two years of the following wave transmission phenomena: (1) scattering; (2) multiple signals; and (3) signal mutilation of short-wave commercial stations are presented with a discussion of the problems of short-wave transmissions and such cognate subjects as the Heaviside layer, fading, and polarization effects. Certain revisions of results presented in previous papers are offered.)

R113.4 Schelleng, J. C. Further note on the ionization in the upper atmosphere. Proc. I. R. E., 17, pp. 1313–15; August, 1929.

(Supplement to "Note on the determination of the ionization in the upper atmosphere" which appeared in Proc. I. R. E., 16, p. 1471; Nov., 1928.)

R113.6 Störmer, C. Kurzwellenechos, die mehrere Sekunden nach dem Hauptsignal eintreffen, und wie Sie sich aus der Theorie des Polarlichtes erklären lassen. (Short-wave echoes that occur several seconds after the main signal and their explanation in the light of the theory of the aurora borealis). *Die Naturwissenschaften*, **17**, pp. 643–51; Aug. 16, 1929.

(Theoretical discussion.)

R125.6 Palmer, L. S. and Honeyball, L. L. K. The action of a reflecting antenna. *Jnl.* I. E. E. (London), **67**, pp. 1045–1051; August, 1929.

(As a study of the action of reflecting antennas the currents produced in two tuned vertical antennas, both acting as receivers in a radiation field, are discussed theoretically. Case 1 treats antennas less than 1 wavelength apart and in line with the transmitter. Case 2 treats antennas less than 1 wavelength apart and at right angles to the transmitter. The conclusions experimentally verified are in the form of an equation, the solutions of which give the critical values of the ratio of the separation distance of the antennas to the wavelength for maximum and minimum antenna currents.)

R125.6 Moser, W. Versuche über Richtantennen bei Kurzen Wellen. (Experiments with short-wave directional antennas). *Zeits. f. Hochfrequenztechnik*, **34**, pp. 19–26; July, 1929.

(A description of experiments and results achieved with several types of short-wave directive antennas.)

R133 Knipping, P. Ueber Barkhausen-Kurz Wellen. (Discussion of Barkhausen-Kurz waves). *Zeits. f. Hochfrequenztechnik*, **34**, pp. 1–12; July, 1929.

(An attempt is made to explain the production of Barkhausen-Kurz oscillations from theoretical considerations of atomic and electronic phenomena.)

R134 Harris, S. An empirical equation for determining the d^2i_g/de_g^2 detectors. Proc. I. R. E., **17**, pp. 1322–25; August, 1929.

(An empirical equation for the grid-current, grid-voltage curve of the C327 electron tube is developed. By obtaining the derivatives of this equation rather than determining them for the i_g-e curve by graphical means the inaccuracy of the graphical method is avoided.)

R134 Warren, A. G. Reduction of distortion in anode rectification. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 423–37; August, 1929.

(The general principles of plate rectification are reviewed. An analysis is presented to show that distortion due to undesired harmonics can be reduced by plate rectification at high grid voltages.)

R134.6 Hollmann, H. E. Frequenzrückkopplung. (Frequency regeneration). *Elektrische-Nachrichten Technik*, **6**, pp. 253–264; July, 1929.

(Ordinarily regeneration refers to amplitude and not to frequency. However, it is possible to either increase or decrease the frequency of a tube circuit by "frequency regeneration" as described in this article.)

R170 Hogan, J. V. L. A study of heterodyne interference. Proc. I. R. E., **17**, pp. 1354–64; August, 1929.

(The problem of cross talk and heterodyne interference due to the simultaneous use by several broadcasting stations of the same frequency channel or adjacent channels is studied. Strict frequency control and judicious assignments of power and frequency to stations with respect ot their geographical locations are remedies suggested.)

R170 Felix, E. H. The radio engineer's responsibility in coping with man-made interference. Proc. I. R. E., **17**, pp. 1385–89; August, 1929.

(The importance of cooperation of radio interests with power companies and manufacturers of electrical equipment in the elimination of man-made interference is stressed.)

R170 Hooven, M. D., Jr. Radio coordination. Proc. I. R. E., **17**, pp. 1390–94; August, 1929.

(Aspects of the radio interference problem are discussed and the necessity for complete coordination of the numerous interests involved if improvement is to be realized is pointed out.)

R170 RMA better radio reception manual: Home-made static and how to avoid it. Pamphlet by the Radio Mfgrs. Association, Inc., 1929. Price 25 cents.

(A general classification of radio interference is offered and suggestions are given for determining the source of controllable interference. Filter systems and their application to the elimination of certain noises are briefly indicated.)

R200. Radio Measurements and Standardization

R210 Braillard, R. and Devoire, E. The measurement of wavelengths of broadcasting stations. *Experimental Wireless and Wireless Engrs.* (London), 6, pp. 412–21; August, 1929.

(An account of the work of the Brussels checking station of the U. R. S. I. is presented. The circuit, the operation and the accuracy of the apparatus used in checking the frequency of European broadcasting stations are described.)

R210 Harries, J. H. O. An electromagnetic monochord for the measurement of audio frequencies. Proc. I. R. E., 17, pp. 1316–21; August, 1929.

(Harmonic monochord theory is outlined and applied in the construction of a secondary audio-frequency standard with the range 32 to 5000 cycles.)

R270 Edwards, S. W. and Brown, J. E. The problem centering about the measurement of field intensity. Proc. I. R. E., 17, p. 1377–84; Aug., 1929.

(Surveys of service areas of broadcasting stations made by the Radio Division of the Department of Commerce are described. Field intensity contour maps are explained.)

R270 Hollingworth, J. A portable radio intensity measuring apparatus for high frequencies. *Jnl.* I. E. E. (London), 67, pp. 1033–1044; August, 1929.

(Circuit for apparatus to measure radio field intensities in the range 12000 to 4547 kc (25 to 66 meters) is described. It includes a local oscillator, an attenuator in the form of a resistance-voltage divider, and a heterodyne receiving set and a rectifying unit for measuring the output. An abstract of this paper appeared in *Exp. Wireless and Wireless Engr.* (London) for June, 1929.)

R300. Radio Apparatus and Equipment

R320 Englund, C. R. and Crawford, A. B. The mutual impedance between adjacent antennas. Proc. I. R. E., 17, pp. 1277–95; August, 1929.

(Using the methods for treating concealed networks the simple theory for the computation of reflecting antennas is sketched. By experiments based on this theory curves are obtained showing the relation of the phase angle between the currents in the transmitting antenna and in the reflecting antenna to the distance in wavelengths between them for the range $\lambda/3$ to infinity where $\lambda = 4.34$ meters.

R330 Jouaust, R. L'etat actuel de la technique des lampes a plusieurs electrodes. (The present state of the art of multi-electrode vacuum tubes). *L'Onde Electrique,* 8, pp. 227–261; June, 1929.

(The results and formulas acquired through progress in vacuum-tube art are assembled and reviewed. Interelectrode capacity, secondary emission, the phenomenon of the virtual cathode are treated. The multi-grid and the heater type tubes are included in the review.)

R331 Decaux, B. Les caracteristiques des lampes de reception modernes et leur choix rationnel. (Characteristics of modern receiving tubes and their rational choice). *L'Onde Electrique,* 8, pp. 262–280; June, 1929.

(A classification of various types of tubes according to their amplification factors and their plate resistances is suggested as a useful guide to users in the choice of a tube for a specific use. The characteristics of multi-grid tubes and the interesting results they offer are noted.)

R343 von Handel, P; Krüger, K; Plendl, H. Quarzsteuerung von Kurzwellen Empfängern. (Crystal control for short-wave receiving sets). *Zeits. f. Hochfrequenztechnik,* 34, pp. 12–18; July, 1929.

(Describes several methods of using crystal control in short-wave receiving sets, the most successful being the crystal controlling of the oscillations of a regenerative detector tube which forms an intermediate frequency with the incoming signal. The intermediate frequency is then amplified and detected.)

R360 Hull, L. M. Some characteristics of modern radio receivers and their relation to broadcast regulation. Proc. I. R. E., 17, pp. 1334–41; August, 1929.

(A report is made of comparative tests on twenty 1927–1928 receiving sets and on twenty-four 1928-1929 receiving sets. The sets are compared with respect to (1) their discrimination between channels; (2) their discrimination within a channel; (3) their uniformity of reception in all channels; (4) their uniformity of reception within a channel: and (5) their range.)

R376.3 Meyer, E. and Just, P. Frequenzkurven von elektrischen Tonabnehmern und mechanischen Grammophonen. (Frequency curves of electrical reproducers and mechanical gramaphones). *Elektrische-Nachrichten Technik*, 6, pp. 264–68; July, 1929.

(Curves are presented.)

R500. Applications of Radio

R550 Marriott, R. H. United States radio broadcasting development. Proc. I. R. E. 17, pp. 1395–1439; August, 1929.

(A detailed account of the development of radio broadcasting in the United States from 1907 to 1928 inclusive; followed by a description of the route of a modern broadcast from the studio to the listener. Possible future developments are discussed.)

Proceedings of the Institute of Radio Engineers
Volume 17, Number 11 *November, 1929*

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Weinberger, Julius: See PROCEEDINGS for September, 1929.

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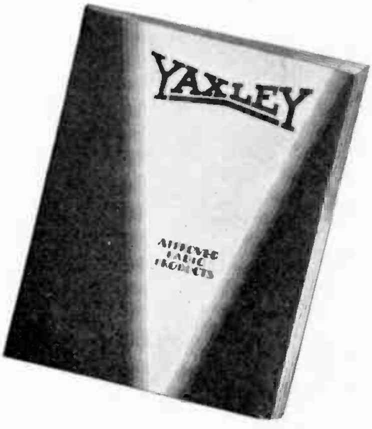

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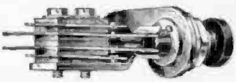

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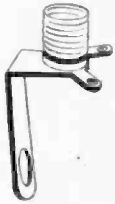

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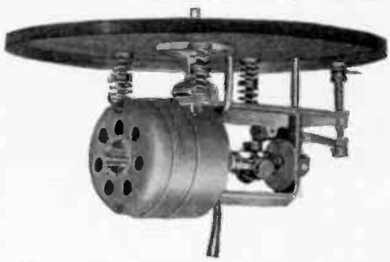

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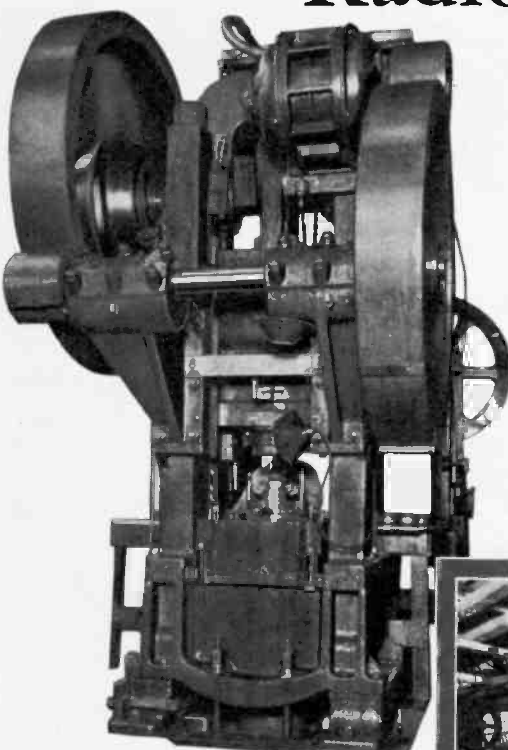

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To Right: Corner of the coil-winding department where multiple coil-winding machines produce the coils for Symington Reproducers.

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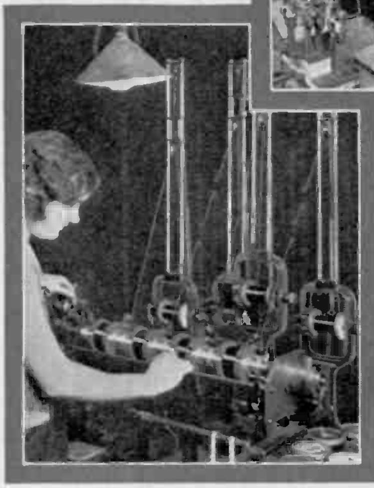
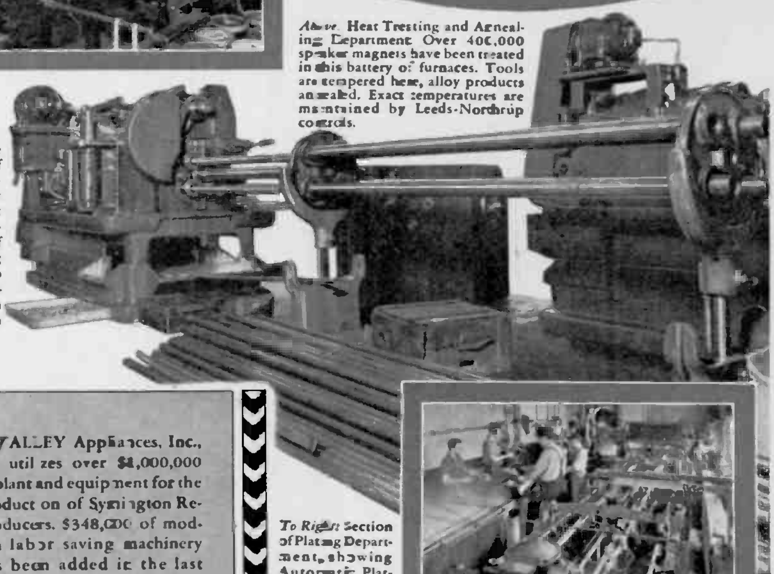


Above. Heat Treating and Annealing Department. Over 400,000 speaker magnets have been treated in this battery of furnaces. Tools are tempered here, alloy products annealed. Exact temperatures are maintained by Leeds-Northrup controls.



To Right: One of a group of large Automatic Screw Machines that complete a sequence of metal-cutting operations to the closest tolerances with almost human ingenuity.

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To Right: Section of Plating Department, showing Automatic Plating equipment. Cadmium, nickel and silver plating is done here.

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At Right: View of Cone Assembly Department where cone parts are assembled ready for final assembly

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At Left: A partial view of the Valley Tool Room—the ultimate in a precision Tool Room for radio design. Costly machines, skilled workmen, fashion the accurate jigs, tools, dies and fixtures necessary for volume production at low cost. Close co-operation with the shop and independence of outside sources count heavily in facilitating production.

Below: A corner of the Laboratory. Our engineering staff is organized and equipped to meet the individual requirements of each customer.

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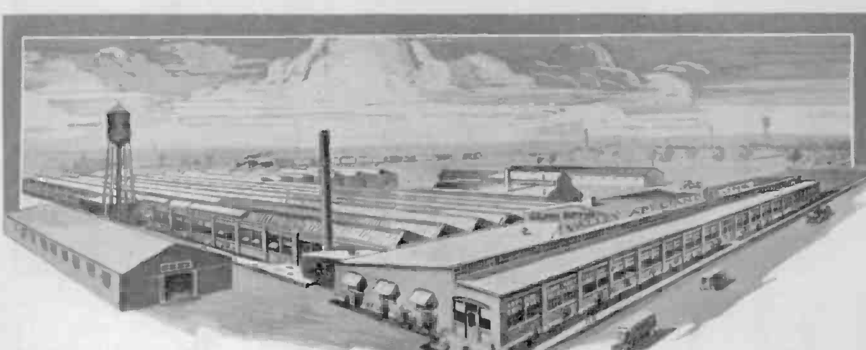

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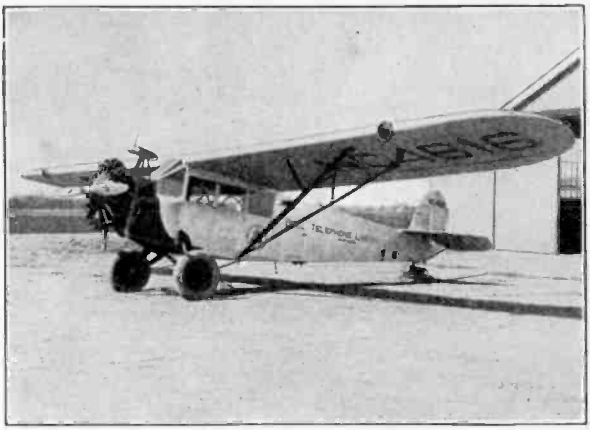

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I certify that the statements made in the record of my training and professional experience are correct, and agree if elected, that I will be governed by the constitution of the Institute as long as I continue a member. I furthermore agree to promote the objects of the Institute so far as shall be in my power, and if my membership shall be discontinued will return my membership badge.

Yours respectfully,

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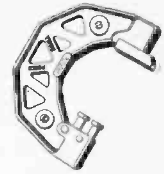

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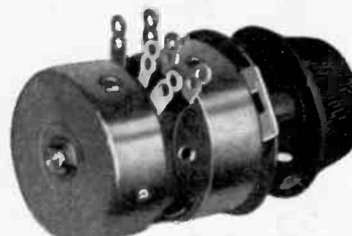

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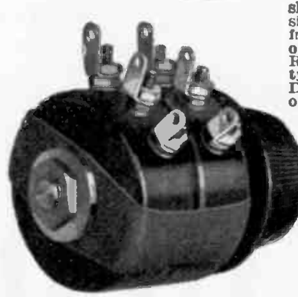

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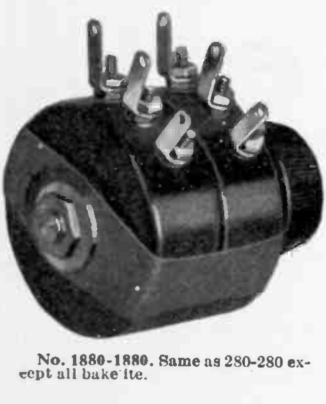

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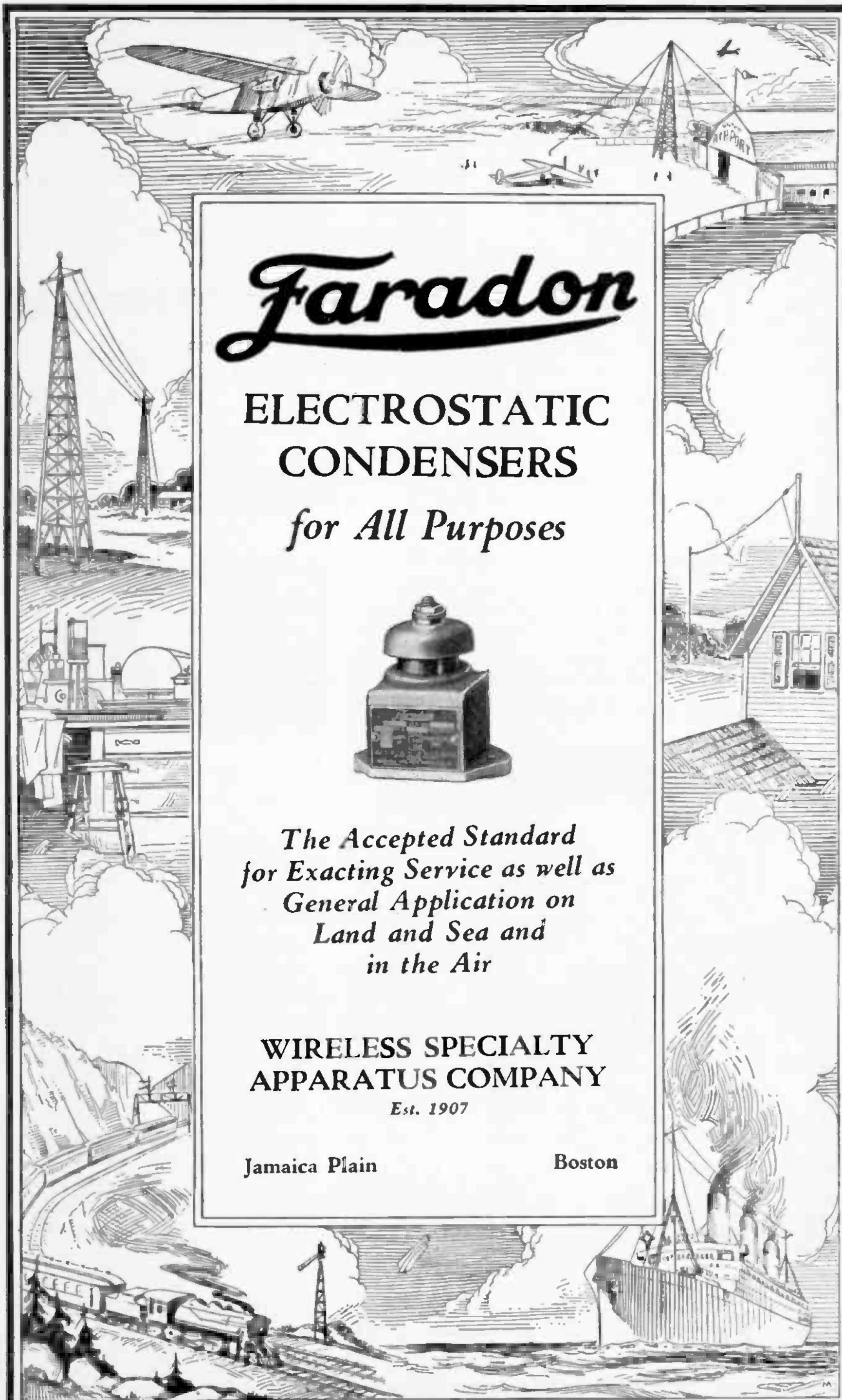
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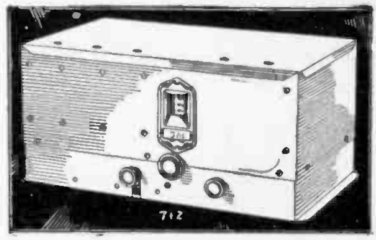

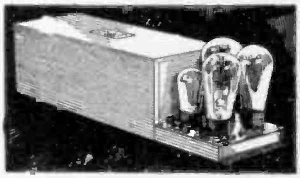

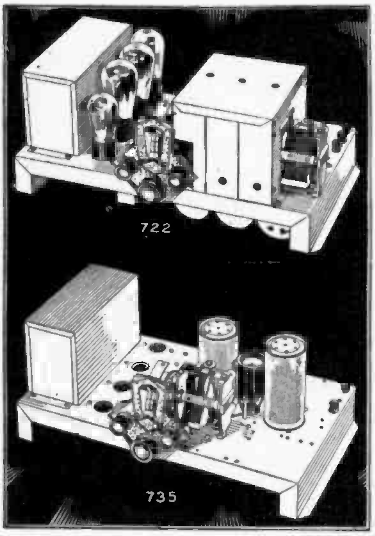

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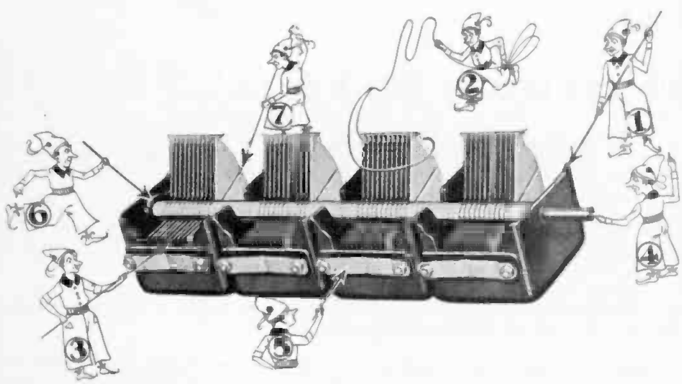

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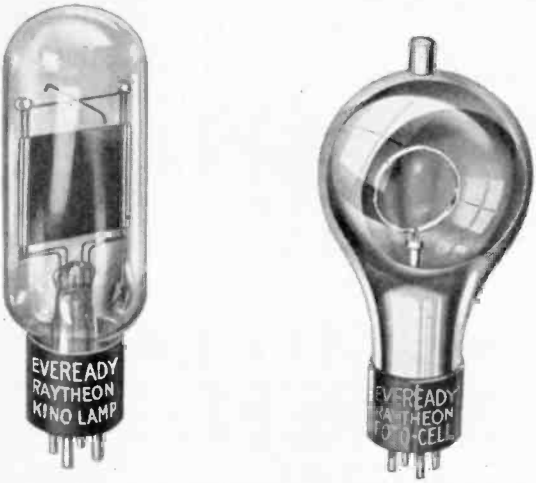

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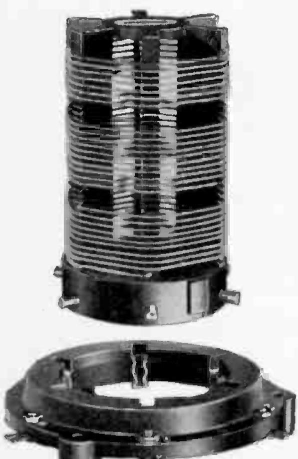

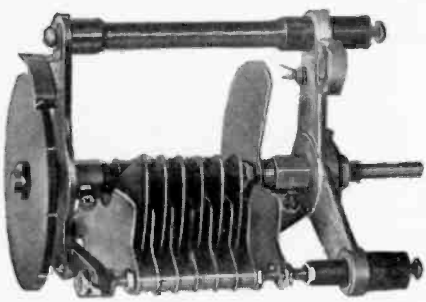

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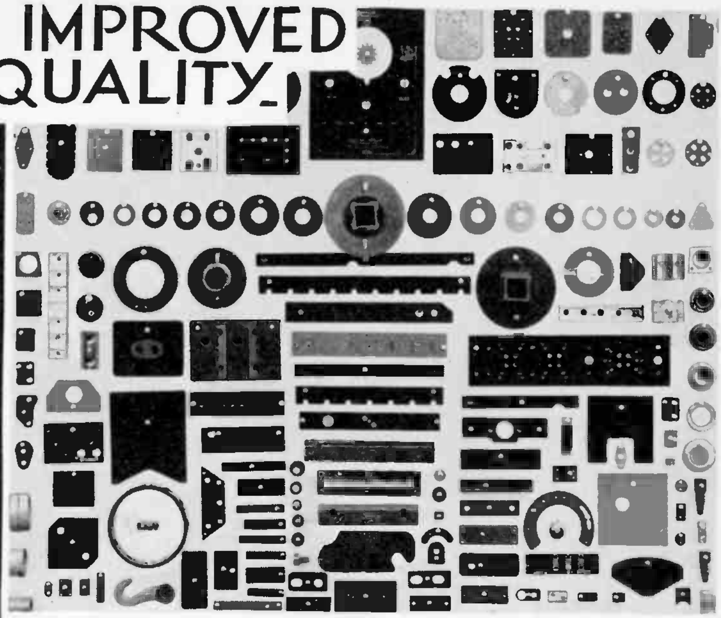

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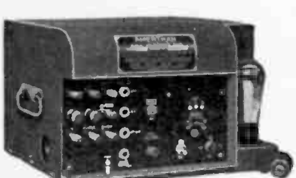

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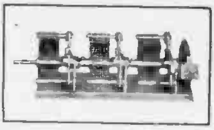

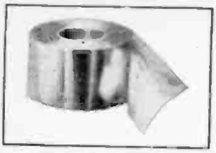

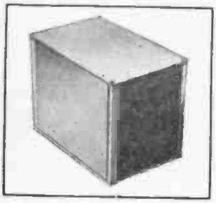

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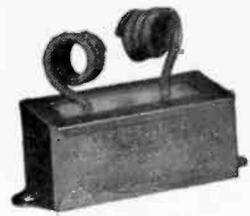

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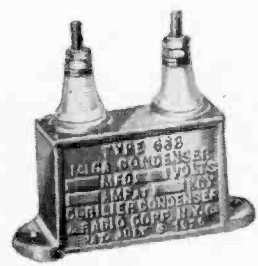

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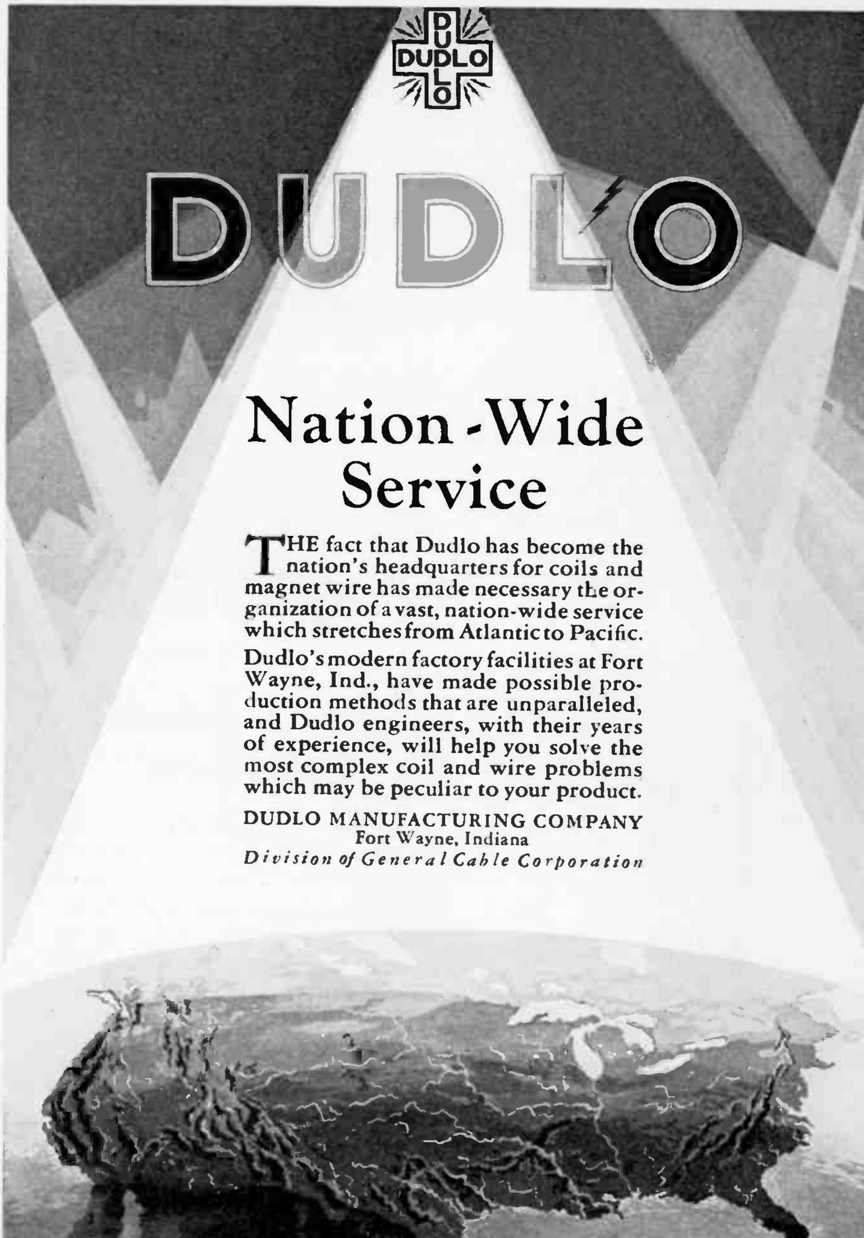
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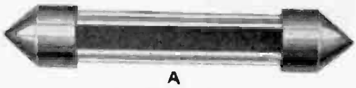

A
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W
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X
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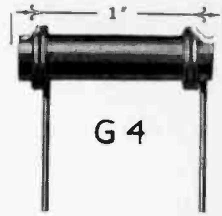

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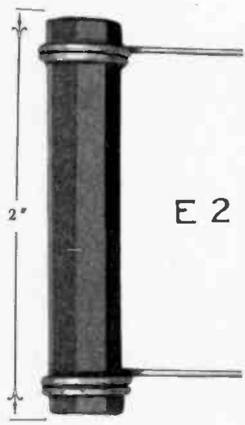

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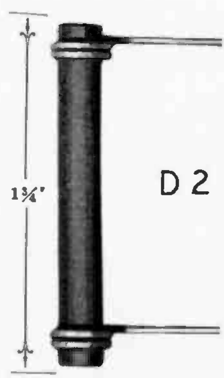

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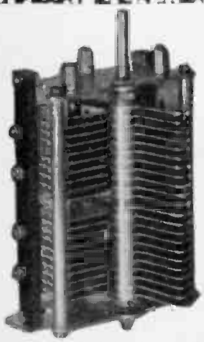

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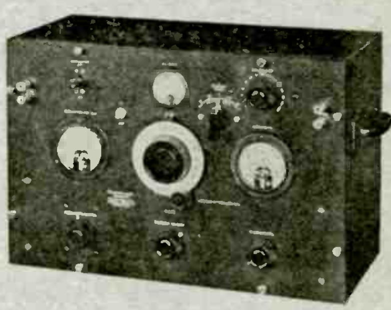

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